IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2017.Doi Number

Business Applications of Blockchain Technology – A Systematic Review

Joe Abou Jaoude[1], and Raafat Saade[1]

[1]Concordia University, Montreal, QC, H3G 1M8, CA
Corresponding author: Raafat Saade (e-mail: raafat.saade@concordia.ca).

ABSTRACT Originally conceived as a mechanism to enable a trustless cryptocurrency – Bitcoin, blockchain has since unbound itself from its original purpose as an increasing number of industries and stakeholders' eye the technology as an attractive alternative to solve existing business solutions as well as disrupt mature industries. This paper presents a systematic literature review of blockchain technology, tracking its increase in popularity in relation to similar technologies such as cryptocurrencies as well as Bitcoin. The objective of the paper is to identify the current standing of blockchain technology within the literature while also identifying the major fields of study and areas of application for which blockchain offers a valuable solution. The paper finds that unique features to the blockchain such as privacy, security, anonymity, decentralization, and immutability provide valuable benefits to various fields and subjects. The paper also finds that exploring the application of blockchain has only begun with some limited studies in areas such as the Internet of Things, Energy, Finance, Healthcare, and Government, that also stand to benefit disproportionately from its implementation.

INDEX TERMS Blockchain, Cryptocurrency, Energy, EGovernment, Finance, Healthcare, Internet of Things, Applications, Review

I. INTRODUCTION

Blockchain can be considered as the newest technology stressing the paradigms of "Internet of Things", icollaboration, artificial intelligence, technostress, and the dark side of digital innovations. Blockchain seems to have stung all industries and created a buzz-seeking opportunity for enhanced business processes and building trust. Yet, some industries such as the financial sector might see it as a disruptive technology that cannot be avoided and needs to be reshaped/managed.

The Blockchain is a technology and a method that allows community users to validate, keep and synchronize the content of a transaction ledger which is replicated across multiple users. In other words, Blockchain is a decentralized transaction and data management technology which gained popularity in 2008 when an anonymous individual (or group) posted a white paper introducing Bitcoin – a Blockchain application of a digital currency [1] [2].

As it stands, most transactions between individuals (financial, education, healthcare, etc.…) are centralized through trusted third-party organizations. For example, when you graduate, your employer requests an official transcript as proof of completion of your studies. This transcript is collected directly from the university, which acts as a trusted intermediary between the student and the employer to ensure that the information is accurate and truthful. Why doesn't the employer ask the student to provide a copy of their transcript? The reason is that of trust, as the candidate can modify the content to their advantage. In short, the true service or commodity offered by a third-party is trust, and that is precisely the Blockchain proposition.

More specifically, Blockchain offers a decentralized environment where no third-party is in control of the data and trust is not required between the stakeholders. This is achieved through a peer-maintained self-sovereign system where the transactions are time-stamped in a ledger chronologically. The transactions are broadcast to the people who participate in the system such that the ledger is publicly auditable [2]. Since the transaction information is copied and maintained with the entire community, it cannot be altered or modified without the approval and update of the ledger. This prevents fraud and ensures a digital form of verification allowing for "trustless" peer to peer transactions.

This proposition offers several advantages to the participants within the network. First, the transactions are transparent and publicly available for everyone to check and

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

validate without needing to go through a central authority; Second, the transparency of the information allows for faster processing of transactions and information exchanges due to the elimination of the middle layer between the parties; Third, the information remains anonymous despite its public availability due to the existence of a set of public and private keys associated with an account. The public key is available to everyone, the private key is strictly known by the individual and the identity of that party remains anonymous.

However, while Blockchain technology does offer a promising future, it has likely suffered from the hype of its potential applications. This hype opened the door for questionable and fraudulent enterprises claiming Blockchain technology as their core business. While this may have eroded some trust and confidence particularly in the finance and technology sectors, it has offered the benefit of increasing public attention and interest in the topic. Consequently, it has provided an incentive for academic research into its technical aspects and applications.

To better understand the true potential of Blockchain as well as its various influences on industry, it is important to assess the current body of research. A systematic review of the current research on Blockchain technology was previously conducted to identify the technical perspective challenges and future directions. The study included works between 2013 and 2015 inclusive [1].

A quick evaluation of the research output in Blockchain revealed that a spike occurred as of 2016. To that effect, we decided to perform an updated literature review to include the research work after 2015 and analyze other than the technical perspective such as Blockchain applications.

More specifically, we address the gap with regards to (1) research work since 2015 (during which articles published on Blockchain have dramatically increased) and (2) focus on the business and management aspects of Blockchain - thereby mapping the existing literature around Blockchain applications and the pertaining fields of industry such as finance, healthcare, internet of things, energy, government, etc.…

In this paper, we contextualize the initial application of Blockchain technology and trace its subsequent evolution into other fields of studies; identify and discuss our literature review methodology, and selection and mapping process. The results of the process are then elaborated followed by a discussion of the Blockchain application research landscape and the various fields covered as well as the respective Blockchain contributions suggested by the literature.

We would like to stress that the use of Blockchain application in this article applies within the scope of the business and industry context and not the technical applications. Consequently, our literature review focuses on the following research questions:

RQ1: WHAT BUSINESS FIELDS HAVE BEEN ADDRESSED IN CURRENT RESEARCH ON BLOCKCHAIN APPLICATIONS AND HOW HAS IT EVOLVED SINCE 2015?

An important outcome of the present literature review is to compare the current state of research in Blockchain since 2015 while exploring, in addition to works with a technical perspective, other relevant areas such its applications and implementation. Collecting and consolidating a comprehensive body of literature will allow us to better understand the breadth and depth of related subject matter as we categorize and map the appropriate components while identifying the important areas that have been addressed.

RQ2: WHAT SOLUTIONS HAVE BEEN PROPOSED FOR THE MAJOR FIELDS OF BLOCKCHAIN APPLICATIONS?

Blockchain was created as the underlying technological solution for bitcoin. However, as time has passed by and a better understanding of Blockchain technology has evolved, its potential application to different sectors of the industry has surfaced. We aim to identify the current researched Blockchain solutions for various industries and business applications.

RQ3: WHAT ARE CURRENT RESEARCH GAPS IN BLOCKCHAIN BUSINESS APPLICATIONS?

The study will help identify the appropriate research gaps either regarding overlooked fields and potential applications within the industry or problems that have yet to be addressed within the industry itself in relation to Blockchain implementation. These findings will also help pave the way and provide guidance and ideas for future research contributions.

RQ4: WHAT ARE THE FUTURE DIRECTIONS FOR BLOCKCHAIN BUSINESS APPLICATIONS?

A direct result of answering the previous research questions should lead to the identification of important research topics and areas of interest for future research. This contribution will allow the academic community to better leverage the existing attention on Blockchain technology and address the important and needed research questions.

II. BACKGROUND

Blockchain is the foundational technology behind bitcoin (a crypto-currency). It is a decentralized transaction and data management technology allowing, in an ideal state for a low trust (or trustless) exchange system. Information in this system does not rely on a third-party and instead leverages the economies of scale of the peer network to peer-validate the entries and disperse transaction details in a ledger. While Blockchain originated as a base for the financial services sector, and is revolutionizing the industry itself, its application has begun to spread to other sectors. The rate of Blockchain spread depends on the industry's potential to benefit from it as well as its sensitivity to the challenges that Blockchain brings into play [2].

The main driver to the adoption of Blockchain technology was the ability to solve the double spending problem while maintaining the anonymity and privacy of the transacting user's information. Double spending is a situation in which a user of a digital currency can spend several times the same

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

amount of money before there has been a realization that the amount has already been spent/claimed.

Blockchain solves the double spending problem with the use of cryptography and having a shared ledger maintained simultaneously by the transacting community, the asymmetric encryption provides the user with a private and public key (similar to a public mailing address and a private key for the mailbox pertaining to that address). Using this combination, users can transact anonymously on the blockchain using their private keys while only being known to the community by their public keys. Through the public keys, the community verifies each transaction across the various copies of the ledger in order to ensure the funds or cryptocurrency has not been previously transferred from the same public address. In the case where two transactions are conducted simultaneously, the transaction that receives the greatest number of confirmations (note not necessarily the one that was conducted first) is the transaction that is validated whereas the other is rejected.

This method is currently the dominant form of blockchain transaction verification and is known as proof of work and suffers from an intensive need for resources and time to verify transactions, sometimes in excess of an hour. This stands in contrast to proof of stake whereby instead of splitting transaction processing relative to computing power, the transactions are split based on the wealth of the miners offered as collateral. Proof of stake offers a faster processing time but poses other risks such as agency issues. The discussion on the advantages and disadvantages of proof of work and proof of stake constitutes a research area and falls outside the scope of this study.

Which allows for (relatively) rapid verification of the transaction's legitimacy by the network's nodes thereby clearing the double-spending problem. User's private information is kept secure by using a public and private key combination attributed to each party on the network, the system allows the users to utilize the public key in order to conduct the transaction. These details pertaining to the transaction are stored within the block.

The block is then sent to the various nodes across the network to validate the transaction by ensuring that there was no double spending, the cryptographic properties of the blockchain allow a low trust system in which a small number of nodes is required to maintain the integrity of the blockchain and prevent an attack. Once the nodes clear the transaction, it is validated and added to the public ledger and details are stored thereafter. This entire process is conducted in complete anonymity, with neither of the parties and nodes involved having information concerning the identity of the participant.

Blockchain technology also lends itself well to transition into the various industry and business applications due to the overall adoption of decentralized development and open source standards. While the above components are important characteristics of most blockchains and contribute significantly to defining their overall purpose, functionality, and applicability within the businesses in which they operate; the most important component of the blockchain technology that cannot be modified or altered is the immutability of the ledger itself. When a transaction is processed and validated by the nodes in the network, the information is permanently recorded in the ledger and cannot be modified or erased from the system. In cases, where some modifications and action are required to be undertaken by an authority, smart contracts would come into play to alleviate the problems posed by the immutability of the Blockchain [2].

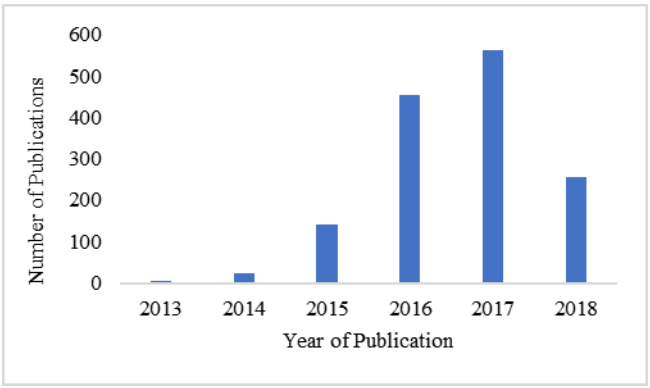

FIGURE 1: Publications with Blockchain in the title by year. The number of publications with Blockchain or its equivalent in the title has increased substantially since 2015.

In the present study, we scoped our literature review to focus on the business management and application aspects (instead of the technical perspective only) of blockchain implementation. The motivation is threefold:

First, the explosion in Blockchain research starting 2016, with 2017 representing the most significant year thus far. This is illustrated in Fig. 1 with the number of articles containing the term Blockchain in the title (using google scholar).

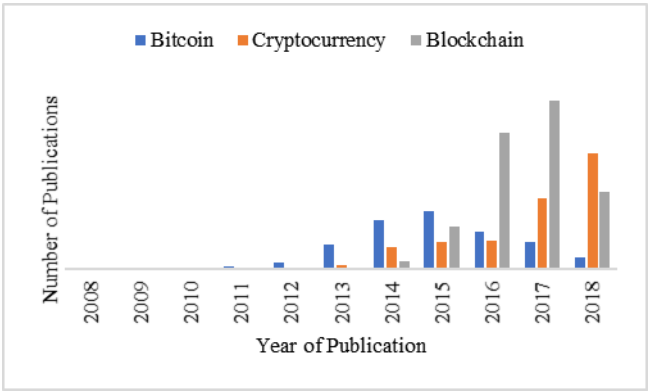

FIGURE 2: Number of publications with Cryptocurrency, Bitcoin or Blockchain in the title by year. In the first four years, bitcoin publications were most of the group. However, 2016 onwards saw Blockchain overtake bitcoin in title occurrences with cryptocurrency on the rise and overtaking Blockchain as well in 2018.

Second, we believe a current study is warranted on the state of research into blockchain domains due to an apparent shift in research trends pertaining to blockchain, cryptocurrencies, and bitcoin within the last 2 years. While roughly 80% of all research articles prior to 2016 revolved

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

around bitcoin, Fig. 2 shows that the evolution of Blockchain research significantly surpassed those of bitcoin, in 2016 and 2017. Furthermore, interest in cryptocurrency research has increased in 2018 and surpassed Blockchain research by about 30%, while research on Bitcoin has decreased gradually since 2015 to its original level in 2011-2012. This provides further justification for the timeliness of the research itself by indicating a relative slowdown in blockchain's research momentum and suggesting that the future direction of research within the field pertains to cryptocurrencies. However, it is important to note that our research focuses on blockchain research specifically and other keywords such as those included in Fig.2 fall outside the scope of this study.

Third, our classification framework focuses on Blockchain related applications and explores the associated fields that these applications address as well as the proposed benefits and contributions offered by blockchain to the major areas. This component of our work is the primary contribution as it was not evaluated before, and since practically every industry from aerospace to banking and the United Nations is presently considering its use in one way or another. Yet, the research to help these non-cryptocurrencies focused organizations make sense of blockchain technology while safely utilizing and taking advantage of the opportunities it brings is scarce.

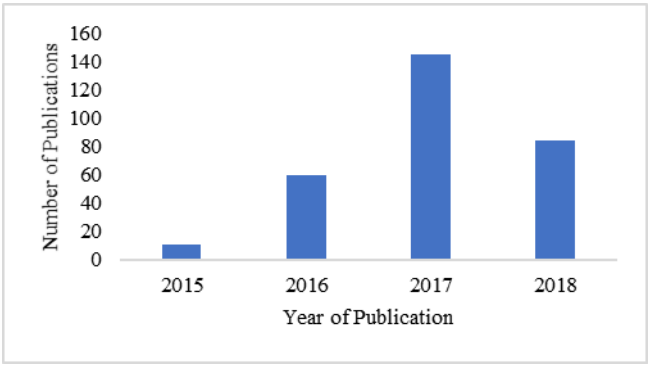

FIGURE 4: Publications from top 4 publishers with Blockchain in the title by year. The number of publications matches the overall trend seen in Fig. 1. However, there is a 2-year lag between the first Blockchain titled publication occurrence in 2013 and those of 2015 for the top publishers.

III. RESEARCH METHODOLOGY

There are many approaches to literature reviews that have been used in previous research. This includes the work of [3] which outlines a systematic mapping process. Similarly, [4] outlines a process to apply the review to the software engineering field. While there are many similarities and overlaps between the various methodologies, their evaluation and comparison fall outside the scope of this paper.

A systematic literature review approach based on the eight category coding steps established by was followed and presented schematically in Fig. 3. The literature review approach is made up of three sequential stages, namely criteria and coding, aggregation and consolidation (article reduction) and synthesis. The third stage includes the synthesis of the final articles set, where we identify the core and most relevant articles to our research questions [5] [6]. We elaborate on the phases and steps taken below.

A. STAGE 1: CRITERIA AND CODING

1) LEVELS OF SYNTHESIS

We mined google scholar for all articles with the word "Blockchain" in the title, variations such as "Blockchains" were also allowed provided they were included in the title as well. The search yielded 1512 articles. We attempted to expand the search to include cryptocurrency and bitcoin in the article title but that lead to an unmanageable number of returned articles. Furthermore, the inclusion of bitcoin or cryptocurrency would incorporate a bias into the finance industry and introduce articles related to the marketing and financing of blockchain technology (i.e. discussing the economic and financial aspects) rather than the application of blockchain within the industry. Since the focus of our research is Blockchain and its applications, we decided to drop the pursuit after cryptocurrency and bitcoin as they fall outside the scope. We then identified the top publishers in order to retain high-quality articles. The resulting publishers/databases are IEEE Xplore, ACM Digital Library, Springer, and Elsevier.

2) CODING STEPS

We screened the articles' title and abstract to ensure that the topics fit the scope and research questions. Whenever needed, the full paper text was consulted. Articles not written in English, full text not available, posters, or articles addressing different fields or research were excluded.

Error! Objects cannot be created from editing field codes.

FIGURE 3: The Literature Review Process. The three stages of the process: Criteria and coding, article reduction and synthesis categorize the 8 steps of the process.

3) OCCURRENCE / FREQUENCY

This step involves the decision of whether the inclusion should be due to the mere occurrence of the criteria (i.e. blockchain or its equivalent) or due to the frequency by which it occurs. Given that the criteria established in this paper require the occurrence of blockchain in the title, we believe the likelihood of frequency is relatively low and that occurrence relative to its significance to the subject of the publication is enough to merit the inclusion of the work.

4) DISTINGUISH AMONG CONCEPTS

In order to distinguish among the various concepts regarding the fields of blockchain application literature; We read through the abstracts in order to identify the appropriate classification and field of study. Once this phase was completed, we identified common keywords and concepts across the literature and did a second pass to map the articles to the appropriate categories based on derived classifications and fields. The resulting research resulted in a list of 300 articles.

B. STAGE 2: ARTICLE REDUCTION:

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

5) PROCESS RULES FROM STEPS 1-4 AND DOCUMENT

TABLE I: Distribution of articles with blockchain in the title by publisher

Publisher	# of Articles
dl.acm.org	58
Elsevier	29
ieeexplore.ieee.org	139
Springer	74
Total	300

Table I represents the breakdown of the 300 publications by the appropriate publishers. We then categorized the fields of those articles that qualified under blockchain business applications. The information in Table I shows that IEEE has emerged since 2015 as the leading source for blockchain publication research with Springer as second and the inclusion of Elsevier as a significant knowledge source.

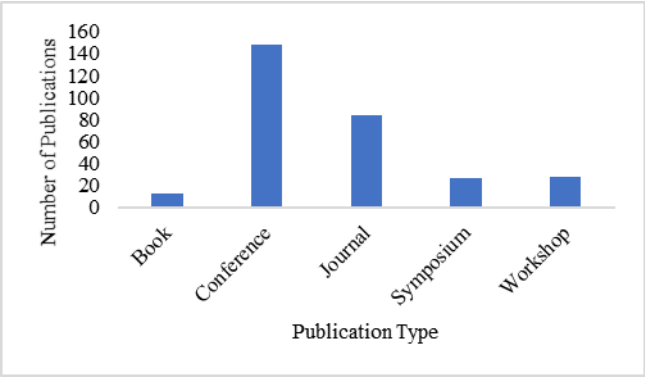

FIGURE 5: Publications from top 4 publishers with Blockchain in the title by type. The number of conference publications is the most significant followed by journal publications. This might indicate a shortage in the number of journal submissions pertaining to Blockchain technology.

6) EXCLUDE IRRELEVANT ARTICLES

While the original number of articles by the top 4 publishers yielded 320, several articles were excluded due to irrelevance, particularly with regards to their fit within the standard classifications by publication type as well as the field of study to which they are attributed. This led to a final number of 300 articles that meet the relevance criteria.

7) ENCODE TEXT / INFORMATION IN ARTICLES AND DOCUMENT

Table II highlights the data items (D…) which were extracted from the papers in question once the screening criteria were completed. D1 to D12 were collected using the information from google scholar whereas D13 to D18 were inputted after reading and reviewing the articles.

TABLE II: Data items

#	Data Item	Description
D0	Study Identifier	Study Id (1,2,3, etc.…)
D1	Cites	# of citations
D2	Authors	Name of the author(s)
D3	Title	Title of the paper
D4	Year	Year of the publication
D5	Source	The event/journal / … from where this originates
D6	Publisher	Source dataset for the article
D7	Article URL	Article link URL
D8	Cites URL	Article URL in google scholar
D9	GS Rank	Articles rank in google scholar
D10	DOI	Citation source where possible
D11	ISSN	Identification number where possible
D12	Query Date	date the information was collected
D13	Type	Type of publication (conference / journal / etc.…)
D14	Abstract	The abstract of the paper
D15	Research Question	The research questions of the paper
D16	Findings	The findings of the paper
D17	Classification	The type of paper (improvement, report, application)
D18	Field of study	In the case of application, which field (finance, energy, etc.…)

C. STAGE 3: SYNTHESIS:

8) ANALYSIS OF RESULTS:

Considering the 320 articles from the previous step, Fig. 5 and Fig. 6 present the number of articles the year and type respectively. While our broader search does show articles containing the term blockchain as of 2013, the data sources selected did not contain such articles until 2015. This was expected as it would take time for Blockchain to build its own momentum as compared to bitcoin. Indeed, as shown in Fig. 2, the prevalent keyword in the article titles until 2013 was “bitcoin” with blockchain appearing with only 4 article titles in 2013 and 25 articles in 2014. In relation to our established databases, 2015 was the first year with such articles titles in 11 publications. This also further highlights the significance of the current research as 2015 represents roughly 3% of all blockchain titles articles, indicating that much of the body of research took place from 2016 onwards.

Fig. 6 provides information concerning the publication type of the papers included in our study. While the percentage of conference articles up to 2015 remained the same since then at 50%, our findings reveal that the percentage of journal articles since 2015 is 28% as compared to 2.4% in 2015. This is indicative of the increased interest in the business of blockchain, and its gradual increase in its maturity as a research area.

We adapted the classification terms used in previous studies, namely “report”, “improvement” and “application”. Note that, an “improvement” article is one that defines a novel approach of protocol in order to address the shortcomings and technical limitations of blockchain technology. A “report” is a discussion, review or incorporation of previously suggested improvements within the context of a larger topic or area of interest pertaining to blockchain. An “applications” article in our study is

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

interpreted differently and addresses the applicability of blockchain to business sector [1]. We note that the context of our initial scope incorporates both technical as well as business applications of blockchain.

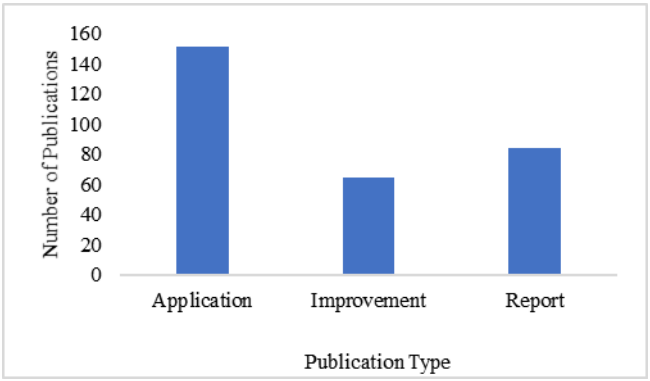

FIGURE 6: Publications from top 4 publishers with Blockchain in the title by classification. The number of applications is 151 out of a total of 300, constituting just over 50%. This is indicative of the overall potential for Blockchain applications in various industries.

Fig. 7 provides a breakdown of the publication classifications from our study. Business topics were 14 out of the top 15 application categories. With blockchain based privacy application constituting the exception among them.

After breaking down the publications by type, we focused on the Blockchain applications related class of articles and proceeded to leverage the 2-step mapping process described earlier in respect to categorizing the primary field covered by the articles. In cases where there were overlapping topics in the title and abstract with no clear preference to a specific area, we went to the article text in order to assess the prevalent theme of the paper and classify it accordingly.

Fig. 7 displays the classification by year of the articles in question. We can see in the graph the overall trend of significant increase in "application" articles since 2015. Another notable change is the decrease in the amount of "improvement" related publications and the rise of "reports" to overtake "improvements".

These results were expected in the initial analysis, as the first stage of the research process is the proposal for improvements and modifications to the existing technology and given that reports are by nature dependent on the prevalence of improvements, it follows that they would first lag then overtake them.

Finally, as applications leverage the implementation of blockchain improvements as well as the reports needed to identify the core areas of competency where an application is efficient, it is expected that applications would be the last to spike and increase in significance as interest in the application and implementation of the technology increases.

Using the mapping process allowed us to identify the common areas of research on blockchain applications. 151 articles were identified for this analysis. Fig. 8 shows the distribution of these "application" articles by field. The Internet of Things (IoT) is the dominant blockchain business application topic. This is likely due to the high priority and concern raised by privacy and security problems in relation to the interconnectivity and data sharing of devices as well as exposing consumers and public infrastructure assets to security vulnerabilities. In fact, the findings corroborate the body of research, whereby the predominant application proposals for blockchain technology are security and privacy followed by trust [1].

At this point, we needed to select the highest quality articles for the final synthesis. Therefore, We chose to include only peer-reviewed journal-based Blockchain application. In our selection process, we chose to include articles from IEEE based magazines with the other journals. Table II presents the final set of articles pertaining to Blockchain applications ready for final analysis and synthesis. The Table includes the authors, title, DOI, Journal, field of application and year.

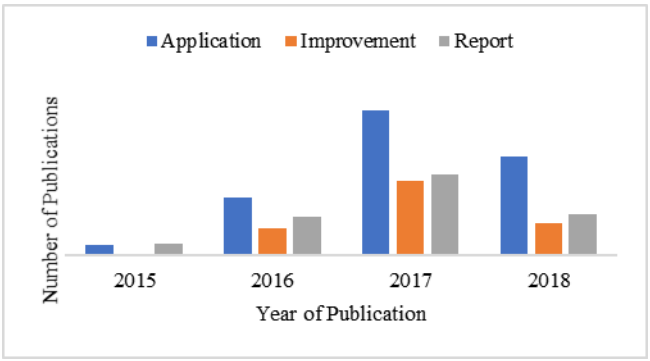

FIGURE 7: Publications from top 4 publishers with Blockchain in the title by classification by year.

IV. LITERATURE REVIEW

We began with a total of 1512 publications containing the word blockchain(s) in the title. The top 4 publishers were identified with a combined article count of 320. An elimination via the selection criteria resulted in 309 articles. Removing articles with an NA publication nature yielded 301. An additional article was removed due to having an out of scope application parameter bringing the total to 300 articles. Of those articles, 151 were blockchain applications, 65 were improvements to the blockchain and 84 were reports regarding blockchain technology. Table III identifies the 53 journal articles published in peer-refereed journals from the 4 top publishers and groups them by the appropriate field of study.

A discussion of the most studied Blockchain applications, including those in Table III is elaborated in this section. After reading all those articles, we analyzed the top 5 clusters (see Fig. 9) which we consider as the primary areas/fields of Blockchain-related studies and extracted the areas of research in each, as presented in Table III.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

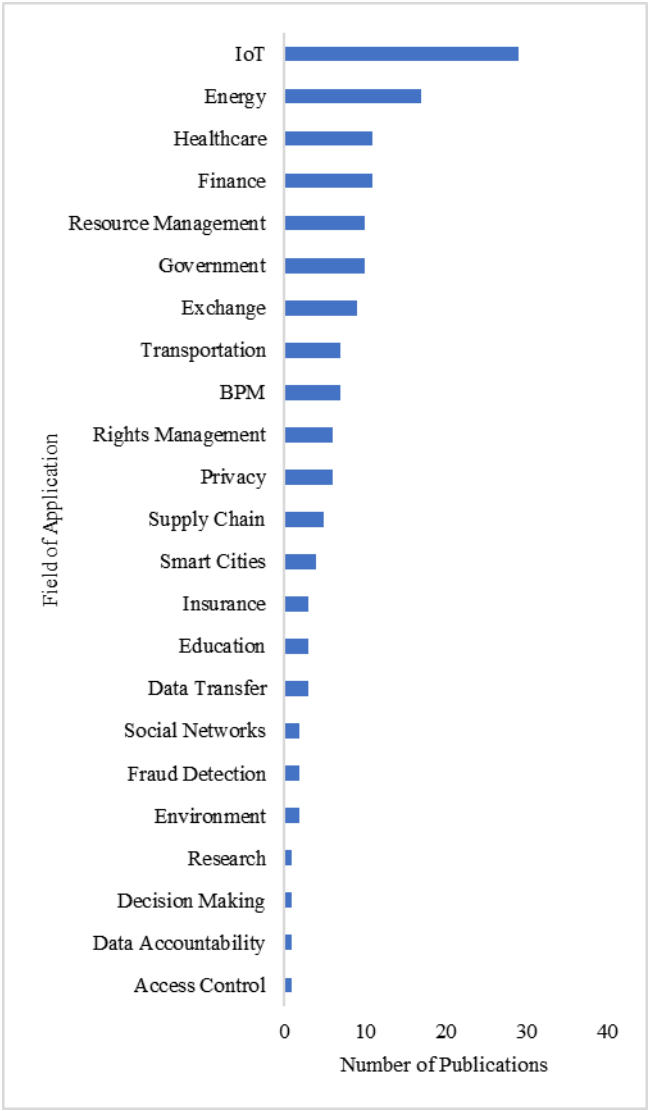

FIGURE 8: Number of publications of Blockchain applications from the top 4 publishers by field. The top 5 fields represent 78 of the 151 Blockchain application literature.

We notice that the distribution of articles published in peer-reviewed journals from the top 4 publishers follows the overall distribution of the 151 studies pertaining to blockchain applications and domains. Furthermore, the top 5 categories also constitute over 50% of the relevant body of research. However, we do note a key difference with regards to the fifth category; specifically, we find that research pertaining to the government domain of blockchain applications is absent with only one study pertaining to the topic itself. This implies a lag between government related blockchain application and those pertaining to the rest of the major domains of study and can, therefore, signal an upcoming area of interest and increase in relation to peer-reviewed publications.

Furthermore, it is important to note the lack of clustering among the authors of the publications included, this indicates that most studies pertaining to the blockchain domain are authored by researchers within the domain to which it is being applied. In turn, this signals a need for more centralized research around blockchain domains and its applications as well as the overall evolution of blockchain research thus far.

By far, it seems that most researchers today associate Blockchain application to the IoT. This is maybe due to the fact the IoT paradigm is integrative in nature and not only encompasses all advantages of the highly networked digital world, but also its bias and challenges. In this case, It seems that Blockchain holds great promise and researchers are exploring how and to what extent Blockchain can address and solve these challenges.

Although still few, research efforts of Blockchain application in Energy, Finance, Healthcare, and Government has been relatively equal. As shown in Table II, there are other dispersed Blockchain application research work (an article here or there) and include fields/areas in education, insurance, supply chain, rights management, transportation, business process management, fraud detection, exchange and resource management.

Overall, it seems that Blockchain applications research is still very young by any standard despite the recent spike in 2017.

A. INTERNET OF THINGS

The internet of things was by far the most popular "application" field. Twenty percent (29) of the 151 articles were related to Blockchain applications. All these articles were making the case for Blockchain's ability to improve and enhance the internet of things paradigm. In reviewing those IoT articles we were able to identify several dominant topics within the area: (1) enhanced security of interconnected devices; (2) maintaining anonymity; (3) smart contract provisions; (4) device management mechanisms and protocols; and (5) network security [7].

1) ENHANCED SECURITY OF INTERCONNECTED DEVICES

A major problem with the interconnectivity of the millions of devices needed to propagate an IoT phenomenon is the exponential increase in security concerns presented by the various interfaces through which network devices communicate. This includes the various security problems pertaining to the IoT including but not limited to low-level concerns such as interlocking adversaries and insecure

TABLE III: journal articles published in peer-refereed journals from the 4 top publishers by field.

Field	Authors	Title	Doi	Journal	Year	Reference
BPM	C. Prybila, et al.	Runtime verification for business processes utilizing the Bitcoin blockchain	10.1016/j.future.2017.08.024	Future Generation Computer Systems	2017	[8]

	J. Mendling, et al.	Blockchains for Business Process Management - Challenges and Opportunities	10.1145/3183367	ACM Transactions on Management Information Systems (TMIS)	2018	[9]
	Ž. Turka and R. Klinc	Potentials of Blockchain Technology for Construction Management	10.1016/j.proeng.2017.08.052	Procedia Engineering	2017	[10]
Education	M. Turkanović, et al.	EduCTX: A Blockchain-Based Higher Education Credit Platform	10.1109/ACCESS.2018.2789929	IEEE Access	2018	[11]
Energy	E. Mengelkamp, et al.	A blockchain-based smart grid: towards sustainable local energy markets	10.1007/s00450-017-0360-9	Computer Science - Research and Development	2017	[12]
	G. Liang, et al.	Distributed Blockchain-Based Data Protection Framework for Modern Power Systems against Cyber Attacks	10.1109/TSG.2018.2819663	IEEE Transactions on Smart Grid	2018	[13]
	J. Sikorskia, et al.	Blockchain technology in the chemical industry: Machine-to-machine electricity market	10.1016/j.apenergy.2017.03.039	Applied Energy	2017	[14]
	J. Kang, et al.	Enabling Localized Peer-to-Peer Electricity Trading Among Plug-in Hybrid Electric Vehicles Using Consortium Blockchains	10.1109/TII.2017.2709784	IEEE Transactions on Industrial Informatics	2017	[15]
	J. Hwang, et al.	Energy Prosumer Business Model Using Blockchain System to Ensure Transparency and Safety	10.1016/j.egypro.2017.11.037	Energy Procedia	2017	[16]
Exchange	A. Pazaitis, et al.	Blockchain and value systems in the sharing economy: The illustrative case of Backfeed	10.1016/j.techfore.2017.05.025	Technological Forecasting and Social Change	2017	[17]
	H. Subramanian	Decentralized blockchain-based electronic marketplaces	10.1145/3158333	Communications of the ACM	2018	[18]
	J. Lee, M. Pilkington	How the Blockchain Revolution Will Reshape the Consumer Electronics Industry [Future Directions]	10.1109/MCE.2017.2684916	IEEE Consumer Electronics Magazine	2017	[19]
	K. Khaqqi, et al.	Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application	10.1016/j.apenergy.2017.10.070	Applied Energy	2018	[20]
Finance	B. Egelund-Müller, et al.	Automated Execution of Financial Contracts on Blockchains	10.1007/s12599-017-0507-z	Business & Information Systems Engineering	2017	[21]
	D. Viana	Two Technical Images: Blockchain and High-Frequency Trading	10.1007/s13347-016-0247-x	Philosophy & Technology	2016	[22]
	E. Morse	From Rai stones to Blockchains: The transformation of payments	10.1016/j.clsr.2018.05.035	Computer Law & Security Review	2018	[23]
	G. Jesús, L. Hernández	Blockchain entrepreneurship opportunity in the practices of the unbanked	10.1016/j.bushor.2017.07.012	Business Horizons	2017	[24]
	Y. Guo, C. Liang	Blockchain application and outlook in the banking industry	10.1186/s40854-016-0034-9	Financial Innovation	2016	[25]
Fraud Detection	H. Hyvärinen, et al.	A Blockchain-Based Approach Towards Overcoming Financial Fraud in Public Sector Services	10.1007/s12599-017-0502-4	Business & Information Systems Engineering	2017	[26]
	Y. Cai, D. Zhu	Fraud detections for online businesses: a perspective from blockchain technology	10.1186/s40854-016-0039-4	Financial Innovation	2016	[27]
Government	C. Sullivan, E. Burger	E-residency and blockchain	10.1016/j.clsr.2017.03.016	Computer Law & Security	2017	[28]

				Review		
Healthcare	C. Esposito, et al.	Blockchain: A Panacea for Healthcare Cloud-Based Data Security and Privacy?	10.1109/MCC.2018.011791712	IEEE Cloud Computing	2018	[29]
	H. Wu, C. Tsai	Toward Blockchains for Health-Care Systems: Applying the Bilinear Pairing Technology to Ensure Privacy Protection and Accuracy in Data Sharing	10.1109/MCE.2018.2816306	IEEE Consumer Electronics Magazine	2018	[30]
	P. Zhanga, et al.	FHIRChain: Applying Blockchain to Securely and Scalably Share Clinical Data	10.1016/j.csbj.2018.07.004	Computational and Structural Biotechnology Journal	2018	[31]
	Q. Xia, et al.	MeDShare: Trust-Less Medical Data Sharing Among Cloud Service Providers via Blockchain	10.1109/ACCESS.2017.2730843	IEEE Access	2017	[32]
	X. Yue, et al.	Healthcare Data Gateways: Found Healthcare Intelligence on Blockchain with Novel Privacy Risk Control	10.1007/s10916-016-0574-6	Journal of Medical Systems	2016	[33]
Insurance	F. Lamberti, et al.	Blockchain or not blockchain, that is the question of the insurance and other sectors	10.1109/MITP.2017.265110355	IT Professional	2017	[34]
	F. Lamberti, et al.	Blockchains Can Work for Car Insurance: Using Smart Contracts and Sensors to Provide On-Demand Coverage	10.1109/MCE.2018.2816247	IEEE Consumer Electronics Magazine	2018	[35]
IoT	B. Lee, J. Lee	Blockchain-based secure firmware update for embedded devices in an Internet of Things environment	10.1007/s11227-016-1870-0	The Journal of Supercomputing	2017	[36]
	K. Christidis, M. Devetsikiotis	Blockchains and Smart Contracts for the Internet of Things	10.1109/ACCESS.2016.2566339	IEEE Access	2016	[7]
	M. Banerjee, et al.	A blockchain future for internet of things security: a position paper	10.1016/j.dcan.2017.10.006	Digital Communications and Networks	2017	[37]
	M. Khan, K. Salah	IoT security: Review, blockchain solutions, and open challenges	10.1016/j.future.2017.11.022	Future Generation Computer Systems	2018	[38]
	M. Hammi, et al.	Bubbles of Trust: A decentralized blockchain-based authentication system for IoT	10.1016/j.cose.2018.06.004	Computers & Security	2018	[39]
	N. Kshetri	Can Blockchain Strengthen the Internet of Things?	10.1109/MITP.2017.3051335	IT Professional	2017	[40]
	O. Novo	Blockchain Meets IoT: An Architecture for Scalable Access Management in IoT	10.1109/JIOT.2018.2812239	IEEE Internet of Things Journal	2018	[41]
	P. Sharma, et al.	A Software Defined Fog Node Based Distributed Blockchain Cloud Architecture for IoT	10.1109/ACCESS.2017.2757955	IEEE Access	2017	[42]
	P. Sharma, et al.	DistBlockNet: A Distributed Blockchains-Based Secure SDN Architecture for IoT Networks	10.1109/MCOM.2017.1700041	IEEE Communications Magazine	2017	[43]
	S. Huckle, et al.	Internet of Things, Blockchain and Shared Economy Applications	10.1016/j.procs.2016.09.074	Procedia Computer Science	2016	[44]
	Y. Zhang, J. Wen	The IoT electric business model: Using blockchain technology for the internet of	10.1007/s12083-016-0456-1	Peer-to-Peer Networking and Applications	2017	[45]

		things				
Resource Management	C. Xu, et al.	Intelligent Resource Management in Blockchain-Based Cloud Datacenters	10.1109/MCC.2018.1081060	IEEE Cloud Computing	2017	[46]
	K. Kotobi, S. Bilen	Secure Blockchains for Dynamic Spectrum Access: A Decentralized Database in Moving Cognitive Radio Networks Enhances Security and User Access	10.1109/MVT.2017.2740458	IEEE Vehicular Technology Magazine	2018	[47]
	Nicolas Herbaut, Nicolas Negru	A Model for Collaborative Blockchain-Based Video Delivery Relying on Advanced Network Services Chains	10.1109/MCOM.2017.1700117	IEEE Communications Magazine	2017	[48]
	Y. Zhang, et al.	Outsourcing Service Fair Payment based on Blockchain and its Applications in Cloud Computing	10.1109/TSC.2018.2864191	IEEE Transactions on Services Computing	2018	[49]
Rights Management	M. Zeilinger	Digital Art as 'Monetised Graphics': Enforcing Intellectual Property on the Blockchain	10.1007/s13347-016-0243-1	Philosophy & Technology	2016	[50]
Smart Cities	J. Sun, et al.	Blockchain-based sharing services: What blockchain technology can contribute to smart citie	10.1186/s40854-016-0040-y	Financial Innovation	2016	[51]
Supply Chain	K. Toyoda, et al.	A Novel Blockchain-Based Product Ownership Management System (POMS) for Anti-Counterfeits in the Post Supply Chain	10.1109/ACCESS.2017.2720760	IEEE Access	2017	[52]
	Q. Lu, X. Xu	Adaptable Blockchain-Based Systems: A Case Study for Product Traceability	10.1109/MS.2017.4121227	IEEE Software	2017	[53]
	R. Casado-Vara, et al.	How blockchain improves the supply chain: case study alimentary supply chain	10.1016/j.procs.2018.07.193	Procedia Computer Science	2018	[54]
Transportation	A. Dorri, et al.	BlockChain: A Distributed Solution to Automotive Security and Privacy	10.1109/MCOM.2017.1700879	IEEE Communications Magazine	2017	[55]
	A. Lei, et al.	Blockchain-Based Dynamic Key Management for Heterogeneous Intelligent Transportation Systems	10.1109/JIOT.2017.2740569	IEEE Internet of Things Journal	2017	[56]
	F. Knirsch, et al.	Privacy-preserving blockchain-based electric vehicle charging with dynamic tariff decisions	10.1007/s00450-017-0348-5	Computer Science - Research and Developmen	2017	[57]
	V. Ortega, et al.	Trusted 5G Vehicular Networks: Blockchains and Content-Centric Networking	10.1109/MVT.2018.2813422	IEEE Vehicular Technology Magazine	2018	[58]
	X. Huang, et al.	An optimal scheduling algorithm for hybrid EV charging scenario using consortium blockchains	10.1016/j.future.2018.09.046	Future Generation Computer Systems	2018	[59]

physical interfaces, intermediate-level security concerns such as insecure neighbor discovery, authentication, and communication to high-level security problems that include insecure interfaces, software/firmware and middleware security [38].

Various Blockchain related solutions pertaining to the problems described in relation to IoT security were tackled. Specifically, Blockchain can leverage its address space (160bit) which allows for a drastic reduction in address collision probability as well as eliminating the need for centralized authorities to manage internet assigned numbers while providing a more scalable solution with the option of having more addresses than with IPv6.

Furthermore, using blockchain's identity management and governance mechanisms, devices related to the IoT can be easily registered and identified in a unified ledger with the ability to tag them to a specific user and the option to quickly and securely transfer rights and ownership of devices among the various parties in the system.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

The integrity of the data is confirmed through the natural design of Blockchain technology and the immutability of its ledger, enabling all data transmitted across the network to be cryptographically proofed which will enable the secure tracking and integrity of the data. Meanwhile, the private/public key mechanism established through Blockchain would allow for drastic simplifications of the security protocols needed to enable security on the traditional communication protocols.

However, the research fails to address the issues pertaining to the adoption of blockchain among devices, specifically regarding the computing power needed to implement the proof of work mechanisms of verification with small and low-cost devices.

2) MAINTAINING ANONYMITY

From the user perspective, there is an inherent lack of trust in having devices that communicate constantly with the companies that spawned them and send private consumer data in a targetable way to profit-seeking entities. Such problems are assumed to be behind the delayed adoption of some home speaker and smart assistant devices for fear that companies would be spying on their customers. Blockchain helps address this problem by allowing "security through transparency" where a secure transfer of data among users would occur while maintaining the anonymity of their specific identity [7].

Blockchain addresses the security dilemma currently faced by constrained devices in an IoT framework where organizations cannot implement current access control standards but at the same time do not want to include powerful centralized mechanisms (due to privacy and data sensitivity concerns). To that end, Blockchain enables the introduction of a decentralized authorization management framework that leverages the consistency of the Blockchain technology in addressing privacy and data sensitivity concerns [61] [60].

However, the studies do not cover the dangers of identity exposure and loss of anonymity using additional information in order to identify the individual associated with the public key indirectly.

3) SMART CONTRACT PROVISIONS

Smart contracts leverage blockchain technology in order to build contracts and agreements between various parties. These agreements are essentially computer programs with specific instructions allowing them to be executed within the context and applicability of precise parameters. Existing on the blockchain, these contracts are part of a decentralized environment and allow for the automation and execution of multi-step procedures thereby facilitating information and currency exchange on the blockchain.

An example of a smart contract can be found on the Ethereum platform, whereby issuers of new cryptocurrencies set certain exchange rates between a new cryptocurrency and that of Ethereum. These parameters depend on the issuer of the contract itself and can range from the volume of the transaction to the overall volume of currency distributed up to that point in time. Through the smart contract, the issuer can automate the process of users sending their Ethereum tokens and receiving the appropriate and equivalent amounts of the cryptocurrency in question.

Smart contracts can also be leveraged for other uses such as content distribution, supply chain management, and the IOT. Through smart contracts, content distribution can be managed by identifying specific metrics pertaining to media and content consumption and implementing the equivalent remuneration for that use, this allows for a disintermediated approach to remuneration for artists and content creators. Similarly, the supply chain can leverage smart contracts to automate the steps needed to be taken when an item ships, arrives or is in transition; this can be augmented by the internet of things using sensors and RFID chips enabling a human-less exchange of information and up to date tracking of items and food sources [1].

While smart contracts do offer several advantages that serve to increase blockchain's attractiveness relative to other systems, issues such as diverse standards and limited functionality continue to be an issue. Specifically, as smart contracts are programs they can be written in several ways and with varying parameters and standards which makes it difficult for non-technical users to understand and apply or agree to the use of smart contracts in a transaction for fear of fraud. This issue is currently being resolved using platform implemented standards such as the EC20 token standard used in Ethereum which specifies the required components and structure needed for a smart contract.

The second issue revolves around the limited use of smart contracts specifically across cryptocurrencies. In the case of Ethereum, the contracts can automate the exchange between a given cryptocurrency and the Ethereum token but cannot create exchanges and transfers from any cryptocurrency to another, which is otherwise known as a side chain. This issue is currently being resolved in the case of Ethereum by allowing such parameters to exist within smart contracts and enabling the blockchain to incorporate these transactions.

Therefore, we can conclude that smart contracts can offer the IOT several advantages especially in the way of device communication automation; however, there are several steps needed to attain a level of maturity needed for this potential to materialize.

4) DEVICE MANAGEMENT

With the use of Blockchain technology, the full automation of device interactions through the network is expected. For multiple interacting devices. Blockchain can allow user-less exchanges of information between the different inputs such as the transmitter from one component and the receiver from another. For example, when a container gets on board a ship, a truck for delivery or to a home address, the interaction is automatically recorded in the Blockchain and removes the human error component and added labor of tracking items.

The research proposes the use of Blockchain as a mechanism to build and manage an IoT network as well as its devices in relation to their synchronization and communications systems. The Blockchain would allow the

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

management of device configurations and associated keys [61] [62] [63] [64] [65].

However, there is a lack of practical application or business model development regarding the use of device management and its implications, namely the cost and maintenance requirements of incorporating such advanced communication equipment into various devices.

5) SECURE UPDATES

A shift towards a decentralized architecture would lead to a more sustainable ecosystem, the current centralized model requires too much maintenance costs, especially for something as simple as distributing a software update to millions of devices not just once, but on a continuous basis even after they are no longer manufactured.

The literature introduces the concept of an update framework in which the Blockchain based system allows for permissionless and distributed checks on the validity of the current firmware maintained on various IoT devices while checking the integrity of the software version and allowing the update procedure through automated processes leveraging the nodes on the network itself [36] [66] [67].

An example can be used to demonstrate the application of anonymity using blockchain's private/public feature found in its hashing algorithm, by considering vehicle intelligence and communication. Specifically, blockchain would leverage asymmetric encryption in order to generate a public and private key which are then assigned to vehicles, thereby enabling them to transact among one another through the public key while retaining anonymity through the securing of the private key. Consequently, cars will be able to exchange data directly with each other using the blockchain peer network infrastructure (such as the one used today for car cryptocurrencies) in order to exchange traffic information and other sensitive data while maintaining the anonymity of the vehicle itself and by extension its driver.

B. ENERGY

The energy field ranked second in our list of Blockchain applications with 17 (roughly 11%) of 151 application articles. We have identified several categories within the area of Energy and energy management Blockchain based applications including (1) electricity market control between machines, (2) Facilitating energy trade, (3) increasing the security of the energy grid, and (4) assisting in the proliferation of green energy.

1) CONTROLLING THE ELECTRICITY MARKET BETWEEN MACHINES

The traditional method of electricity consumption may not benefit significantly from Blockchain implementation as it relies on the framework of one supplier, all customers. However, recent advances in energy production and consumption have begun shifting habits and market interactions away from the traditional model. Specifically, the ability for household level electricity generation using renewable energy such as solar energy paves the way for a distributed energy market with customers becoming suppliers depending on the time and conditions. As such, a platform is needed allowing for the secure transaction of energy generation and consumption information across the different parties while optimizing human involvement and maintaining privacy.

Blockchain may be a solution as it offers the potential for a framework that operationalizes machine-to-machine interaction and establishes an electricity marketplace where a consumer can choose from various suppliers and select the appropriate offer autonomously [14]. Another problem pertaining to energy transactions among machines is the seemingly continuous payment requirements among the nodes with regards to the electricity provided or withdrawn. Micropayments are transactions with minimal nominal amounts of currency and are used to pay on a continuous basis for various small items. The introduction of micropayments allows direct interaction between machines as the authentication of the various parties is automated and decentralized [68].

However, we need to consider the complexity of the parameters involved in trading energy such as distance from the source as well as the overall need for fast and efficient switching between energy sources in order to prevent power outages which may be difficult under certain blockchain clearing algorithms such as proof of work.

2) FACILITATING ENERGY TRADE

The shift in the energy market discussed earlier opens the door to various exchanges between the different stakeholders in an energy community. Blockchain has to potential to establish a space for the creation of local electricity markets leveraging user's various energy generation mechanisms towards the democratizing of the energy market. However, there are several barriers standing in the way of energy trade.

Energy consumption privacy concerns and sharing information in the market is another problem in decentralizing the energy grid as the energy generation and consumption information of various individuals would be publicly available. A Blockchain solution can solve this by creating an exchange of information where the identity of the individual involved is not exposed. Furthermore, the solution would allow for the creation of automated auction mechanisms as mentioned earlier which would streamline energy exchange, regulate energy levels while improving security [15]. Meanwhile, the introduction of payment processing mechanisms within the Blockchain would facilitate transactions across microgrids [69] [68].

Implementations of these models should consider the relative impact such markets may have on a government's ability to predict and control energy demand and markets thereby allowing mechanisms for government intervention and moderation.

3) INCREASING ENERGY GRID SECURITY

Regardless of the model used to deliver and leverage electricity production, energy markets face a constant threat of security which poses a modern digital dilemma. An increase in digitization can leave energy manufacturers/facilities vulnerable to attack while a lack thereof would reduce efficiency and service quality.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

Blockchain is a potential solution to the energy digitization dilemma – namely the introduction of a Blockchain-based approach that leverages smart contracts for the management of energy exchanges between the various power consumer/providers would allow a sustainable and increasingly secure mechanism for energy exchange while leading to a more decentralized and resilient power grid [70]. Meanwhile, a framework for transaction anonymity within the Blockchain would allow for an increase in the security and privacy of the transacting parties in the microgrid [71] while also having the ability to protect the energy network from a cyber attack by laying out a protection framework based on the distributed ledger [13].

However, research should include the cost of increased security in the form of lack of recourse and alterations in the case of an error or fraud, whereby the anonymity and immutability of the ledger would increase the difficulty of pursuing the issue by authorities. Therefore, research on blockchain implementations should also incorporate an aspect of know your customer for government and official purposes.

4) GREEN ENERGY ASSISTANCE

As energy systems continue to evolve and renewable energy sources become more accessible to the individual consumer, the market is likely to transform into a decentralized model comprising various energy production and storage mechanisms. This poses the opportunity to reduce the environmental impact of energy production and consumption by increasing the overall efficiency and reducing waste.

Blockchain technology can be useful in an energy management framework. The introduction of green certificates via the Blockchain allowing for the authentication of the source of energy production (i.e. produced from renewable energy, simply stored traditionally generated energy in a battery or other storage mechanisms) would allow greater government incentives and programs by enabling authorities to establish adequate mechanisms for rewards and benefits [72].

Current research should also consider the required complexity needed to establish exchanges across markets for various energy sources.

We can consider the example of a household generating solar power and engaging in an active exchange in the energy market in order to supply excess power generated during peak times and offset shortages caused due to the unpredictable nature of renewable energy sources. However, there are several issues that stand in the way of such an ecosystem including the household's concerns regarding the maintenance and engagement required in order to participate as both supplier and consumer within the same market, specifically in reference to finding appropriate bids and offering ones in return at various points of time every day. Blockchain technology offers to solve the problem by decentralizing the exchange of information between households, assigning a public/private key to each household as well as leveraging smart contracts to set specific energy consumption and supply parameters. Using the smart contracts, households can set preferences regarding energy supply and demand prices and automate the exchange, which will be protected by the decentralized and immutable nature of the blockchain and household identity will remain private due to the use of asymmetric encryption.

C. FINANCE

Finance was another major category aggregated from the literature review, with 11 (around 7%) out of 151 articles studied the interaction between finance and blockchain applications: (1) Better transaction processing, (2) sustainable banking and finance, (3) enhance financial security and (4) privacy as well as automated financial contracts.

1) BETTER TRANSACTION PROCESSING

While banking institutions have helped the world move forward in commerce and trade, the rapid expansion in overall trade coupled with the digitization of financial currencies continue to apply pressures from limitations on the current system, where centralized databases hold highly sensitive information and require several days of processing for even simple payment transactions to clear banking institutions. This slows down the pace of trade and exchange and keeps it from fully replacing the traditional fiat currencies with regards to transactions.

There are many benefits posed by the Blockchain framework in relation to the banking industry with regards to improved transaction processing and performance. Specifically, the Blockchain framework can assist governments in setting up single account structure which would automate the processing and balancing of fund accounts thereby reducing idle cash balances, unnecessary borrowing costs as well as reducing costs on central banks through improved liquidity [73].

Blockchain-based systems can be established not merely as components within banking institutions but also as competitors to them, with increased integration and decentralization as the main drivers for improved operations and faster transaction processing [74].

However, studies should consider the disadvantage faced by blockchain and other novel systems with regards to proliferation and acceptance when compared to traditional methods. Furthermore, the increased transaction speed and capability to engage in instant transactions have increased dramatically in countries where technologies such as pay pass, apple pay, google pay as well as others have been implemented. This implies that absent the added anonymity and security, the main advantage of blockchain directly to consumers will be its implications to international transfers and trade.

2) SUSTAINABLE BANKING AND FINANCIAL TRANSACTIONS

Despite the 2008 crash and the subsequent rebound of the financial market, traditional banking systems still suffer from a sustainability problem. A bankruptcy by a bank leads to severe financial implications to its customers as well as chain effects for the rest of the industry. This situation made possible the global implications that arose during the

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

financial crisis and the subsequent terming of too big to fail for most financial institutions.

The overall role of Blockchain in the future of banking and financial transactions can be seen from the perspective of achieving a sustainable financial system in the global economy. Decentralizing the storage of wealth to the individuals holding it and decoupling the value of wealth from the economy (or financial condition of a specific country or region) will allow for a globally decentralized ledger, leading to theoretically more stable financial wealth values as well as a more robust economic system [75].

However, research covering this potential application must consider the business model implications to existing financial intermediaries and its impact on the lending market.

3) ENHANCED FINANCIAL SECURITY AND DATA PRIVACY

An inherent flaw in the existing data structure of the banking system is that of centralized datasets and information. Banks are vulnerable to hacking and security breaches. Whereas this can be problematic in the cases where the data are social and general demographic, the problem is much more severe when it touches on financial assets and financial identity. Another concern posed using third-party financial institutions is the lack of anonymity, with stringent ID requirements and a lack of freedom in financial transactions.

There are several advantages to the implementation of blockchain technology from the perspective of cybersecurity given the unique characteristics and potential that it offers. Specifically, the decentralization of the ledger information would render the information more secure and impervious to hacking attempts, and the increased privacy and anonymity resulting from leveraging the blockchain private/public key allows greater freedom and protection in financial transactions such as identity theft [76].

However, research should also focus on the costs associated with such anonymity and privacy whereby the identification of a user's private key would enable the attacker to commit fraud and steal information without recourse.

4) AUTOMATING FINANCIAL CONTRACTS

Blockchain enables the automation of financial contracts thereby leveraging the protocol for faster and more economical financial operations; with the potential for annual savings of roughly 11 to 12 billion dollars. This is due to blockchain's ability to implement level 3 contracts which not only execute a specific action but also automate its execution [21].

Consider an example where an individual is seeking to send money abroad to a country in the developing world. There are several issues that stand to complicate the transaction, first of which is the length of time (normally in days) required for the transfer to go through. This is exacerbated by the risks of instability for financial service providers and financial institutions in the developing world. Blockchain would allow each of the sender and receiver to have a public and private key while decentralizing and encrypting the exchange of information. As such, the individual would be able to send the required payment directly and have the transaction processed in a matter of minutes rather than days while maintaining the safety of the asset in a decentralized platform away from the financial institutions.

D. HEALTHCARE

Healthcare is the 4th category in blockchain applications with 11 (approximately 7%) out of 151 articles. A review of healthcare applied articles resulted in the identification of the following advantages: (1) Easier access to medical data, and (2) facilitated sharing of medical records, and (3) unification and standardization of medical records.

1) EASIER ACCESS TO MEDICAL DATA

Overall, medical records continue to suffer a lack of innovation. This may be due to the sensitivity of healthcare information, the costly overhaul of information technology systems, and the overall regulatory environment and privacy concerns.

Blockchain may offer a solution by helping patients get easy access to their data. Instead of having to navigate through multiple laws and processes of medical service providers in order to retrieve the information, this can be accomplished with the help of the distributed ledger and the ability to maintain privacy through the public and private key. Moreover, easy identification of the user and granting access to the appropriate medical records while keeping the overall data anonymous is made possible in the Blockchain. The decentralized aspect also removes the need to store the information with one provider, as the information is shared and will be accessible across all medical stakeholders upon request [77] [78].

However, research promoting these uses needs to account for the difficulty of accessing patient medical records in cases of accidents, incapacitation, as well as other issues of consent and authorized sharing.

2) MEDICAL DATA SHARING

Aside from the initial problem of patients being able to easily and efficiently access their data, another problem in relation to healthcare and medical information stems from the privacy and anonymity concerns pertaining to medical information in patient files. The dilemma faced by the medical profession is that medical data are extremely valuable for research purposes and the improvement of overall medical conditions and operations, but at the same time this information is highly sensitive and faces massive legal hurdles with regards to sharing and aggregating the information from the various sources.

Blockchain solves this by allowing the anonymization of the patient's medical data while keeping intact all pertinent medical information and rendering it serviceable in the aggregate. Using the Blockchain, the patient would remain anonymous by keeping his/her private key secure and only sharing their information via their public key; meanwhile, the information remains publicly available for research purposes without the risk of revealing the identity of the patient [79].

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

However, researchers experimenting with such systems should evaluate the impact of governing bodies and regulatory agencies with respect to authorizing and acknowledging the use of data collected through blockchain systems. Furthermore, business models such as remuneration for participants and health care professionals need to be considered.

3) UNIFYING MEDICAL RECORDS

The decentralization of medical records through a common Blockchain ledger would also allow for the unification and standardization of medical record information. This will allow easy transferability and follow-up across the spectrum of health service providers which would lead to the improvement of overall health and patient services.

However, researchers exploring this implementation should consider the issue of having multiple blockchain based healthcare systems which would lead to a divergence in the format of information and therefore cause an issue with regards to record unification.

We take the example of a patient wishing to transfer to the services of another doctor or hospital in order to demonstrate the application of decentralizing medical information on the blockchain. Currently, a transfer requires the release of information directly from the previous party which can take several days and complicates proceedings.

Furthermore, the records themselves may be in a different format and may contain sensitive information that the patient does not wish to share with their physician. In the case of blockchain, the medical information would be decentralized thereby rendering it available directly to the patient, who can leverage the asymmetric encryption of the blockchain in order to share their medical data with their physician while maintaining personal identity anonymity. Furthermore, the blockchain system would allow for a standardized data format that would make it easier to share and communicate with different physicians. Finally, users can choose to participate anonymously in medical research by offering their data to studies without the risk of personal identification.

E. GOVERNMENT

With 10 (about 6.5%) out of 151 Blockchain business applications literature, government is the fifth highest category of study interest. Upon review of articles pertaining to government and blockchain; we were able to identify the following advantages: (1) eGovernment, (2) Creating a true digital identity, (3) eVoting, (4) Improving measuring instruments regulation.

1) eGOVERNMENT

eGovernment refers to the leveraging of digital tools and technologies by government officials in order to improve the overall services and benefits while enhancing its interaction with its citizens.

The integration of Blockchain into government offers several advantages. First, the scalable nature of Blockchain technology coupled with the decentralized nature of the ledger requires minimal effort to maintain and administer [80] [81]. Furthermore, the introduction of smart contracts would allow the completion and execution of complex government bureaucratic operations in a streamlined method. These advantages would allow governments to simultaneously increase the number of services offered while improving the overall quality and processing times of existing services.

Second, the decentralization of the Blockchain database allows for a greater amount of transparency and accessibility between the government and its citizens, by anonymizing the data, overall government transactions can be audited and monitored for anomalies without identifying the direct party, thereby also improving overall justice services by assisting in the removal of bias [82].

Third, leveraging a private/public key combination would allow the government to open the information sharing services across the different organizations as well as to the public and the decentralized nature of the ledger means the information will be more standardized and accessible in more areas and parts than before.

Finally, the immutable nature of the ledger and its integration of financial transactions allow users to build and maintain a reliable and shareable financial history which can improve the overall quality and reliability of the credit system [83].

However, research should consider the relative significance of the large transactions and the potential risk involved in the theft of an individual's private key in order to proceed with a transaction.

2) CREATING A TRUE DIGITAL IDENTITY

Current government systems rely heavily on paper-based and traditional forms of document authenticity and identity requirements. In most countries in the world, it is not possible to use a digital ID to receive sensitive or critical government services. This is due to the lack of adoption of digital identity frameworks and standards that can both ensure privacy and security while allowing unique identification of individuals within a society.

Blockchain is aptly able to solve this problem by allowing the creation of a public and private ID whereby the individual would be able to authenticate themselves at any point while allowing the sharing of public information to be anonymous. Furthermore, the immutability and decentralization aspects of its management ensure that the information shared with the appropriate authorities is accurate and authentic [28].

However, research in this area should consider the significant dangers and implications of identity theft in the case of loss or collection of an individual's private key thereby allowing illicit behavior such as identity theft without recourse.

3) eVOTING

As government attempt to transition from the traditional voting systems that leverage paper ballots and signatures to a more modern and digital solution, a common problem persists: the centralized nature of the system means that there is a unique supplier that possesses the ability to control and manipulate the data as needed and therefore can pose a risk to the fundamentals of a country's democracy [84].

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

Blockchain can provide the solution with its open source nature and the decentralization of its ledger allowing governments to mitigate risks of data manipulation and fend off security attacks from foreign governments. Concurrently, the ability of Blockchain to allow for proper authentication while maintaining complete anonymity in the aggregate lends itself very well to the purposes and uses of voting mechanisms.

However, research should consider the computational demands of such a system especially given the nature of the election cycle under the proof of work protocol. Another consideration is the potential for identity theft through the exposure of user's private keys

4) IMPROVING MEASURING INSTRUMENTS REGULATION

Improving measuring instruments regulation: As science has progressed, so have the measuring instruments required to identify and quantify the different variables needed for scientific research; and with the increased adoption of standardized measuring instruments across different countries in general and the developing world in particular, certain challenges begin to develop with the added complexity of new instruments. The challenges pertain specifically to the amount of data being measured as well as the security risks of manipulating and modifying the data.

With the increase in the amount of information captured and needed to quantify and compute measurements, required resources have proven to be prohibitive for certain governments and developing countries. Blockchain can overcome this problem using distributed computations and measurements. By allowing the decentralization of measurement computations and dispersing it across the world while maintaining the security and integrity of the data, Blockchain can help governments overcome the limitations and obstacles of increased resource requirements. Furthermore, the decentralization of the data will make data and security breaches much more difficult, whereas the immutability of the ledger will ensure that the consistency, accuracy, and integrity of the data are maintained [85] [86].

Research should also consider issues regarding differences in international measurements of values and their implication on the sustainability and widespread adoption of such systems.

We can use an example to demonstrate the application of a true digital identity using blockchain. A patron ordering an alcoholic beverage at a bar is currently required to provide a form of personal ID upon request in order to satisfy the appropriate legal requirements. However, along with providing the needed information such as age, the patron is also providing a vast amount of personal information such as the exact date of birth, address, and various other personal information. Using the blockchain's asymmetric encryption and decentralization, users would always be given a private/ public key capable of being used and validated due to the decentralized nature of the data. In the case of the patron, the digital identity would allow the individual to disclose only the pertinent information such as age while maintaining the identity of the individual.

V. DISCUSSION

RQ1: WHAT BUSINESS FIELDS HAVE BEEN ADDRESSED IN CURRENT RESEARCH ON BLOCKCHAIN APPLICATIONS AND HOW HAS IT EVOLVED SINCE 2015?

Our research revealed several insights into the Blockchain research landscape, particularly to Blockchain applications and improvements.

Blockchain research has increased substantially over the last 2 years and by around 32% as compared to 2015 and before. Furthermore, the outlets in blockchain publications have been through major publication sources primarily Elsevier and IEEE Xplore, which emerged as top publishers. The distribution of the articles has also shifted. Although the rate of publishing in conferences has remained the same, our study shows an important increase in journal publications. This we consider a sign of increase curiosity and demand for answers about the applicability of Blockchain. Relative to other domains of research, the Blockchain body of knowledge is still weak as it is at its infancy. The increase in research in the last two years is not impressive and it needs to be many folds more in order to reach an initial stage of maturity with possible theoretical proposals, models and designs. Expansion of the blockchain research landscape is of utmost importance, and the publication of Blockchain studies in high-quality journals and outlets is necessary if we are to make sense out of its future.

Another significant shift is the increase in application type publications. In 2015, Blockchain based applications represented 8 of 41 publications [1]. However, 7 of those publications were introduced in 2015 thereby signaling a potential shift in the publication landscape towards blockchain applications. Our study corroborates the existence of this trend with the identification of 151 blockchain application articles.

Research findings from the studies presented in Table II reveal six Blockchain applications sectors (Finance, Insurance, Education, Supply Chain, Healthcare and Energy), one paradigm (IoT and Smart Cities) and six business fields (Transportation, Business Process Management, Fraud detection, Exchange, Resource Management and Rights Management). IoT seems to be treated as an all-encompassing paradigm. Many areas of business have not been addressed in Blockchain. This includes a long and not comprehensive list of manufacturing, production, operations, purchasing, marketing, sales, customer relationships, information technology, adoption, anxiety, outsourcing, logistics, business development, human resources management, and risk management. Moreover, there are many other sectors (other than energy and healthcare) and bodies that need to consider Blockchain and which includes but is not limited to: aviation and aerospace, pharmaceuticals, not for profit organizations, the United Nations, hospitality and tourism, real estate, retail, politics, economic development, environment and sports.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

We believe that Blockchain technology holds great promise as it puts forth a very courageous and ambitious proposal on the table of human evolution. It has the potential to change the human course. Relatively speaking, and considering the outcomes of this study, researchers have just begun to probe with their minds the form and function of the Blockchain technology. At the same time, it seems that businesses are very cautious and maybe scared (or lacking the understanding) to experiment with it. Are businesses waiting for researchers or the other way around? What is holding them back?

RQ2: WHAT SOLUTIONS HAVE BEEN PROPOSED WITH THE MAJOR FIELDS OF BLOCKCHAIN APPLICATIONS?

Of the 151 blockchain related applications classified in our study, publications related to the Internet of Things, Energy, Finance, Healthcare, and government were the most prominent, constituting over 53% of the total Blockchain application literature; similar to previous studies [1]. Furthermore, they elaborated in their research gap discussion section the ability for blockchain to benefit fields outside of the cryptocurrency and the bitcoin space, including the use of blockchain application for improvements in the operation and governance of other related fields, among others. Table IV summarizes the solutions that Blockchain technology has the promise to solve in the various businesses and sectors.

IoT was initially discussed, with blockchain's ability to leverage its user privacy protection through public key anonymization which was identified as a valuable resource for maintaining privacy in a future with millions of interconnected devices sharing data and engaging in constant communication. Furthermore, the decentralized and immutable nature of the blockchain ledger allows IoT based devices quick, easy and distributed access to the information while permitting constant contributions and additions to the data set from various parties due to the integral security of the information. Finally, smart contracts were found very valuable in allowing IoT devices to interact directly with one another, helping further push the boundaries of automation and remove steps of human intervention from the process of communications and processing.

Blockchain research on energy predominately focused on the usefulness of blockchain's decentralized nature in democratizing the energy supply and demand industry while accommodating a more scalable and flexible solution for the world with consumers alternating as providers on the energy grid. The blockchain's privacy and anonymity features allow for the induction of multiple consumers and providers in the market and the creation of microgrids within the energy sector while preserving the data consumption and pricing preferences of the individuals engaging in the transactions. Finally, smart contracts allow the energy sector to automate and self-execute transactions between the various participants, enabling machine to machine interactions and allowing government authorities to reliable identify green energy sources and provide the appropriate motivation incentives to their producers.

In Finance, blockchain's decentralized ledger allows for easy and convenient access to user's financial information from multiple locations while limiting the impact and loss of wealth and information due to the shutdown or bankruptcy of a central authority. The decentralization also allows global currencies tied to international market values rather than national banks and currency systems. Furthermore, the ability to anonymize transactions and maintain privacy allows for greater interaction between the various parties within the financial system and facilitates the exchange of good and services directly between individuals rather than through businesses as the private identity is kept confidential while allowing a secure exchange. Smart contracts allow the creation of level 3 ledgers capable of not only executing certain financial contracts and commitments but also automating the execution process and criteria given preset conditions and values, thereby allowing a more sustainable and flexible financial system.

Blockchain is also suggested as a method to spur and grow innovation in the healthcare sector, with the decentralization of patient data allowing users immediate and quick access to their important medical information from anywhere in the world rather than having to go through the service provider, furthermore, the immutability of the ledger would allow patients and their health service providers to freely update the ledger without concerns over data integrity and any party modifying the information for nefarious purposes. This will also increase accountability in the medical field, as mistakes would not be hidden; in addition, the enhanced privacy and anonymity of interaction within the blockchain will strengthen doctor-patient confidentiality while also allowing medical professionals open access to massive amounts of medical data previously walled off for privacy concerns.

Whether through aspects of eGovernment, digital identity, voting or measuring instruments; governments stand to gain significantly from the potential of blockchain applications. Through the decentralization of the dataset, governments can expand and enhance the quality of their services by removing the need for database administration and maintenance. It will also allow for proper digital voting as it solved the important problem of entrusting the voting data in the hands of a single company or database with the motivation to manipulate the information. Decentralization will also help better run measuring instruments and the data they capture and run by removing the obstacle of costly computing and storage equipment and securing the information from manipulation through the blockchain, the immutability will also allow for the creation of a proper digital identity capable of removing the obligation of physical proof documents as the ledger will be trustable enough to confirm the information. The enhance privacy through public/private keys will allow the government to more freely grant access to its data to other government agencies and research groups allowing for a better understanding of current problems and proposals of solutions as needed. The added privacy will also improve the voting process by providing regulators and the government access to all voting information but maintaining the private

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

identity of the voters themselves. Smart contracts will help alleviate the bureaucratic process of government systems by simplifying multi-step basic procedures thereby improving the overall efficiency and quality of services provided.

TABLE IV: Major subjects of study within the top 5 fields of Blockchain application solution research.

Field of application	Number of Articles	Solution suggested by the body of knowledge
Internet of Things	29	1. Enhanced Security of Interconnected Devices
		2. Maintaining Anonymity
		3. Smart contract provisions
		4. Device management mechanisms and protocols
		5. Network security
Energy	17	1. Electricity Market Control Between machines
		2. Facilitating Energy Trade
		3. Increasing the Security of the Energy Grid
		4. Assisting in the positive reinforcement and proliferation of green energy
Finance	11	1. Better transaction processing
		2. Sustainable banking and finance
		3. Enhanced financial security
		4. Automation of financial contracts
Healthcare	11	1. Easier access to medical records
		2. Facilitated sharing of medical information
Government	10	1. eGovernment
		2. Creating a true digital identity
		3. eVoting
		4. Improving measuring instruments regulation

RQ3: WHAT ARE CURRENT RESEARCH GAPS IN BLOCKCHAIN APPLICATIONS RESEARCH?

We were able to identify several gaps in the existing blockchain research landscape. First of which is the fact that the top 5 fields of blockchain research accounted for over 53% of the articles identified in the study. While blockchain does pose a significant advantage to these particular sectors, there are various other areas where these same advantages can prove to be useful such as the research sector, be it academic or industrial which can stand to benefit in much the same way as the healthcare industry by opening up data sources and eliminating the need for universities to maintain and administer databases while increasing the reliability of scientific findings and the integrity of the data used in the research itself. Other areas such as education, environment, insurance and supply chain are important areas that have collectively entailed only 13 articles.

The second was the broad discussion on the technical application of blockchain into the specific sectors and how the advantages of the technology can help assist these fields in improving the overall quality and scope of services offered. However, blockchain does not merely represent a new technology platform for the storage and communication of data; it also presents a new business model landscape whereby the supplier and the seller are often interchangeable. This new structure requires massive changes in the current way of doing business and research on different business models and processes to build a blockchain have been limited. Existing research on the energy market has begun to touch on this with references to energy market creation and price matching through the blockchain.

Third, whereas the literature has expanded to discuss the uses and advantages of blockchain within the various industries, there has been few or little discussion concerning the challenges of blockchain implementation and the materialization of those benefits within specific industries. Some literature does discuss the challenges and limitations of blockchain technology, but it is mostly from an overall perspective that considers the limitations rather than their application to that particular field.

Fourth, the literature discusses the applications of Blockchain in relation to specific industries and circumstances. While useful, they do not touch on the overarching use of the underlying innovations used to render the solution itself feasible. Table V highlights some of the general solutions proposed across the various industries as well as some of the spinoff innovations that can be applied to across the board. Smart contracts have the capacity to radically alter and accelerate the adoption timeline for Blockchain technology, whereas machine to machine interaction will have dramatic applications in relation to big data, machine learning and artificial intelligence. More research is needed to classify and categorize the various spinoff innovations and map their use and applicability across the industry sectors.

Finally, the blockchain applications surveyed tended to be descriptive in nature, proposing the implementation of technology to a sector with little guidelines on actual implementation or development of the application or concept needed to make the system work. Thus far such research has been limited to industry and the introduction of whitepapers around the various businesses and concepts involved in blockchain technology. However, more work is needed to push for higher quality studies and bring these efforts into the academic sector.

TABLE V: Blockchain Solutions and Resulting Spinoff Innovations

Solutions	
1	Decentralizing data and information
2	Privacy protection
3	Security of information
4	Fast and easy access to data and information
5	Remove human intervention from processing
6	Remove intermediary Service providers
7	The Democratization of data and information
8	Scalability
9	Financial losses due to time delays
10	Quality of service
Spinoff Innovations	
1	Smart Contracts

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2019.2902501, IEEE Access

2	Machine to machine communication and processing

RQ4: WHAT ARE THE FUTURE DIRECTIONS FOR BLOCKCHAIN APPLICATIONS?

Despite the seemingly rapid acceleration and continuous increase of interest in Blockchain technology, we feel that the momentum for exponential growth is not enough yet. This is evident from the body of literature as the breadth and depth of Blockchain-related studies are still lacking quality, substance, cohesion, and direction. The literature does not provide any hints of direction.

Our preliminary exploration of the literature including the term cryptocurrency has shown that research output in cryptocurrency surpassed that of blockchain in 2018. After increasing dramatically over the past 2 years, see cryptocurrencies-Blockchain research to continue to increase as part of the evolution of blockchain research. However, cryptocurrency and bitcoin are not part of the scope of research and therefore we shall not analyze this area, however, we do question the impact of cryptocurrency research on Blockchain research. Is cryptocurrency research preventing Blockchain application research or Blockchain application research is waiting for cryptocurrency research to mature first? It seems to us that cryptocurrency is a new paradigm for the financial sector pushing the envelope for new financial models. But Blockchain itself, viewed beyond the cryptocurrency space, involves organizations at a level beyond the technical domain with significant impact on their strategies, processes and competitive advantage. It follows that when it comes to Blockchain research, a strong partnership between industry and researchers must be forged for it to grow significantly, otherwise it will remain sluggish.

During our study, we observed some research on user technology acceptance. As most research today introduced blockchain into various fields and in general terms, little has been done on the usability and perceptions of users with regards to the implementation of blockchain technology. Furthermore, we find that digital rights management and digital content distribution stands to gain disproportionately from blockchain implementation and that high-quality academic research is needed since neither of them has improved since 2015 [1].

Finally, we expect an increase on the environmental impact of blockchain and the inclusion of environmental factors within the business model solutions of blockchain research due to the high amount of energy required to deploy and maintain the network system. While decentralized and shifted away from the enterprising, Blockchain poses concerns to regulatory bodies and society with regards to the sustainability of blockchain, and which constitutes an important area of future research.

VI. LIMITATIONS:

Being a systematic literature review, the paper suffers from the conventional limitations of such studies. Publication bias is a concurrent concern as there is a higher likelihood of publications with positive results to appear than negative results due to citation and publication time established in [3] [87]. This was addressed in our study by mining a collective research engine (google scholar) and drawing the largest possible number of articles available in the body of knowledge, then identifying the top sources of publication and incorporating them in our analysis. This focus on increasing the range of article searches is expected to increase the likelihood of yielding papers with negative results. Another potential solution to the problem is to expand the search even further to include SSRN sources drafts and industrial whitepapers. However, this poses problems of its own, primarily in the way of publication quality and the difficulty of obtaining an accurate and solid version of the publications in question.

Selection bias can stem from the criteria used to identify and collect the relevant publications in our survey which in turn can lead to statistical biases. Specifically, our core criteria of having blockchain or its equivalent in the article title might exclude other papers dealing with the general topic without the keyword. We attempted to solve for this by mining cryptocurrency and bitcoin-related keywords, however this posed its own set of problems, namely the increase of articles to over 3000 potential publications, the duplication of many articles with multiple keywords in the title and the divergence in the research topic is publications with cryptocurrency and bitcoin keywords have had other focuses and applications. Regardless, our objective was to build on the existing literature while investigating the growth of blockchain application literature within the various industry fields, of which we were able to identify 151 articles relating to the topics covered.

Data extraction bias was addressed using well established and regarded search engine allowing for the collection of publications and articles across different publishers, and while there remains the chance of missed articles from the search, we are confident that the method used provides increased reliability relative to other article data extraction methods.

VII. CONCLUSION

Blockchain technology possesses certain characteristics that render it a valuable tool for industrial applications and a potential source of disruption for established industries. These include the immutability of the ledger, the decentralization of the data, the preservation of privacy, the allowance of trustless transactions, the efficiency and sustainability of processes as well as the ability to automate multi-step processes using smart contracts.

We use a systematic mapping process to understand the current state of blockchain research as well as contrast it to past literature reviews and discuss its future implications for academic and industry stakeholders. The study approached the review from the standpoint of blockchain applications and publications dealing with the integration of blockchain into specific sectors and industries. Our final output resulted in 151 blockchain application publications extracted from a pool of over 1500 academic works and sifted by including only the top publishers.

Blockchain applications have focused heavily on sectors of the industry, namely IoT, Energy, Finance, Healthcare, and Government; this focused interest is likely due to the propensity for such industries to benefit by the unique combination of advantages that blockchain offers into the market.

Our study indicates that blockchain research is expanding rapidly with a distinct evolution pattern among the different layers and concepts of blockchain implementation, with initial research focusing on blockchain's first application Bitcoin, then progressing to study the underlying technology itself in the past 3 years while gradually shifting from blockchain improvement related works into application papers.

Furthermore, we identify the next wave of research to center around cryptocurrencies and related user-centered acceptance and adoption research in order to create interfaces and business models capable of streamlining blockchain integration into the various specialties.

REFERENCES

[1] J. Yli-Huumo, D. Ko, S. Choi, S. Park and K. Smolander, "Where Is Current Research on Blockchain Technology? —A Systematic Review", *PLOS ONE*, vol. 11, no. 10, p. e0163477, 2016. DOI: 10.1371/journal.pone.0163477

[2] T. Aste, P. Tasca and T. Di Matteo, "Blockchain Technologies: The Foreseeable Impact on Society and Industry", *Computer*, vol. 50, no. 9, pp. 18-28, 2017. DOI: 10.1109/mc.2017.3571064

[3] K. Petersen, S. Vakkalanka and L. Kuzniarz, "Guidelines for conducting systematic mapping studies in software engineering: An update", *Information and Software Technology*, vol. 64, pp. 1-18, 2015. DOI: 10.1016/j.infsof.2015.03.007

[4] P. Brereton, B. Kitchenham, D. Budgen, M. Turner and M. Khalil, "Lessons from applying the systematic literature review process within the software engineering domain", *Journal of Systems and Software*, vol. 80, no. 4, pp. 571-583, 2007. DOI: 10.1016/j.jss.2006.07.009

[5] K. Carley, "Coding Choices for Textual Analysis: A Comparison of Content Analysis and Map Analysis", *Sociological Methodology*, vol. 23, p. 75, 1993. DOI: 10.2307/271007

[6] R. Saade and H. Nijher, "Critical success factors in enterprise resource planning implementation", *Journal of Enterprise Information Management*, vol. 29, no. 1, pp. 72-96, 2016. DOI: 10.1108/jeim-03-2014-0028

[7] K. Christidis and M. Devetsikiotis, "Blockchains and Smart Contracts for the Internet of Things", *IEEE Access*, vol. 4, pp. 2292-2303, 2016. DOI: 10.1109/access.2016.2566339

[8] C. Prybila, S. Schulte, C. Hochreiner and I. Weber, "Runtime verification for business processes utilizing the Bitcoin blockchain", *Future Generation Computer Systems*, 2017. DOI: 10.1016/j.future.2017.08.024

[9] J. Mendling, S. Dustdar, A. Gal, L. García-Bañuelos, G. Governatori, R. Hull, M. Rosa, H. Leopold, F. Leymann, J. Recker, M. Reichert, I. Weber, H. Reijers, S. Rinderle-Ma, A. Solti, M. Rosemann, S. Schulte, M. Singh, T. Slaats, M. Staples, B. Weber, M. Weidlich, W. Aalst, M. Weske, X. Xu, L. Zhu, J. Brocke, C. Cabanillas, F. Daniel, S. Debois, C. Ciccio and M. Dumas, "Blockchains for Business Process Management - Challenges and Opportunities", *ACM Transactions on Management Information Systems*, vol. 9, no. 1, pp. 1-16, 2018. DOI: 10.1145/3183367

[10] Ž. Turk and R. Klinc, "Potentials of Blockchain Technology for Construction Management", *Procedia Engineering*, vol. 196, pp. 638-645, 2017. DOI: 10.1016/j.proeng.2017.08.052

[11] M. Turkanovic, M. Holbl, K. Kosic, M. Hericko and A. Kamisalic, "EduCTX: A Blockchain-Based Higher Education Credit Platform", *IEEE Access*, vol. 6, pp. 5112-5127, 2018. DOI: 10.1109/access.2018.2789929

[12] E. Mengelkamp, B. Notheisen, C. Beer, D. Dauer and C. Weinhardt, "A blockchain-based smart grid: towards sustainable local energy markets", *Computer Science - Research and Development*, vol. 33, no. 1-2, pp. 207-214, 2017. DOI: 10.1007/s00450-017-0360-9

[13] G. Liang, S. Weller, F. Luo, J. Zhao and Z. Dong, "Distributed Blockchain-Based Data Protection Framework for Modern Power Systems against Cyber Attacks", *IEEE Transactions on Smart Grid*, pp. 1-1, 2018. DOI: 10.1109/tsg.2018.2819663

[14] J. Sikorski, J. Haughton and M. Kraft, "Blockchain technology in the chemical industry: Machine-to-machine electricity market", *Applied Energy*, vol. 195, pp. 234-246, 2017. DOI: 10.1016/j.apenergy.2017.03.039

[15] J. Kang, R. Yu, X. Huang, S. Maharjan, Y. Zhang and E. Hossain, "Enabling Localized Peer-to-Peer Electricity Trading Among Plug-in Hybrid Electric Vehicles Using Consortium Blockchains", *IEEE Transactions on Industrial Informatics*, vol. 13, no. 6, pp. 3154-3164, 2017. DOI: 10.1109/tii.2017.2709784

[16] J. Hwang, M. Choi, T. Lee, S. Jeon, S. Kim, S. Park and S. Park, "Energy Prosumer Business Model Using Blockchain System to Ensure Transparency and Safety", *Energy Procedia*, vol. 141, pp. 194-198, 2017. DOI: 10.1016/j.egypro.2017.11.037

[17] A. Pazaitis, P. De Filippi and V. Kostakis, "Blockchain and value systems in the sharing economy: The illustrative case of Backfeed", *Technological Forecasting and Social Change*, vol. 125, pp. 105-115, 2017. DOI: 10.1016/j.techfore.2017.05.025

[18] H. Subramanian, "Decentralized blockchain-based electronic marketplaces", *Communications of the ACM*, vol. 61, no. 1, pp. 78-84, 2017. DOI: 10.1145/3158333

[19] J. Lee and M. Pilkington, "How the Blockchain Revolution Will Reshape the Consumer Electronics Industry [Future Directions]", *IEEE Consumer Electronics Magazine*, vol. 6, no. 3, pp. 19-23, 2017. DOI: 10.1109/mce.2017.2684916

[20] K. Khaqqi, J. Sikorski, K. Hadinoto and M. Kraft, "Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application", *Applied Energy*, vol. 209, pp. 8-19, 2018. DOI: 10.1016/j.apenergy.2017.10.070

[21] B. Egelund-Müller, M. Elsman, F. Henglein and O. Ross, "Automated Execution of Financial Contracts on Blockchains", *Business & Information Systems Engineering*, vol. 59, no. 6, pp. 457-467, 2017. DOI: 10.1007/s12599-017-0507-z

[22] D. Viana, "Two Technical Images: Blockchain and High-Frequency Trading", *Philosophy & Technology*, vol. 31, no. 1, pp. 77-102, 2016. DOI: 10.1007/s13347-016-0247-x

[23] E. Morse, "From Rai stones to Blockchains: The transformation of payments", *Computer Law & Security Review*, vol. 34, no. 4, pp. 946-953, 2018. DOI: 10.1016/j.clsr.2018.05.035

[24] G. Larios-Hernández, "Blockchain entrepreneurship opportunity in the practices of the unbanked", *Business Horizons*, vol. 60, no. 6, pp. 865-874, 2017. DOI: 10.1016/j.bushor.2017.07.012

[25] Y. Guo and C. Liang, "Blockchain application and outlook in the banking industry", *Financial Innovation*, vol. 2, no. 1, 2016. DOI: 10.1186/s40854-016-0034-9

[26] H. Hyvärinen, M. Risius and G. Friis, "A Blockchain-Based Approach Towards Overcoming Financial Fraud in Public Sector Services", *Business & Information Systems Engineering*, vol. 59, no. 6, pp. 441-456, 2017. DOI: 10.1007/s12599-017-0502-4

[27] Y. Cai and D. Zhu, "Fraud detections for online businesses: a perspective from blockchain technology", *Financial Innovation*, vol. 2, no. 1, 2016. DOI: 10.1186/s40854-016-0039-4

[28] C. Sullivan and E. Burger, "E-residency and blockchain", *Computer Law & Security Review*, vol. 33, no. 4, pp. 470-481, 2017. DOI: 10.1016/j.clsr.2017.03.016

[29] C. Esposito, A. De Santis, G. Tortora, H. Chang and K. Choo, "Blockchain: A Panacea for Healthcare Cloud-Based Data Security and Privacy?", *IEEE Cloud Computing*, vol. 5, no. 1, pp. 31-37, 2018. DOI: 10.1109/mcc.2018.011791712

[30] H. Wu and C. Tsai, "Toward Blockchains for Health-Care Systems: Applying the Bilinear Pairing Technology to Ensure Privacy Protection and Accuracy in Data Sharing", *IEEE Consumer Electronics Magazine*, vol. 7, no. 4, pp. 65-71, 2018. DOI: 10.1109/mce.2018.2816306

[31] P. Zhang, J. White, D. Schmidt, G. Lenz and S. Rosenbloom, "FHIRChain: Applying Blockchain to Securely and Scalably Share Clinical Data", *Computational and Structural Biotechnology Journal*, vol. 16, pp. 267-278, 2018. DOI: 10.1016/j.csbj.2018.07.004

[32] Q. Xia, E. Sifah, K. Asamoah, J. Gao, X. Du and M. Guizani, "MeDShare: Trust-Less Medical Data Sharing Among Cloud Service Providers via Blockchain", *IEEE Access*, vol. 5, pp. 14757-14767, 2017. DOI: 10.1109/access.2017.2730843

[33] X. Yue, H. Wang, D. Jin, M. Li and W. Jiang, "Healthcare Data Gateways: Found Healthcare Intelligence on Blockchain with Novel Privacy Risk Control", *Journal of Medical Systems*, vol. 40, no. 10, 2016. DOI: 10.1007/s10916-016-0574-6

[34] F. Lamberti, V. Gatteschi, C. Demartini, C. Pranteda and V. Santamaria, "Blockchain or not blockchain, that is the question of the insurance and other sectors", *IT Professional*, pp. 1-1, 2017. DOI: 10.1109/mitp.2017.265110355

[35] F. Lamberti, V. Gatteschi, C. Demartini, M. Pelissier, A. Gomez and V. Santamaria, "Blockchains Can Work for Car Insurance: Using Smart Contracts and Sensors to Provide On-Demand Coverage", *IEEE Consumer Electronics Magazine*, vol. 7, no. 4, pp. 72-81, 2018. DOI: 10.1109/mce.2018.2816247

[36] B. Lee and J. Lee, "Blockchain-based secure firmware update for embedded devices in an Internet of Things environment", *The Journal of Supercomputing*, vol. 73, no. 3, pp. 1152-1167, 2016. DOI: 10.1007/s11227-016-1870-0

[37] M. Banerjee, J. Lee and K. Choo, "A blockchain future for internet of things security: a position paper", *Digital Communications and Networks*, vol. 4, no. 3, pp. 149-160, 2018. DOI: 10.1016/j.dcan.2017.10.006

[38] M. Khan and K. Salah, "IoT security: Review, blockchain solutions, and open challenges", *Future Generation Computer Systems*, vol. 82, pp. 395-411, 2018. DOI: 10.1016/j.future.2017.11.022

[39] M. Hammi, B. Hammi, P. Bellot and A. Serhrouchni, "Bubbles of Trust: A decentralized blockchain-based authentication system for IoT", *Computers & Security*, vol. 78, pp. 126-142, 2018. DOI: 10.1016/j.cose.2018.06.004

[40] N. Kshetri, "Can Blockchain Strengthen the Internet of Things?", *IT Professional*, vol. 19, no. 4, pp. 68-72, 2017. DOI: 10.1109/mitp.2017.3051335

[41] O. Novo, "Blockchain Meets IoT: An Architecture for Scalable Access Management in IoT", *IEEE Internet of Things Journal*, vol. 5, no. 2, pp. 1184-1195, 2018. DOI: 10.1109/jiot.2018.2812239

[42] P. Sharma, M. Chen and J. Park, "A Software Defined Fog Node Based Distributed Blockchain Cloud Architecture for IoT", *IEEE Access*, vol. 6, pp. 115-124, 2018. DOI: 10.1109/access.2017.2757955

[43] P. Sharma, S. Singh, Y. Jeong and J. Park, "DistBlockNet: A Distributed Blockchains-Based Secure SDN Architecture for IoT Networks", *IEEE Communications Magazine*, vol. 55, no. 9, pp. 78-85, 2017. DOI: 10.1109/mcom.2017.1700041

[44] S. Huckle, R. Bhattacharya, M. White and N. Beloff, "Internet of Things, Blockchain and Shared Economy Applications", *Procedia Computer Science*, vol. 98, pp. 461-466, 2016. DOI: 10.1016/j.procs.2016.09.074

[45] Y. Zhang and J. Wen, "The IoT electric business model: Using blockchain technology for the internet of things", *Peer-to-Peer Networking and Applications*, vol. 10, no. 4, pp. 983-994, 2016. DOI: 10.1007/s12083-016-0456-1

[46] C. Xu, K. Wang and M. Guo, "Intelligent Resource Management in Blockchain-Based Cloud Datacenters", *IEEE Cloud Computing*, vol. 4, no. 6, pp. 50-59, 2017. DOI: 10.1109/mcc.2018.1081060

[47] K. Kotobi and S. Bilen, "Secure Blockchains for Dynamic Spectrum Access: A Decentralized Database in Moving Cognitive Radio Networks Enhances Security and User Access", *IEEE Vehicular Technology Magazine*, vol. 13, no. 1, pp. 32-39, 2018. DOI: 10.1109/mvt.2017.2740458

[48] N. Herbaut and N. Negru, "A Model for Collaborative Blockchain-Based Video Delivery Relying on Advanced Network Services Chains", *IEEE Communications Magazine*, vol. 55, no. 9, pp. 70-76, 2017. DOI: 10.1109/mcom.2017.1700117

[49] Y. Zhang, R. Deng, X. Liu and D. Zheng, "Outsourcing Service Fair Payment based on Blockchain and its Applications in Cloud Computing", *IEEE Transactions on Services Computing*, pp. 1-1, 2018. DOI: 10.1109/tsc.2018.2864191

[50] M. Zeilinger, "Digital Art as 'Monetised Graphics': Enforcing Intellectual Property on the Blockchain", *Philosophy & Technology*, vol. 31, no. 1, pp. 15-41, 2016. DOI: 10.1007/s13347-016-0243-1

[51] J. Sun, J. Yan and K. Zhang, "Blockchain-based sharing services: What blockchain technology can contribute to smart cities", *Financial Innovation*, vol. 2, no. 1, 2016. DOI: 10.1186/s40854-016-0040-y

[52] K. Toyoda, P. Mathiopoulos, I. Sasase and T. Ohtsuki, "A Novel Blockchain-Based Product Ownership Management System (POMS) for Anti-Counterfeits in the Post Supply Chain", *IEEE Access*, vol. 5, pp. 17465-17477, 2017. DOI: 10.1109/access.2017.2720760

[53] Q. Lu and X. Xu, "Adaptable Blockchain-Based Systems: A Case Study for Product Traceability", *IEEE Software*, vol. 34, no. 6, pp. 21-27, 2017. DOI: 10.1109/ms.2017.4121227

[54] R. Casado-Vara, J. Prieto, F. la Prieta and J. Corchado, "How blockchain improves the supply chain: case study alimentary supply chain", *Procedia Computer Science*, vol. 134, pp. 393-398, 2018. DOI: 10.1016/j.procs.2018.07.193

[55] A. Dorri, M. Steger, S. Kanhere and R. Jurdak, "BlockChain: A Distributed Solution to Automotive Security and Privacy", *IEEE Communications Magazine*, vol. 55, no. 12, pp. 119-125, 2017. DOI: 10.1109/mcom.2017.1700879

[56] A. Lei, H. Cruickshank, Y. Cao, P. Asuquo, C. Ogah and Z. Sun, "Blockchain-Based Dynamic Key Management for Heterogeneous Intelligent Transportation

Systems", *IEEE Internet of Things Journal*, vol. 4, no. 6, pp. 1832-1843, 2017. DOI: 10.1109/jiot.2017.2740569

[57] F. Knirsch, A. Unterweger and D. Engel, "Privacy-preserving blockchain-based electric vehicle charging with dynamic tariff decisions", *Computer Science - Research and Development*, vol. 33, no. 1-2, pp. 71-79, 2017. DOI: 10.1007/s00450-017-0348-5

[58] V. Ortega, F. Bouchmal and J. Monserrat, "Trusted 5G Vehicular Networks: Blockchains and Content-Centric Networking", *IEEE Vehicular Technology Magazine*, vol. 13, no. 2, pp. 121-127, 2018. DOI: 10.1109/mvt.2018.2813422

[59] X. Huang, Y. Zhang, D. Li and L. Han, "An optimal scheduling algorithm for hybrid EV charging scenario using consortium blockchains", *Future Generation Computer Systems*, vol. 91, pp. 555-562, 2018. DOI: 10.1016/j.future.2018.09.046

[60] A. Ouaddah, A. Elkalam and A. Ouahman, "Towards a Novel Privacy-Preserving Access Control Model Based on Blockchain Technology in IoT", *Advances in Intelligent Systems and Computing*, pp. 523-533, 2016. DOI: 10.1007/978-3-319-46568-5_53

[61] T. Hardjono and N. Smith, "Cloud-Based Commissioning of Constrained Devices using Permissioned Blockchains", *Proceedings of the 2nd ACM International Workshop on IoT Privacy, Trust, and Security - IoTPTS '16*, 2016. DOI: 10.1145/2899007.2899012

[62] S. Huh, S. Cho and S. Kim, "Managing IoT devices using blockchain platform", *2017 19th International Conference on Advanced Communication Technology (ICACT)*, 2017. DOI: 10.23919/icact.2017.7890132

[63] M. Samaniego and R. Deters, "Using Blockchain to push Software-Defined IoT Components onto Edge Hosts", *Proceedings of the International Conference on Big Data and Advanced Wireless Technologies - BDAW '16*, 2016. DOI: 10.1145/3010089.3016027

[64] M. Samaniego and R. Deters, "Hosting Virtual IoT Resources on Edge-Hosts with Blockchain", *2016 IEEE International Conference on Computer and Information Technology (CIT)*, 2016. DOI: 10.1109/cit.2016.71

[65] M. Samaniego and R. Deters, "Blockchain as a Service for IoT", 2016 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), 2016. DOI: 10.1109/ithings-greencom-cpscom-smartdata.2016.102

[66] A. Boudguiga, N. Bouzerna, L. Granboulan, A. Olivereau, F. Quesnel, A. Roger and R. Sirdey, "Towards Better Availability and Accountability for IoT Updates by Means of a Blockchain", *2017 IEEE European Symposium on Security and Privacy Workshops (EuroS&PW)*, 2017. DOI: 10.1109/eurospw.2017.50

[67] B. Liu, X. Yu, S. Chen, X. Xu and L. Zhu, "Blockchain Based Data Integrity Service Framework for IoT Data", *2017 IEEE International Conference on Web Services (ICWS)*, 2017. DOI: 10.1109/icws.2017.54

[68] T. Lundqvist, A. de Blanche and H. Andersson, "Thing-to-thing electricity micro payments using blockchain technology", *2017 Global Internet of Things Summit (GIoTS)*, 2017. DOI: 10.1109/giots.2017.8016254

[69] E. Munsing, J. Mather and S. Moura, "Blockchains for decentralized optimization of energy resources in microgrid networks", *2017 IEEE Conference on Control Technology and Applications (CCTA)*, 2017. DOI: 10.1109/ccta.2017.8062773

[70] M. Mylrea and S. Gourisetti, "Blockchain for smart grid resilience: Exchanging distributed energy at speed, scale and security", *2017 Resilience Week (RWS)*, 2017. DOI: 10.1109/rweek.2017.8088642

[71] J. Bergquist, A. Laszka, M. Sturm and A. Dubey, "On the design of communication and transaction anonymity in blockchain-based transactive microgrids", *Proceedings of the 1st Workshop on Scalable and Resilient Infrastructures for Distributed Ledgers - SERIAL '17*, 2017. DOI: 10.1145/3152824.3152827

[72] F. Imbault, M. Swiatek, R. de Beaufort and R. Plana, "The green blockchain: Managing decentralized energy production and consumption", *2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 2017. DOI: 10.1109/eeeic.2017.7977613

[73] G. Peters and E. Panayi, "Understanding Modern Banking Ledgers Through Blockchain Technologies: Future of Transaction Processing and Smart Contracts on the Internet of Money", *Banking Beyond Banks and Money*, pp. 239-278, 2016. DOI: 10.1007/978-3-319-42448-4_13

[74] T. MacDonald, D. Allen and J. Potts, "Blockchains and the Boundaries of Self-Organized Economies: Predictions for the Future of Banking", *Banking Beyond Banks and Money*, pp. 279-296, 2016. DOI: 10.1007/978-3-319-42448-4_14

[75] Q. Nguyen, "Blockchain - A Financial Technology for Future Sustainable Development", *2016 3rd International Conference on Green Technology and Sustainable Development (GTSD)*, 2016. DOI: 10.1109/gtsd.2016.22

[76] S. Singh and N. Singh, "Blockchain: Future of financial and cyber security", *2016 2nd International Conference on Contemporary Computing and Informatics (IC3I)*, 2016. DOI: 10.1109/ic3i.2016.7918009

[77] A. Azaria, A. Ekblaw, T. Vieira and A. Lippman, "MedRec: Using Blockchain for Medical Data Access and Permission Management", *2016 2nd International Conference on Open and Big Data (OBD)*, 2016. DOI: 10.1109/obd.2016.11

[78] P. Liu, "Medical Record System Using Blockchain, Big Data and Tokenization", *Information and Communications Security*, pp. 254-261, 2016. DOI: 10.1007/978-3-319-50011-9_20

[79] M. Mettler, "Blockchain technology in healthcare: The revolution starts here", 2016 IEEE 18th International Conference on e-Health Networking, Applications and Services (Healthcom), 2016. DOI: 10.1109/healthcom.2016.7749510

[80] H. Hou, "The Application of Blockchain Technology in E-Government in China", *2017 26th International Conference on Computer Communication and Networks (ICCCN)*, 2017. DOI: 10.1109/icccn.2017.8038519

[81] A. Stanciu, "Blockchain Based Distributed Control System for Edge Computing", *2017 21st International Conference on Control Systems and Computer Science (CSCS)*, 2017. DOI: 10.1109/cscs.2017.102

[82] S. Ølnes and A. Jansen, "Blockchain Technology as s Support Infrastructure in e-Government", *Lecture Notes in Computer Science*, pp. 215-227, 2017. DOI: 10.1007/978-3-319-64677-0_18

[83] S. Ølnes, "Beyond Bitcoin Enabling Smart Government Using Blockchain Technology", *Lecture Notes in Computer Science*, pp. 253-264, 2016. DOI: 10.1007/978-3-319-44421-5_20

[84] P. Noizat, "Blockchain Electronic Vote", *Handbook of Digital Currency*, pp. 453-461, 2015. 10.1016/b978-0-12-802117-0.00022-9

[85] W. Melo, A. Bessani and L. Carmo, "How blockchains can help legal metrology", Proceedings of the 1st Workshop on Scalable and Resilient Infrastructures for Distributed Ledgers - SERIAL '17, 2017. DOI: 10.1145/3152824.3152829

[86] W. Melo, L. Carmo, A. Bessani, N. Neves and A. Santin, "How blockchains can improve measuring

instruments regulation and control", *2018 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, 2018. DOI: 10.1109/i2mtc.2018.8409724

[87] A. Fernandez, E. Insfran and S. Abrahão, "Usability evaluation methods for the web: A systematic mapping study", *Information and Software Technology*, vol. 53, no. 8, pp. 789-817, 2011. DOI: 10.1016/j.infsof.2011.02.007

Joe Abou Jaoude (MBA) is a Ph.D. candidate in Business Administration (SCBTM) at Concordia University since 2013. He holds multiple awards including the Frederick Lowy Scholars Fellowship and is assistant to the Van Berkom Investment Management Program. He is also involved in consulting for international organizations such as the International Civil Aviation Organization. His research interests include Collaborative Learning, Hybrid Education, Blockchain, Cryptocurrencies, Online Learning, Technology Acceptance, Initial Coin Offering, and Education.

Dr. Raafat George Saade is an Associate Professor and Chair of the Department of Supply Chain and Business Technology Management. He has been teaching in the faculty since 1998. He obtained his Ph.D. in 1995 (Concordia University) after which he received the Canadian National Research Council postdoctoral fellowship, which he completed at McGill University in Montreal. Dr. Saade has published in journals such as Information & Management, Decision Sciences, Computers and Education, Computers in Human Behavior, Decision Support Systems, and Expert Systems with Applications. His research interests include the development and assessment of information systems, the supply chain of digital information products, The United Nations, IT-driven change and change management, and eLearning.