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Demystifying blockchain: A critical analysis of challenges, applications and opportunities

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A R T I C L E I N F O

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Adoption barriers
Innovation characteristics
Organizational characteristics
Environmental characteristics

A B S T R A C T

The blockchain is considered to be the potential driver of the digital economy. The Blockchain technology outweighs the challenges associated with the traditional transaction business governed and regulated by the third trusted party. There is a growth in the interest among the researchers, the industry, and the academia to study and leverage the potential of Blockchain. Blockchain provides a decentralized and distributed public ledger for all the participating parties. Though it seems that blockchain is a viable choice and solution for all the centralized governed and regulated transactions (in digital online space), it has potential challenges that need to be resolved; opportunities to be explored, and applications to be studied. This paper utilizes a systematic literature review to study several research endeavors made in the domain of blockchain. To further research on blockchain adoption, the paper theoretically constructs an integrated framework of the blockchain innovation adoption process in an organization considering organizational and user acceptance perspectives. This would facilitate its widespread adoption, thereby achieving sustained leadership solutions. The paper offers 23 propositions to information systems (IS)/information management (IM) scholars with respect to innovation characteristics, organizational characteristics, environmental characteristics, and user acceptance characteristics. Further, the paper explores several areas of future research and directions that can provide deep insights for overcoming challenges and for the adoption of blockchain technology.

1. Introduction

A lot of attention is received in the public domain for the disrupting technologies (Swan, 2015). The advocates of the blockchain technology argue that the blockchain technology is the foundation for trust-free economic transactions (Glaser, 2017). Gartner. (2016) claims blockchain technology as the most trending technologies having the potential to impact businesses. The idea of the Blockchain was coined in the year 2008, and since then the discipline has been continuously evolving (Davidson, De, & Potts, 2018). Initially, blockchain technology got the fame as the underlying technology for Bitcoin (Beck & Muller-Bloch, 2017). Bitcoin, the decentralized peer-to-peer digital (crypto) currency, is the most sought-after application of the Blockchain. Bitcoin provides the decentralized environment for the cryptocurrency, where the goods and services could be bought and exchanged via digital transaction using digital currencies. Though bitcoin attracted the financial markets in transforming the digital transactions, the application of the Blockchain technology is not limited to the financial markets and can disrupt any centralized governed and regulated system that coordinates the valuable information (Wright & De Filippi, 2015). Blockchain contributes to the revolution in the information and communication technology (Swan, 2015), economics of the money (Hendrickson, Hogan, & Luther, 2015; Moser, Bohme, & Breuker, 2013; White, 2015), public sector applications (Warkentin & Orgeron, 2020) and information, technological challenge and innovation (Pilkington, 2016; Swan, 2015; Wiles, 2015). Glaser (2017) mentions the concern of absence of real, innovative and effective use cases for the blockchain technology.

The Blockchain technology has two important dimensions – *distributed consensus* and *anonymity* and applies to any digital asset transaction exchanged digitally (online). It has the potential to revolutionize the digital transactions (past or present) by verifying it at any given point of time in the future by leveraging the *distributed consensus model.* Despite having great expectations from the blockchain technology, there is a paucity of knowledge to understand challenges, potential opportunities, and applications leading to its widespread adoption. Blockchain technology maintains the ever-growing list of records in a decentralized, distributed fashion conforming to the participating nodes. The information about every transaction is placed and is

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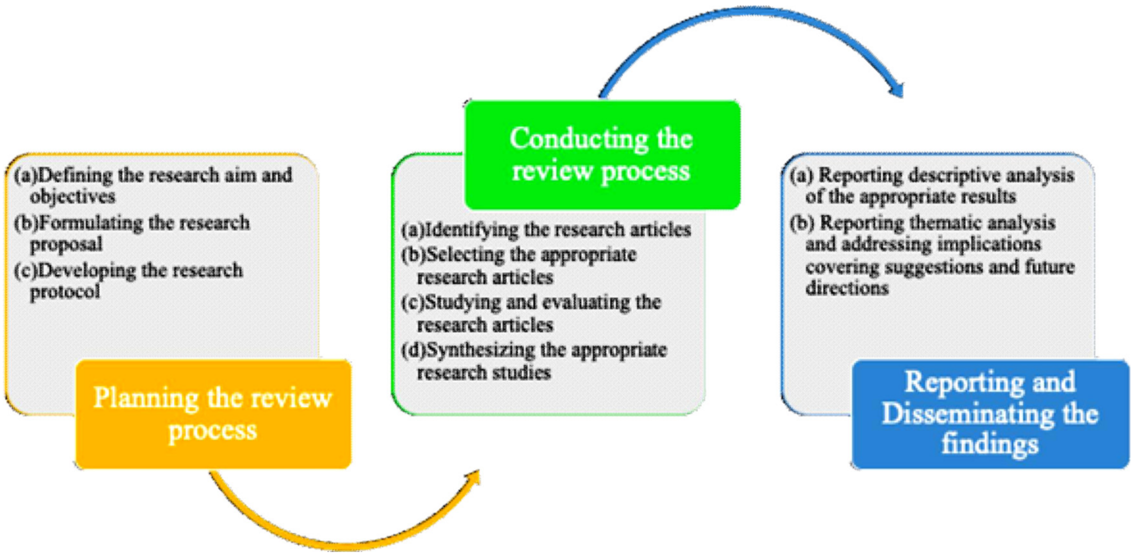

Fig. 1. 3-stage process of the systematic literature review.

available in a public ledger which is shared among all the participating nodes and involvement of a trusted third party is not needed. Moreover, the nodes participating in the blockchain are treated as anonymous thus they provide more security to other nodes to initiate and confirm the transaction.

Though it seems that blockchain is a viable choice and solution for all the centralized governed and regulated transactions (in digital online space), it has potential challenges that need to be resolved, opportunities to be explored, and applications to be studied. Prior work in this area is limited to review and synthesis of technical research – including protocol improvements, a survey about decentralized currencies and implications of cryptocurrencies (Glaser & Bezzenberger, 2015; Morisse, 2015; Tschorsch & Scheuermann, 2016; Yli-Huumo, Ko, Choi, Park, & Smolander, 2016). These studies do not cover an elaborative and comprehensive understanding of the blockchain challenges, opportunities, and applications. Schuetz and Venkatesh (2019) perform a detailed review through the lens of information management and information system while Hughes et al. (2019) conduct study exploring adoption in finance in India. Frizzo-Barker et al. (2019) argue that the mainstream discussion of the blockchain is still within the scope of innovators and early adopters. Moreover, Pan, Pan, Song, Ai, and Ming (2019) argue the relevance of organizational operational capabilities and its total asset to implement the blockchain technology. Thus, more in-depth exploration is required to broaden the research study for understanding organizational spectrum and decision-making around the adoption of blockchain technologies (Frizzo-Barker et al., 2019; Warkentin & Orgeron, 2020). Such studies will not only help to understand the blockchain adoption enterprise-wide but also to explore the diffusion of a new innovation (Ligaya, 2017). This paper utilizes a systematic literature review to study several research endeavors made in the domain of blockchain. The main purpose is to understand the pertinent and potential challenges, opportunities and applications associated with the blockchain. Organizations seeking adoption of blockchain are unclear about the structured framework that can guide them in an effective way. To advance research on blockchain adoption, the paper theoretically constructs an integrated framework of the blockchain innovation adoption process in an organization considering organizational and user acceptance perspectives. The paper offers 23 propositions for information systems (IS)/information management (IM) scholars in terms of innovation characteristics, organizational characteristics, environmental characteristics and user acceptance characteristics. Further, the paper explores several areas of future research and directions that can provide deep insights into overcoming challenges and adoption of the blockchain technology.

The rest of the paper is organized as follows: Section 2 presents the methodology adopted to perform the systematic literature review. In Section 3, descriptive analysis of the SLR is presented. Section 4, presents the detailed exploration of the pertinent and potential challenges, opportunities and applications associated with the blockchain. In Section 5, the discussion and theoretical development of the integrated framework for blockchain innovation adoption process is presented. Further, several research propositions are formulated and discussed which are followed by the research agenda and the implications and limitations of the current research study. Finally, Section 6 provides the conclusion of the paper.

2. Methodology

A systematic literature review (Jones & Gatrell, 2014; Okoli, 2015; Webster & Watson, 2002) is employed to focus on the challenges, opportunities, and applications related to the Blockchain. The SLR is deployed at collecting and investigating all of the credible state-of-the-art literature that deals with Blockchain. More specifically, the extraction of salient features, challenges, opportunities, and applications are described. The paper aims to develop an in-depth analysis of the field rather than provide a descriptive and surface overview (Jones & Gatrell, 2014). This SLR process follows the 3-stage process defined in Tranfield, Denyer, and Smart (2003) and Kitchenham and Charters (2007), see Fig. 1. A detailed description of the 3-stage process of the SLR that is followed in this paper is presented in the Appendix A and it consists of:

- Planning the review process: It comprises three steps:
(a) Defining the research aim and objectives (A1.1)
(b) Formulating the research proposal (A1.2)
(c) Developing the research protocol (A1.3)
- Conducting the review process: It comprises four steps:
(d) Identifying the research articles (A1.4)
(e) Selecting the appropriate research articles (A1.5)
(f) Studying and evaluating the research articles (A1.6)
(g) Synthesizing the appropriate research studies (A1.7)
- Reporting and Disseminating the findings: It consists of two steps
(h) Reporting descriptive analysis of the appropriate results (A1.8)
(i) Reporting thematic analysis and addressing implications covering suggestions and future directions (A1.9)

To achieve the aims and identification of the challenges, opportunities and applications following research questions are framed:

RQ1: What challenges have been addressed in the current research on Blockchain?

The blockchain is nowadays considered to be a novel and mainstream technology. Understanding the challenges will help to mitigate risks and barriers associated with the Blockchain technology.

RQ2: What opportunities have been addressed in the current research on Blockchain?

Acknowledging opportunity is a critical pathway to build Blockchain applications and market leadership. The answer to this question helps to understand opportunity space for utilizing Blockchain.

RQ3: What applications have been addressed in the current research on Blockchain?

Most often Blockchain is referred as Bitcoin cryptocurrency, but it is not the only application of the Blockchain. Thus, identification of the potential applications help to understand other directions and ways to use Blockchain.

The answers to the above questions (RQ1-RQ3) would aid in identifying future research directions in the domain of Blockchain. It will also help the key stakeholders of the blockchain to develop new applications, embrace new opportunities and acknowledge and resolve challenges leading to its widespread adoption.

3. Descriptive analysis

Adhering to the research methodology, a total of 89 articles were found suitable for the investigation of the research questions. Fig. 2 shows the number of the papers related to blockchain challenges, applications and opportunities. The growth of the scholarly research is limited till year 2016 and then it is sky-rocketed. It is worth noting that the work related to blockchain challenges, applications and opportunities began to appear in the year 2017. This signifies that the research community has slowly yet significantly picked up the potential blockchain area. Though the blockchain was coined in the year 2008 as the core technology behind bitcoin, the focus of the people for the initial few years was building the infrastructure rather than exploring challenges, applications and opportunities. Figs. 3 and 4 show the contributory papers related to challenges, applications and opportunities. It is worthwhile to note, that the publication of application related paper is 42 %, which signifies that the scholars focus mostly on developing applications. On the other side, there are relatively fewer papers related to challenges (13 %) and opportunities (26 %) and thus it projects the grey area where scholars need to produce research and knowledge corpora to develop and strengthen blockchain area. Data in Fig. 5 supports that scholarly works presented in conferences are higher in number than those published in journals over a certain period of time. Fig. 6 depicts the distribution of the research work in accordance with the country/territory. Considering the availability of the resources and the infrastructure ecosystem, United States is having the maximum number of publications which is being followed by China and the United Kingdom. Moreover, it is worth noting that developing nations, such as India, are also taking a keen interest in understanding and exploring the possibilities of the blockchain.

4. Blockchain - challenges, opportunities and applications

4.1. RQ1 - what challenges have been addressed in current research on blockchain?

Even though blockchain seems to be a viable choice to transform the existing system, processes, and businesses, many challenges remain open to materialize the benefits of prospective business domains and stakeholders. In this sub-section, the potential challenges of the blockchain are summarized considering the SLR process. Further, the challenges are categorized under lack of clarity, governance and legal, security and privacy, and other aspects.

4.1.1. Lack of clarity

The difficulty in identifying and developing use cases for the blockchain technology is potent. Moreover, the businesses and stakeholders are unclear about the way blockchain technology operates and the short- and long-term market development potential. The perceived immaturity of the blockchain technology creates a barrier for the businesses to adopt it (Avital, 2018; Beck & Muller-Bloch, 2017). Besides, unavailability of skilled human resources to develop, manage and control blockchain solutions limits the extent to which blockchain solutions can be developed, deployed and utilized. The lack of sufficient knowledge, awareness, and potential of blockchain technology restrict its wide spread adoption (Daniel & Zhu, 2018; Veuger, 2018). The early adoption throws some risks such as incompatible blockchain models, poor interoperability, upfront high costs for “mining”, and unclear running costs of the blockchain (Koteska, Karafiloski, & Mishev, 2017; Li, Cai, Deng, Yao, & Wang, 2018). There exists a lack of clarity in the way blockchain technology would interact with the existing systems. To materialize full functional blockchain, it is necessary that exchange of information between ledgers and legacy system happens freely and seamlessly (Tschorsch & Scheuermann, 2016). But, unfortunately, such a system exists in vain and recent development in technology showcases that businesses are unclear about their actions in restructuring systems, processes and legacy IT structures (Smith, 2018; Tan, Zhao, & Halliday, 2018).

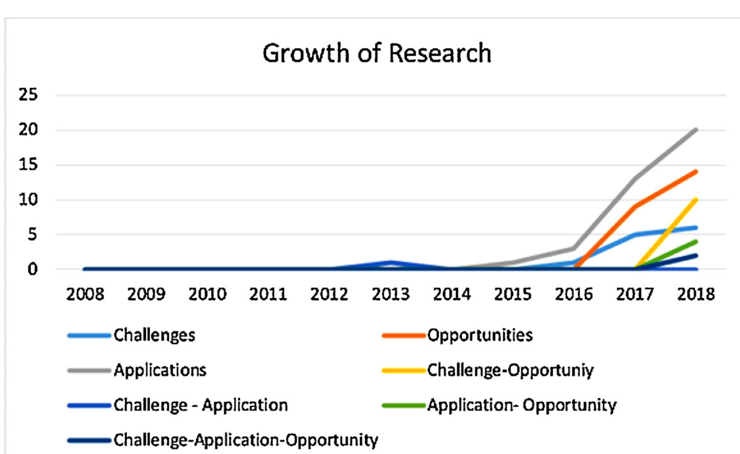

Fig. 2. Articles by year.

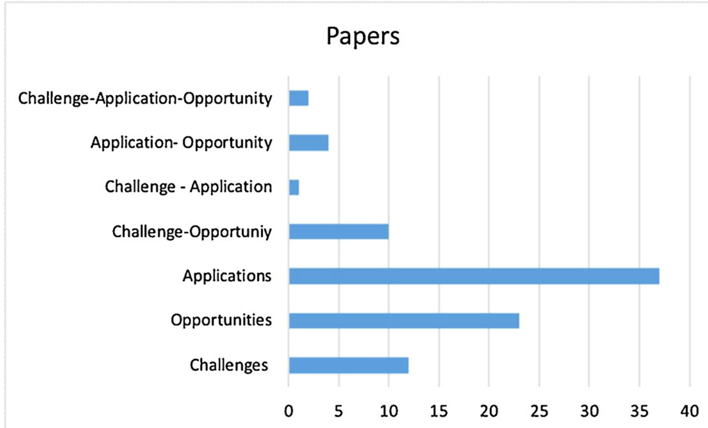

Fig. 3. Articles/papers by focus – challenge, application and opportunity.

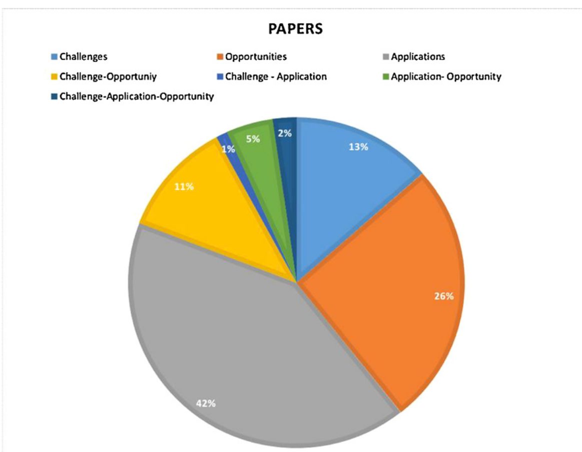

Fig. 4. Percentage of Articles/papers.

4.1.2. Governance and legal

Both permissioned and permission fewer ledgers face challenges such as accountability related to responsibilities and terms of use for participants; ownership related to automatic execution of permission by virtue of the user status (particularly in the case of anonymous users), unmanageable implications related to compliance with legislation and regulation, and management of keys and protocols for key loss or theft. Besides, the permission less ledger depending upon the design may give rise to high aggregated costs once the network grows. It also leads to periodic 'forks' resulting in slowing the transaction processing and decision making. Regulatory bodies play a key role in managing blockchain, especially in executing and managing operation and services responsible for transferring of assets or data across different jurisdiction or for ledgers involving anonymous interaction (Böhme, Christin, Edelman, & Moore, 2015; Yeoh, 2017). However, lack of appropriate and favorable policies restricts blockchain adoption (Savelyev, 2017). Goldenfein and Leiter (2018) raise challenges regarding necessary 'legal' development for transacting with these technologies. They mention few challenges such as - linking computational transactions to natural language contracts and the capacity for dispute resolution and legal enforcement. Savelyev (2018) outlines the existing challenges for distribution of copyrighted works in the digital environment, such as-storage location of the copyrighted content (on blockchain or "off-chain"), online intermediaries legal status, balance between immutable nature of blockchain and copyright law. Moreover, the author shows concern about the usage and applicability of the smart contract in compliance with legal contracts. Kirkman and Newman (2018) raise the alarm on the outdated Service Level Agreement (SLA) model, untrusted third parties with access to the customers data, unknown data location, and unwanted data movement contributing to the negative affect trust in the cloud. Boireau (2018) presents protection of both the cryptographic keys and blockchain applications as the top concern for any organization or an individual interested in blockchain to transact anything of value. Zhou, Wang, Cui, and Xing (2018) show concern about the traceability for the execution and running of the illegal software in

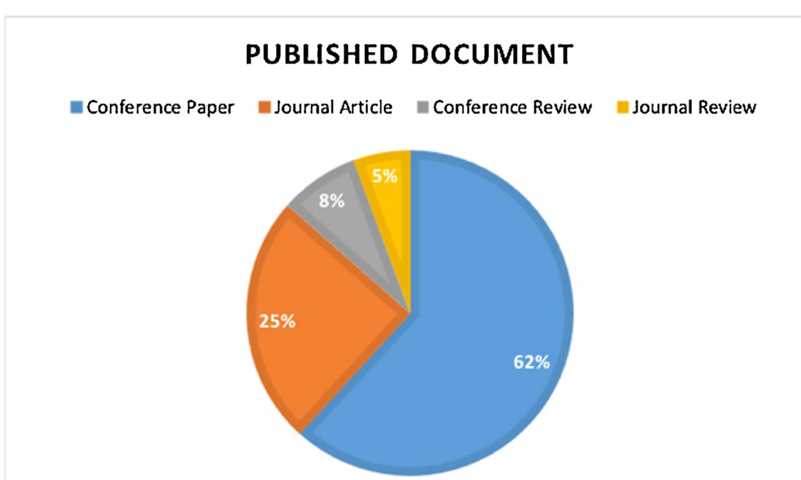

Fig. 5. Document type by percentage.

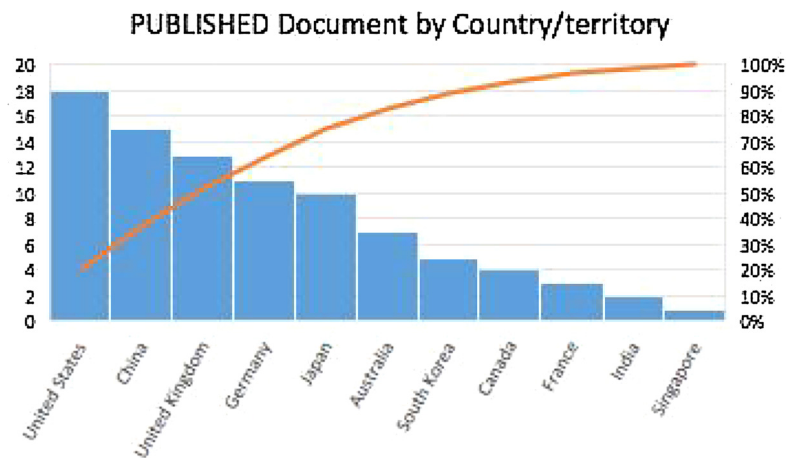

Fig. 6. document by country/territory.

the user computing environment.

4.1.3. Security and privacy

Conti, Kumar, Lal, and Ruj (2018) highlight the challenges related to vulnerabilities, security, and privacy. The blockchain is perceived to be safe as the transaction happens with generated addresses rather than the real identities. The possibility of a security risk is potent when a 'miner' controls more than 51 percent of the computing power to modify the transactions on the ledger. Though the blockchain presents an immutable nature of the transactions and data, it raises concerns related to the removal of data (in a long-term) if the participating individual wishes to remove the data. Another challenge is to deal with end-user errors such as accidental loss of keys. The upgradation and installation of software also give rise to potential privacy leakages. Due to the inherent nature of distribution and presence of multiple copies of the ledger, a security risk is surfaced when system undergo a cyber-attack or a failure. Gao et al. (2018) share concerns regarding payment records in V2G networks which are useful for extracting user behaviors and facilitating decision-making for optimized power supply, scheduling, pricing, and consumption. Sharing payment and user information, however, raise serious privacy concerns in addition to the existing challenge of secure and reliable transaction processing. Yang, Xie, Huang, and Wei (2018) present the challenges related to data storage, security, and transmission in the marine domain. Esposito, Palmieri, and Choo (2018) discuss the issues related to violation of privacy and integrity for resolving mobile application. The authors mention that the cloud-messaging solutions inherently are often characterized by vulnerabilities. Ding, Wang, Xu, Chen, and Hong (2018) raise issues such as trust and privacy to establish efficient energy blockchain.

4.1.4. Other challenges

The distributed nature of blockchain, particularly where changes are made to multiple copies, poses significant energy-intensive tasks. Also, the maintenance costs of the blockchain are pushed away from the center of the network resulting in complex management issues of cost-effective running of the systems (Rifi, Rachkidi, Agoulmine, & Taher, 2018). The smart contracts are a piece of code that get executed automatically when a particular condition is triggered. Although smart contracts provide huge potential for removing bias, manual intervention, and increasing transparency. The available evidence shows a significant challenge of blockchain in implementing and executing smart contracts. The legal understanding and coverage of smart contracts between participating parties are still unclear. Also, another challenge is to effectively map the legal code into a smart contract with the precise representation of involving parties, business entities, legal terms, business logic, roles, and responsibilities (Püttgen & Kaulartz, 2017). It is so to be understood by the parties regarding actions (in case of a code failure). To remove subjectivity to a greater extent, a party is constrained to create simpler smart contracts considering it into a binary fashion (i.e. contract is either fulfilled or not fulfilled). Scalability of transaction is a potent challenge. An increase in the required amount of transactions over the blockchain results into slowing down the overall process. For example, the bitcoin blockchain can process only seven transactions per second and is not at all ready to process real-time transactions (considering a million transactions per second). Besides, miners based on the transaction fee choose the blocks to be processed resulting in delaying the whole process (for the leftover blocks).

Further, miners having the power of hashing can manipulate the blockchain network (Eyal, 2017). Mertz (2018) puts the challenge related to getting data from one clinician to another even when a patient's data has been digitized and maintained under the electronic health records. It becomes more important when patients often have multiple doctors ordering tests, prescribing drugs, and providing treatment. Zhang, Schmidt, White, and Lenz (2018) present the issue of energy power distribution and loading due to the rise of electric vehicles (EV). The authors assert that the significant rise in the usage of the EVs results into high intermittency and variability issues in the electric power grid. Elsden et al. (2018) demystify the challenges related to the design and the application of blockchain.

Further, the authors argue that the HCI community should concentrate on integrating technology with the human experience and values (Tsai, Bai, & Yu, 2017). Püttgen and Kaulartz (2017) address the challenges such as jurisdiction-specific ontology and regulation related to insurance implementation through smart contracts. The authors believe that though blockchain holds a promising potential in the insurance industry, incorporation of a legal semantic layer in line with the regulatory requirement is essential. Table 1 summarizes challenges related to the blockchain.

4.2. RQ2 - what applications have been addressed in the current research on blockchain?

We can see the growth of blockchain applications in the diverse areas of interest. This sub-section summarizes potential applications of the blockchain considering the SLR process. The blockchain application is defined as a solution that has been developed using blockchain technology. The solutions that were conceptualized, prototyped and piloted are also studied. Further the applications are categorized under finance, energy, security and privacy, healthcare, government, education, supply chain, and internet of things.

4.2.1. Finance

Blockchain triggered much potent application and use case

Table 1
Typology of challenges related to the blockchain.

Authors	Key Category	Challenges
Avital, 2018; Beck & Muller-Bloch, 2017; Daniel & Zhu, 2018; Veuger, 2018; Koteska et al., 2017; Li, Cai et al., 2018; Tschorsch & Scheuermann, 2016; Tan et al., 2018; Smith, 2018	Lack of clarity	difficulty to identify and develop use cases; unclear about the way that blockchain technology operates; perceived immaturity of the blockchain technology; unavailability of skilled human resources; lack of sufficient knowledge, awareness; interact with existing systems; unclear about actions in restructuring systems, processes and legacy IT structures
Böhme et al., 2015; Yeoh, 2017; Savelyev, 2017; Goldenfein & Leiter, 2018; Savelyev, 2018; Kirkman & Newman, 2018; Boireau, 2018; Zhou et al., 2018	Governance and Legal	accountability related to responsibilities and terms of use for participants; ownership related to automatic execution of permission by virtue of the user status; unmanageable implications related to compliance with legislation and regulation; management of keys and protocols for key loss or theft; traceability for the execution and running of the illegal software; distribution of copyrighted works in the digital environment; outdated Service Level Agreement (SLA) model; unknown data location; unwanted data movement, complex legal sematic layer
Conti et al., 2018; Gao et al., 2018; Yang et al., 2018; Esposito et al., 2018; Ding et al., 2018	Security and Privacy	forking of the blockchain; 'miner' controls more than 51 percent of the computing power; immutable nature of the transactions; loss of keys; cyber-attack or a failure; data transmission; illicit commerce; trust between parties; selfish miner,
Rifi et al., 2018; Püttgen & Kaulartz, 2017; Eyal, 2017; Mertz, 2018; Zhang et al., 2018; Elsden et al., 2018; Tsai, Bai et al., 2017	Other	energy-intensive tasks; complex management issues of cost-effectively running the systems; difficulty in implementing and executing smart contracts; clear legal understanding and coverage of smart contracts; mapping legal code into the smart contract; scalability; block priority; slow transaction process; lack of standards; design and interaction,

scenarios in the finance domain. Trust is fundamental to execute scenarios related to deposit banking, custody insurance and secondary trading. The cost of trust varies widely- from those related to security regimes, policies, compliance team, safeguard protocols, claim and settlement process, cybersecurity, firewall, and anti-theft procedures, to the overhead cost associated with the bank and other centralized institutions. The financial crisis of 2008 reminds us that centralized intermediaries concentrate risks. The cross-border payments involve multiple intermediaries, and often the payment process is opaque resulting in pricing uncertainty, counterparty risks, and increased frauds. Ripple uses a blockchain to support the near real-time cross-border payments and achieves cost reduction and price transparency. Wu and Liang (2017) have demonstrated the inter-bank application based on blockchain to ensure secure and consistent trade and transactions. Financial institutions are also trying to mitigate the duplication of data points during 'Know-Your-Customer' checks. In Singapore, multiple banks in collaboration have piloted a blockchain based project to allow account-holders to export one-time attestation of their bonafide entities to the financial institutions. Foxconn, an electronic giant, is partnering with its suppliers to boost their working capital. The company is encouraging all its suppliers to submit their data on a blockchain [distributed ledger network] to improve coordination among partners thereby reducing payment term cycle.

Blockchain technology also has shown potential in securities clearing and settlement, derivatives clearing and processing. Nasdaq is piloting on its private securities market for clearing and settlement. The inclusion of the smart contracts is achieving post-trade process for derivative transactions (e.g., collateral management, payment on expiration). International Swapo and Derivatives Association (ISDA) is working to generate a standard set of digital definitions and smart contracts to reduce costs and counterparty risks. Financial institutions have also tried to execute a process related to dispersing corporate loan portfolio through blockchain. This process helps in achieving the reduction of operational costs, shorten the life cycle of the process and increase transparency. Liao and Wang (2017) have piloted blockchain based lottery system to ensure their fairness and transparency. Vo, Mehedy, Mohania, and Abebe (2017) have demonstrated blockchain application to transparently managing and analyzing data in a pay-as-you-go car insurance application. The application ensures that the drivers, insurance companies and financial institution are confident about the data related to trips, premiums and offers tamper proof. Rozario and Vasarhelyi (2018) have developed blockchain application for performing automatic execution of audit procedures on behalf of the auditor. The application claims to upport audit data analytics and is close to real-time audit reporting.

4.2.2. Energy

The use of blockchain has also been demonstrated in the energy domain. To encourage the use of solar energies, solarcoin has been proposed to reward the solar energy producers (Tai, Sun, & Guo, 2017). Wu, Meng et al. (2017) have explored applications in smart grid management considering the demand issue and incorporate machine-to-machine interaction. The authors have further shown the feasibility of the proposed application scenario by validating it with the smart contract for power management. Zhang et al. (2018) have brought out the concept of the blockchain-based cryptocurrency component in maintaining the effectiveness of a load of EV charging. Zhang, Wang, Kang, Cheng, and He (2016) have showcased the blockchain application for energy internet considering generation, transmission, consumption, and storage. The application supports authentication of carbon emission right, securing a cyber-physical system, coordinating a multi-energy system and trading a virtual power resource. Tai et al. (2017) discuss the application to manage the process for the electricity transactions. According to them, the transactions are stored on the blockchain and with the help of smart contracts the money transaction is executed. The benefit and the efficiency of the application have been validated with the help of the case example. The authors suggest the inclusion of an independent central operator to deal with the congestion problem. Chavez and Kleber (2016) have piloted an application that undertakes automatic hopping among mining pools in the Bitcoin network. The authors recommended that the application attained efficiency and validated it with the case example considering money transaction on the blockchain. Sikorski, Haughton, and Kraft (2017) discuss the blockchain application to facilitate machine-to-machine (M2M) interactions and establishes M2M electric market. The authors have prototyped the application with the scenario of trading workloads execution based on a proof-of-concept. Kim (2018) propose a light weight mobile charger billing system for the electric vehicles that ensures a secure online transaction in a peer-to-peer manner. Fu, Shu, and Liu (2018) have developed blockchain based on an innovative environmentally sustainable solution for the fashion apparel manufacturing industry (FAMI).

Further, the application incorporates the Emission Trading Scheme (ETS), and a novel "emission link" system, and exposes carbon emission to the public and establishes a feature to reduce the emissions for all key steps of clothing making. Tang, Zhang, and Yu (2018) propose an application to support the seamless vehicle data exchange by integrating the blockchain model and cryptography technology. Goranovic et al. (2017) discuss blockchain application to provide peer-to-peer trading, where energy is exchanged and traded locally. The authors advocate that the application is particularly suitable for implementing control and business processes in microgrids.

4.2.3. Security and privacy

The concerns such as security are paramount for the successful execution of digital transactions and scenarios. Blockchain can potentially be used to improve the security of the distributed networks. Li, Cai et al. (2018) have built an application to provide intrusion detection capability based on blockchain technology. DeCusatis, Zimmermann, and Sager (2018) have developed user identity management based on blockchain technology for cloud-based applications. Zhang, Wang, Kang, Cheng, and He (2016) have developed, Town crier, an authenticated data feed system that acts as a bridge between smart contracts and websites to enable private data requests and attain security. Ritzdorf et al. (2018) provide the application for secure cloud sharing on the blockchain to avoid the limitation of the file ownership and unilateral access control decisions in the cloud environment. Bhaskaran et al. (2018) describe the design and implementation of a smart contract for consent-driven and double-blind data sharing on the Hyperledger Fabric blockchain platform. The authors further mention that such kind of application would be helpful in addressing the trustworthy and transparent execution of transactions involving multiple parties. Banerjee and Joshi (2018) have built an application, "LinkShare", to automatically execute privacy policy on data operations and also to track the flow of data among the stakeholders. Novo (2018) have developed the application integrating blockchain and IoT to provide secure communication and scalable access management. Norta (2017) describes the bitcoin application, smart contracts and their utility for the digital economy. Wright and Serguieva (2018) have built application to support automated management of contracts. The authors claim that the application achieves a sustainable adaptive mechanism for the service infrastructures. To commission an IoT device into the cloud system, a new architecture was proposed and realized (Frey et al., 2017). Following the elements of the architecture, the device does not have to undergo any third-party authentication and is allowed to register anonymously. It is not uncommon that mobile services and social networks are collecting private sensitive information. For example, recurring incidences of a privacy breach in the social media applications Novo (2018). Usually, the collected information is stored in high storage centralized servers of service providers, which are susceptible to malware and cyberattacks. Lee (2017) explore blockchain to introduce a new ID as a service to support identity management and secure the data against privacy issues. Zyskind, Nathan, and Pentland (2015) propose that by using blockchain one can improve the protection of the data against privacy issues such as – data ownership, data transparency, and auditability and fine-grained access control. Further, the authors propose the distributed personal data management system and realize improved protection of data against privacy issues.

4.2.4. Government

One of the potential government applications of blockchain is maintaining and registering the land records. Kirkman and Newman (2018) describe the process of land management based on the blockchain, in which the information related to lands such as the status of ownership, transfer or mortgage are recorded and publicized. Government departments quite often work in silos and do not share data or keep redundant data. Maintaining common stakeholders' information and sharing it across the Government department not only increase operation success and efficiency but also result in more transparency, accountability and decision making. Wang, Liu, and Han (2018) introduce a novel Blockchain-based Government information resource sharing system (BGIRSS) to facilitate information sharing among the government bodies. The authors claim that the application solution results in low implementation and adoption cost and also provide high reliability and security as compared to the traditional systems and services. Kirkman and Newman (2018) have developed the application that supports - storing policies in an authoritative source outside the cloud, improving cloud trust by using decentralization and providing a data movement policy model. Hanifatunnisa and Rahardjo (2018) propose an application for e-voting recording. The conventional electoral systems are based on a centralized model and thus pose a threat and are vulnerable to security, privacy, and integrity. The e-voting recording application proposes to reduce database manipulation. Lee (2017) explores blockchain to introduce a new ID as a service that works as an identity and authentication management infrastructure. Huckle and White (2017) introduce the blockchain application to prove the origins of the content. The authors advocate that the application is capable of indicating the authenticity of digital media by controlling the provenance of any source of digital media. Blockchain can also be used in other Government services such as marriage registration, patent registration, income tax filing, and processing, healthcare, education, citizen services, etc. The deployment of blockchain integrated with the smart devices to run the Government services showcases promising results in managing and sharing information, reducing operational delays and overheads, building effective collaboration networks and achieving improved efficiency and performance.

4.2.5. Education

Turkanović, Hölbl, Košič, Heričko, and Kamišalić (2018) have built an application to constitute a globally trusted, decentralized higher education credit. The application's platform, "EduCTX", for global higher education credit aims to minimize the barriers related to language and administration in the higher educational institutes. Besides, if we consider '*learning modules*' as blocks and '*learning achievements'* as coins, then the concept of blockchain technology can be established seamlessly. Considering learning and teaching process as currency, Duan, Zhong, and Liu (2018) propose a blockchain based learning application service.

4.2.6. Healthcare

Liang, Shetty et al. (2018) have developed an application to share healthcare data and collaborate with health care providers and insurance companies. The application achieves the integrity and privacy of data by utilizing the blockchain network. Magyar (2018) application penetrates the digital health space. The application balances out the tradeoffs for the privacy and research availability for EHR data. The application proposes to provide data security and data availability. Liang, Zhao, Shetty, Liu, and Li (2018) have developed an application for personal health data management (PHDM) where the data integrity and accountability are maintained and achieved. The users easily synchronize the data across different devices and platforms without compromising privacy, integrity, and trust. Azaria, Ekblaw, Vieira, and Lippman (2016) have built application, MedRec, for the healthcare domain. The application manages authentication, confidentiality, accountability and data sharing - crucial considerations when handling sensitive information. The application uses proof-of-work to manage the information and secure the network. Alhadhrami, Alghfeli, Alghfeli, Abedlla, and Shuaib (2018) have developed an application to provide interoperability on data sharing among patients, hospitals, clinics, and other medical stakeholders. The authors claim that the application reduce redundancy, eliminate trusted third party and attain data security and privacy.

4.2.7. Supply chain

Tse, Zhang, Yang, Cheng, and Mu (2018) introduce blockchain technology in the food supply chain. The authors claim that the blockchain application facilitates seamless information exchange between partners and participants of the food supply chain and achieve integrity, privacy, and trust. Nakasumi (2017) discusses the blockchain application to resolve the issues related to double marginalization and information symmetry in the supply chain. Bocek, Rodrigues, Strasser, and Stiller (2017) discuss the blockchain application in the pharmaceutical supply-chain. The authors claim that by using the IoTs and blockchain technology, reduction in operational costs can be achieved. The smart contract assesses the product attributes as governed in compliance with the medical industry control process and raises the alarm in case of any deviation in the expected quality of the products in the supply-chain. Xie, Sun, and Luo (2017) have provided a blockchain application to track the agriculture products which ensures that the agricultural products data is not maliciously tampered or captured.

4.2.8. Internet of things

Internet of Things (IoT) is a promising information and communication technology that is achieving enormous growth. The philosophy behind IoT is to integrate [collaborate] the things (also named as smart entities/objects) within the internet network and provide services to the users. Some of the potential applications of IoT are in- smart home, e-Health, smart grids (Fan, Ren, Wang, Li, & Yang, 2018), logistic management (Kim & Laskowski, 2018), maritime industry (Wang, Li et al., 2018), etc. Yang et al. (2018) propose to develop smart toy by integrating IOT with edge computing and blockchain. Pieroni, Scarpato, Nunzio, Fallucchi, and Raso (2018) present the solution related to smart city. The authors suggest that the smart energy grid based on blockchain technology can solve the pertinent issues such as joining the grid, exchanging the information and buying/selling of the energy. Han, Kim, and Jang (2017) argue that the existing smart door lock systems are prone to security due to a vulnerability in the data sharing. The authors have built a blockchain based smart door lock system to provide data integrity and non-repudiation which is related to the safety of the user. Teslya and Ryabchikov (2018) have developed the cyber-physical smart space for the intelligent robots' coalition formation and functioning, based on the concept of the "blackboard" with the support of smart contracts over the blockchain technology. Table 2 describes the typology of the blockchain applications.

4.3. RQ3 - What opportunities have been addressed in current research on blockchain?

After understanding the challenges and applications landscape, we can now look into the opportunities that the development and adoption of blockchain could present. This sub-section summarizes potential opportunities of the blockchain considering the SLR process. Further, the opportunities are categorized under business practices and excellence, sectorial specific operational aspect, legal and others.

4.3.1. Business practice and excellence

It is possible to automate some business processes with blockchain that currently involve human intervention or a third-party involvement. Such automation will provide efficiency gains. For example, involvement of a trusted third party performing intermediated data synchronization and concurrency control in a supply chain can be removed (Avital, 2018; Beck & Muller-Bloch, 2017). Similar observations are evident in other studies where authors argue that removal of intermediate trusted third-party in sectors results in cost removal, novel business model, new revenue streams, improved transactional efficiency and increased transparency (Li, Cai et al., 2018; Notheisen, Cholewa, & Shanmugam, 2017). Cocco, Pinna, and Marchesi (2017) advocate that the usage of blockchain results in reducing costs as the reliance on propriety infrastructure is not applicable. Businesses can deploy and adopt blockchain to generate new revenue streams, products, and services.

Further, new business models can be built as blockchain and can be leveraged for high-data analysis, improved processes and decision making. Besides, public ledgers are useful triggering innovative processes and applications based on fairness, ethical constructs, and transparency. The automation of the business process and execution of the transactions helps businesses to reduce process overheads resulting in improved cash flows, and effective management of resources (Daniel & Zhu, 2018). Also, smart contract contributes to reducing administrative costs and lowering risks in the transaction as it allows self-enforcement and self-execution of mutual agreements among businesses, individual or machines (Wright & Serguieva, 2018). Since blockchain provides a transparent trail of transactions, it results in effective auditing and logging. The businesses can build 'shared-economy' model leading to generate a variety of business models such as multiple programmers can contribute lines of code to a program but retain copyright for their discrete contribution and distribution. Similarly, organizations can be formed based on ledgers and can be governed through smart contracts.

4.3.2. Sectoral specific

The opportunity for a sectoral specific potential of blockchain varies. Some evidence of huge investment in areas like financial services, supply chain, and healthcare are in support of opportunity space. Such sectors find blockchain's ability to provide an audit trail beneficial to control and manage services and resources. In the financial sector, to build the network effect interoperability seems to be critical. Healthcare sector identifies security, interoperability and identity management as crucial and achieves those by deploying unified architecture for sharing of data and services and by execution of smart contracts for the seamless offering of services.

Further, the IoT specific landscape must consider privacy and payments-related concepts in an M2M economy. Blockchain also provides opportunity space to increase resilience of systems and data storage due to its inherent nature of distribution and lack of single point of failure. Such systems are helpful in building new identity systems where data owned by users remains non-destroyable and universally consistent. Key areas of opportunity are about cybersecurity, authentication of trust, identification, and verification of user identities, and doing so through a transparent mechanism (Axon, Goldsmith, & Creese, 2018; DeCusatis et al., 2018).

Van and Keijzer (2018) propose the usage of blockchain technology to provide privacy and security guarantees such as anonymous authentication, auditability, and confidentiality thereby attaining the mutual authentication integrated with the smart contract for the 'Industry 4.0′-era. Cheng, Zeng, and Huang (2017) address the opportunity to avoid the forking of the blockchain by building a statechain which uses a bitcoin blockchain to propagate the application log. The authors further claim that the results are promising for creating a new opportunity space for developers and practitioners to develop new functionality without forking the blockchain. Gao et al. (2018) explore the opportunity to minimize throughput time for the execution of the smart contracts. The authors advocate that the parallel execution is beneficial not only for cost effectiveness but also for the resource consumption.

Further, the use of parallel execution develops a huge opportunity for the industries to minimize cost and resource utilization (Tsai, Yu, Wang, Liu, & Deng, 2017). Zhou et al. (2018) propose a consortium blockchain based cleanroom security service protocol (CSSP). Authors propose two-fold benefit of the protocol opportunity, first, tracking the deployment and usage of the user's software in a secure and tamper-resistant measure and second, preventing the running of error or illegal software in a user computing environment. Khan, Arshad, and Khan (2018) list out the features of the blockchain that can be utilized to tackle the most persistent IoT security problems. The IoT devices are easy to hack and compromise as typically these IoT devices are limited in computing, storage, and network capacity, and therefore they are more vulnerable to attacks than other endpoint devices such as

Table 2
Typology of applications related to the blockchain.

Authors	Key Category	Application description
Wu & Liang, 2017; Liao & Wang, 2017; Vo et al., 2017; Rozario & Vasarhelyi, 2018	Finance	inter-bank application based on blockchain to ensure secure and consistent trade and transactions Application to allow account-holders to export one-time attestation of their bonafide entities to the financial institutions Application to improve coordination among partners thereby reducing payment term cycle securities clearing and settlement derivatives clearing and processing private securities market for clearing and settlement Post-trade process for derivative transactions disperse corporate loan portfolio continuous monitoring and processing system for cyber insurance lottery system to ensure their fairness and transparency automatic execution of audit procedures on behalf of the auditor. transparently managing and analyzing data in a pay-as-you-go car insurance application
Tai et al., 2017; Wu, Meng et al., 2017; Zhang et al., 2018, 2016; Chavez & Kleber, 2016; Sikorski et al., 2017; Kim, 2018; Fu et al., 2018; Tang et al., 2018; Goranovic et al., 2017	Energy	use of solar energies smart grid management maintaining the effectiveness of a load of EV charging energy internet considering generation, transmission, consumption and storage trading virtual power resources managing the process for the electricity transactions undertaking automatic hopping among mining pools facilitating machine-to-machine (M2M) interactions and establishes M2M electric market trading workloads execution seamless vehicle data exchange peer-to-peer trading, where energy is exchanged and traded locally environmentally sustainable solution based on Emission Trading Scheme for the fashion apparel manufacturing industry
Li, Cai et al., 2018; DeCusatis et al., 2018; Zhang et al., 2016; Ritzdorf et al., 2018; Bhaskaran et al., 2018; Banerjee & Joshi, 2018; Novo, 2018; Norta, 2017; Wright & Serguieva, 2018; Frey et al., 2017; Lee, 2017; Zyskind et al., 2015	Security and Privacy	intrusion detection capability antimalware environment user identity management authenticated data feed system that acts as a bridge between smart contracts and websites to enable private data requests and attain security secure cloud sharing to avoid the limitation of the file ownership and unilateral access control decisions the smart contract for consent-driven and double-blind data sharing automatically executing privacy policy on data operations and also to track the flow of data among the stakeholders providing secure communication in smart greenhouse farming introducing a new ID as a service to support identity management and secure the data against the privacy issues developing distributed personal data management system supporting data ownership, data transparency and auditability and fine-grained access control supporting automated management of contracts executing self-identify operational problems and to deploy software updates on their own, all autonomously
Kirkman & Newman, 2018; Wang, Li et al., 2018; Kirkman & Newman, 2018; Hanifatunnisa & Rahardjo, 2018; Lee, 2017; Huckle & White, 2017	Government	maintaining and registering the land records maintaining common stakeholders information and sharing it across the Government department supporting the storage of policies in an authoritative source outside the cloud, improving cloud trust by using decentralization, and providing a data movement policy model e-voting recording application to reduce database manipulation executing new ID as a service that works as an identity and authentication management infrastructure proving the origins of the content executing marriage registration, patent registration, income tax filing and processing, healthcare, education, citizen services securing transfer of the private and sensitive information
Turkanović et al., 2018; Duan et al., 2018	Education	executing globally trusted, decentralized higher education credit deploying learning application service

(*continued on next page*)

Table 2 (*continued*)

Authors	Key Category	Application description
Liang, Shetty et al., 2018; Magyar, 2018; Liang, Zhao et al., 2018; Azaria et al., 2016; Alhadhrami et al., 2018	Healthcare	sharing healthcare data and collaborating with health care providers and insurance companies balancing out the tradeoffs for the privacy and research availability for EHR data developing and delpoying personal health data management (PHDM) where the data integrity and accountability is maintained and achieved. manageing authentication, confidentiality, accountability and data sharing - crucial considerations when handling sensitive information providing interoperability on data sharing among patients, hospitals, clinics, and other medical stakeholders.
Tse et al., 2018; Nakasumi, 2017; Bocek et al., 2017; Xie et al., 2017	Supply Chain	facilitating seamless information exchange between partners and participants of the food supply chain resolving the issues related to double marginalization and information symmetry in the supply chain assessing the product attributes using smart contract as governed in compliance with the medical industry control process and raising the alarm in case of any deviation in the expected quality of the products in the supply-chain tracking the agriculture products which ensures that the agricultural products data is not maliciously tampered or captured
Fan et al., 2018; Wang, Li et al., 2018; Yang et al., 2018; Kim & Laskowski, 2018; Pieroni et al., 2018; Han et al., 2017; Teslya & Ryabchikov, 2018	Internet of Things	building smart home developing and deploying e-Health deploying smart grids – to solve the pertinent issues such as joining the grid, exchanging the information and buying/selling of the energy developing and deploying logistic management developing and deploying processes maritime Industry developing and deploying smart toy developing and deploying smart door lock system to provide data integrity and non-repudiation which is related to the safety of the user. creating cyber-physical smart space for the intelligent robots' coalition formation and functioning, based on the concept of the "blackboard" with the support of smart contracts over the blockchain technology deploying smart transaction application to support trading and exchange of sensor data creating smart city

smartphones, tablets, or computers. Gao et al. (2018) explore the opportunities of blockchain technology to develop a mechanism that introduces a registration and data maintenance process that ensures the anonymity of user payment data while enabling payment auditing by the privileged user in the V2G networks. Novo (2018) claims that blockchain provides an opportunity to manage billions of devices in the IoT considering the distributed paradigm which works well for the attributes of scalability and complexity. Kshetri (2018) describes the issues related to supply chain management objectives such as cost, quality, speed, dependability, risk reduction, sustainability, and flexibility. Further, the author proposes that the blockchain helps in increasing transparency and accountability and thus overcomes the issues related to supply chain objectives. The validation is achieved through incorporation of the IoT in blockchain-based solutions and the degree of deployment of blockchain to validate individuals' and assets. Zhang et al. (2018) discuss blockchain as the potential technology for the healthcare industry. The authors propose that the blockchain technology provide interoperability and integrity which is essential in data sharing and data privacy. Kim and Laskowski (2018) describe the usage of traceability ontology with blockchain and IoT to achieve provenance of physical goods. Further, they provide a use case to translate the ontological statements to the smart contracts for automatic executions of a provenance trace.

Sharma, You, Palmieri, Jayakody, and Li (2018) propose a new DMM schema based on the blockchain, capable of resolving hierarchical security issues without affecting the network layout, and also satisfying fully distributed security requirements with less consumption of energy. Li, Cai et al. (2018) identify context-aware vehicular applications according to the perspectives of information and energy interactions. Further, the authors propose blockchain-inspired data coins and energy coins to achieve the proof of work. Ding et al. (2018) propose to develop strategies of energy blockchain from three perspectives- private key lost, privacy disclosure and protocol attack. The authors suggest that consensus mechanisms, encryption algorithms, and smart contracts synergy contribute to the efficient energy blockchain. Kim (2018) presents use cases to build intelligent vehicle communication network based on the blockchain. The author states that "blockchain is potential technology to establish tryst network among intelligent vehicles".

4.3.3. Legal

Goldenfein and Leiter (2018) advocate that legal engineering exercises under the blockchain periphery should be drawn on historic examples from the common law and international arbitration and thus one can work well with the competitive dynamics likely to be shaping legal engagements on the blockchain. Kirkman (2018) looks at the intersection of consumer belief model, blockchain and cloud as a means to establish trust and transparency in the cloud environment. Hofman (2017) advocates that the inclusion of the semantic legal layer on top of the smart contract would execute the legal structure. To achieve such a structure, the critical requirements are- robust, jurisdiction-specific ontologies, records and contracts.

4.3.4. Others

Teslya and Ryabchikov (2018) propose to incorporate smart contracts for processing and storing information wrt to the interaction between smart space components. Tosh, Shetty, Liang, Kamhoua, and Njilla (2018) highlight the need to develop proof-of-stake for data provenance in a cloud platform. Wong, Yee, and Nøhr (2018) advocate the usage of blockchain to consider a clinical transformation from "information" to "value and trust". Savelyev (2018) emphasizes on the legal aspects of the application of blockchain technologies in the copyright spectrum. Moreover, scalability and security issues may arise due to the excessive numbers of IoT objects in the network. The server/

Table 3
Typology of opportunities related to the blockchain.

Authors	Key Category	Opportunity description
Avital, 2018; Beck & Muller-Bloch, 2017; Li, Cai et al., 2018; Notheisen et al., 2017; Cocco et al., 2017; Daniel & Zhu, 2018; Wright & Serguieva, 2018	Business practice and excellence	Managerial: improved efficiency; improved identity management; personalized services; efficient service delivery Operational: data synchronization; concurrency control; improved transactional efficiency and increased transparency; effective auditing and logging; anonymous transactions Strategic: establish fairness and trust; build ethical construct and transparency; reduce fraud and corruption; promote economic growth Infrastructure: non-propriety; open source; less physical infrastructure; robust infrastructure; low maintenance and service cost Organization: new business models, "shared-economy' model, reduced administrative costs; new revenue streams, competitive advantage; innovation
Axon et al., 2018; DeCusatis et al., 2018; Van & Keijzer, 2018; Cheng et al., 2017; Gao et al., 2018; Tsai, Bai et al., 2017; Zhou et al., 2018; Khan et al., 2018; Novo, 2018; Kshetri, 2018; Zhang et al., 2018; Kim & Laskowski, 2018; Sharma et al., 2018; Li, Cai et al., 2018; Ding et al., 2018; Kim, 2018	Sectoral Specific	Finance: building the network effect interoperability seems to be critical; increasing the resilience of systems and data storage due to its inherent nature of distribution and lack of single point of failure; executing identification and verification of user identities; establishing trust and transparency Energy: executing identification and verification of user identities; deploying parallel execution of smart contracts for the industries to minimize cost and resource utilization; establishing trust and transparency; building context-aware vehicular applications; deploying effective integrated demand response (IDR) in the energy market Security and Privacy: executing identification and verification of user identities; tracking the deployment and usage of the user's software in a secure and tamper-resistant measure; preventing running of error or illegal software in user computing environment; deplyoing semantic legal layer on top of the smart contract will execute the legal structure; establishing trust and transparency; managing private key lost, privacy disclosure and protocol attack; providing interoperability and integrity which is essential in data sharing and data privacy Government: executing identification and verification of user identities; building semantic legal layer on top of the smart contract will execute the legal structure; establishing trust and transparency; executing trust-based e-governance Education: executing identification and verification of user identities; establishing trust and transparency; deploying peer-review system to maintain the quality of academic discourse. Health care: identifying security, interoperability and identity management as crucial and achieve those by deploying unified architecture for sharing of data and services and by execution of smart contracts for seamless offering of services; executing identification and verification of user identities; establishing trust and transparency; providing interoperability and integrity which is essential in data sharing and data privacy Supply Chain: executing identification and verification of user identities; to establish trust and transparency; improving reliability and trustworthiness of construction logbooks, work performed and material quantities recorded Internet of Things: considering privacy and payments-related concepts in a M2M economy; executing identification and verification of user identities; managing anonymous authentication, auditability, and confidentiality thereby attaining the mutual authentication; establishing trust and transparency; context-aware vehicular applications; building intelligent vehicle communication network; introducing a registration and data maintenance process to ensure the anonymity of user
Goldenfein & Leiter, 2018; Kirkman, 2018; Hofman, 2017	Legal	executing convergence of legal engineering, the blockchain, common law, and international arbitration; accomplishing trust and transparency; developing and deploying semantic legal layer
Tosh et al., 2018; Wong et al., 2018; Teslya & Ryabchikov, 2018; Savelyev, 2018; Tosh et al., 2018; Li, Cai et al., 2018, 2018; Chen et al., 2018; Hawlitschek et al., 2018; Fan et al., 2018; Chalaemwongwan & Kurutach, 2018; Pass & Shi, 2017; Yang et al., 2018; Reijers & Coeckelbergh, 2018; Esposito et al., 2018; Smith, 2018; Hsiao et al., 2018; Avital, 2018; Khan et al., 2018; Axon et al., 2018; Yoo & Won, 2018; Hou, 2017; Wu, Zeng et al., 2017; Turk & Klinc, 2017; Dubovitskaya et al., 2017	Others	incorporating smart contracts for processing and storing information wrt to the interaction between smart space components; data provenance; building clinical transformation from "information" to "value and trust"; managing legal-related aspects of the application of blockchain technologies in the copyright spectrum; addressing scalability; executing cryptographic membership authentication scheme to bind a digital identity object to its real-world entity; replacing trust in platform providers; developing trusted interfaces for blockchain-based sharing economy ecosystems; attributing to dependability, security and trust; providing public and transparent voting process; building automated sale system; identifying expense-reduction effect of system management; developing of standards

client model requires all devices to be connected and authenticated through the server, which creates a single point of failure. Tosh et al. (2018) suggest that integration of blockchain with IoT in the real world provides varied opportunity to establish new business models and distributed applications. Li, Cai et al. (2018) address the implications of the opportunity of utilizing blockchain-based security architecture for distributed cloud storage. Li, Sy, and McMurray (2018) have designed and developed a cryptographic membership authentication scheme (i.e., authenticating graph data) to support blockchain-based identity management systems (BIMS). Such a system is designed to bind a digital identity object to its real-world entity. Chen, Ma, Ye, Zheng, and Zhou (2018) offer a platform based on JointCloud Blockchain and discuss a novel case of smart traveling based on the proposed platform. Hawlitschek, Notheisen, and Teubner (2018) look into the tip of the hype cycle of the blockchain and propose that trust interfaces are required to build the trust-free systems and trust differs substantially between contexts of blockchain and the sharing economy.

Fan et al. (2018) explore the opportunity of establishing data sharing scheme using blockchain. The authors propose that by using blockchain based on the Paillier cryptosystem to realize the confidentiality of the shared data, the shared data can be prevented from being tampered, and use. Chalaemwongwan and Kurutach (2018) advocate the exploration of the opportunity for the adoption summary appropriate to the blockchain. The authors stress on the consensus protocol to verify the block which is distributing the network node. Consensus has many practices such as Byzantine general problem, Proof of work, and Proof of stake (Pass & Shi, 2017). Tan et al. (2018) propose to build an LCL Export Platform (LEP) using the blockchain concept to optimize the LCL operations for international trading, by integrating and sharing information among forwarder agencies and their clients. Yang et al. (2018) propose a blockchain model to tackle the issues related to data security and transmission in the marine domain. Reijers and Coeckelbergh (2018) propose an ontological framework of "narrative technologies" to facilitate the configuration of the social world, which enables the process of employment. Esposito et al. (2018) address the opportunity landscape in resolving mobile application vulnerabilities. The authors claim that utilizing blockchain technology reduces violation in privacy and integrity. Smith (2018) advocates the success of blockchain attributing to dependability, security, and trust. Hsiao, Tso, Chen, and Wu (2018) describe blockchain utility in providing public and transparent voting process. The authors advocate that the blockchain based voting process will achieve anonymity of voter's identity, the privacy of data transmission and verifiability of ballots.

Avital (2018) addresses the issue related to peer-review to maintain the quality of academic discourse. The author advocates that the blockchain enabled token-based-peer-review payment system will lead to efficient peer-review process resulting in quality academic corpora. Khan et al. (2018) advocate the usage of blockchain to achieve an effective scheme for e-voting. The authors describe that the usage of the cryptography and transparency are the two critical elements contributing to the success of e-voting. Axon et al. (2018) explore the usage of private blockchain and methods for enabling parties to act pseudonymously to achieve privacy requirements. Yoo and Won (2018) study automated sale system and find that the inclusion of blockchain-based smart contracts enable users to know the quantity of the products or the status of service provision and help system administrator to identify the expense-reduction effect of system management. Hou (2017) presents issues such as information security, cost and credit system related to e-governance specially to Chinese government services. The author describes that the blockchain enabled solutionsl., offer reliable, trustworthy and secured services. Wu, Zeng, Li, and Zeng (2017) discuss the issue with the integrated demand response (IDR) in the energy market. The conventional technology is unable to resolve such IDR and blockchain is proposed as a viable solution to support the IDR resource transaction in the decentralized energy market and promote IDR resource as per the market mechanism. Turk and Klinc (2017) describe the importance of blockchain in the construction management such as – improving reliability and trustworthiness of construction logbooks, works performed and material quantities recorded. Dubovitskaya, Xu, Ryu, Schumacher, and Wang (2017) present the blockchain application for radiation oncology. The application supports a secure and trustable EMR data management and sharing system. Table 3 describes the typology of the blockchain applications.

5. Discussion

Blockchain technology has multiple capabilities such as immutability, transparency, integrity, traceability, trackability that makes it attractive to the various stakeholders (Hernandez, 2017). Moreover, adopting a distributed trust paradigm through the consensus mechanism paves its way to the disintermediation and reduced information asymmetry. The potential application opportunities are endless as the foundational use case of the blockchain technology is to materialize greater transparency and transactions of value. It is not unknown that to drive the blockchain application and service space, skilled resources, and complex infrastructure are required which are scarce at present (Aru, 2017). Schuetz and Venkatesh (2019), suggest that blockchain technologies can be used to facilitate financial inclusion in rural Indian areas. The authors argue that blockchain adoption can solve various global supply chain challenges like high costs, geographical access, financial literacy and inappropriate banking products. The blockchain technology offers immense opportunities for organizations to redesign existing and develop new business models. Irrespective of the uncertainty about the cryptocurrencies, there is enough evidence that the research, academic and practitioner community are exploring blockchain to develop new and efficient solutions not only in finance (Treleaven, Brown, & Yang, 2017) but also in other domains such as supply chain management (Queiroz & Wamba, 2019; Tönnissen & Teuteberg, 2019; Kamble, Gunasekaran, & Sharma, 2019), e-commerce solution for Hainan Airlines (Ying, Jia, & Du, 2018), agriculture and migration crisis (Hughes et al., 2019). Thakur, Doja, Dwivedi, Ahmad, and Khadanga (2019) propose the blockchain solution to tackle the land records management issues in India. Vaio and Varriale (2019) describe benefits of blockchain technology in contributing to a sustainable performance. The authors explore the case of an Italian airport and suggest use of blockchain for supply chain and sustainable performance. Few scholars report importance of blockchain in achieving transparent and traceable solution of supply chains. For example, Liu and Li (2019) present solution for the product traceability problem in the supply chain management focusing on product transactions and traceability in e-commerce. Behnke and Janssen (2019) claim that setting the boundary condition in the food supply chain, which is enabled by the blockchain technology, will lead to the increased traceability. Bumblauskas, Mann, Dugan, and Rittmer (2019) suggest to build a more transparent, reliable, efficient and cost-effective food traceability solution by blockchain. Yong et al. (2019) demonstrate solution for safe vaccine supply chain and present a blockchain application for Chinese supply chains. Their solution helps the stakeholders to trace the vaccines, prevent frauds, provide a more effective demand forecasting and, consequently, minimize the expiration of vaccines.

Wamba and Queiroz (2019) claim that blockchain will impact new business models, transform relationships, and improve performance and competitive advantage in operations and supply chain management. Further, the authors suggest that more effort is required to understand the various blockchain adoption stages. It is important to note that the blockchain is in the nascent stage of development and the availability of scholarly literature is limited thus it is difficult to predict the evolution of blockchain space (Schuetz & Venkatesh, 2019; Yli-Huumo et al., 2016). Nonetheless, based on the SLR, the ontological constructs of blockchain challenges, application focus, and prospective opportunities are presented. Fig. 7 shows the representative ontological construct of the blockchain challenges, applications, and opportunities.

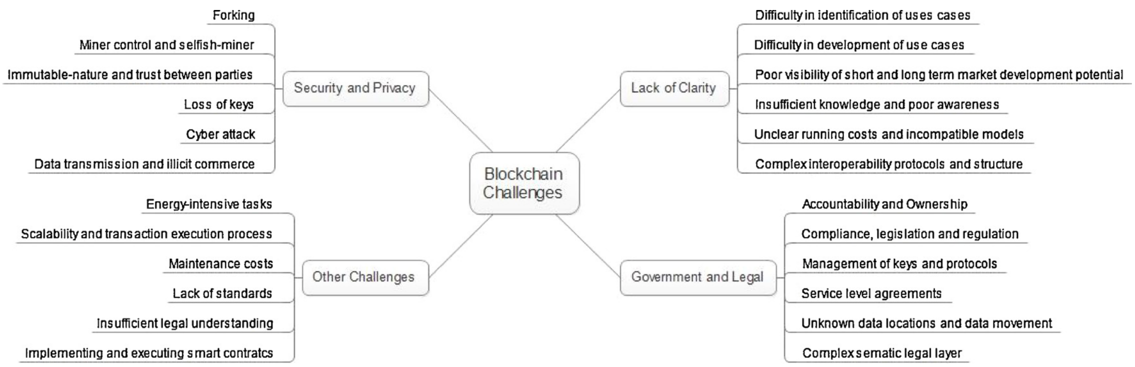

Fig. 7. Ontological constructs of blockchain challenges, applications, and opportunities.
(a). Ontology of blockchain challenges.
(b). Ontology of blockchain applications.
(c). Ontology of blockchain opportunities.

The blockchain technology is promising and emerging, but currently, the understanding of the whole phenomenon is limited and thus extensive study and research is needed. Moreover, the organizations seeking to adopt the blockchain have limited access and knowledge about the structured blockchain adoption process (Frizzo-Barker et al., 2019). To advance research on blockchain adoption, the paper theoretically constructs an integrated framework of the blockchain innovation adoption process in an organization considering organizational and user acceptance perspectives.

5.1. Theoretical framework

Blockchain is considered as the IT innovation (Swan, 2015) and is a disrupting technology impacting industrial and cultural context (Mougayar, 2016; Hughes et al. (2019). Considering the evidence and claims in the literature, organizations need to understand and explore the utility, adoption, and management of blockchain solutions. Karamchandani, Srivastava, and Srivastava (2019) demonstrate the utility of technology acceptance model (TAM) and the innovation diffusion theory (IDT) to address the issue of enterprise blockchain adoption. Moreover, they identify six supply chain management

Fig. 7. (*continued*)

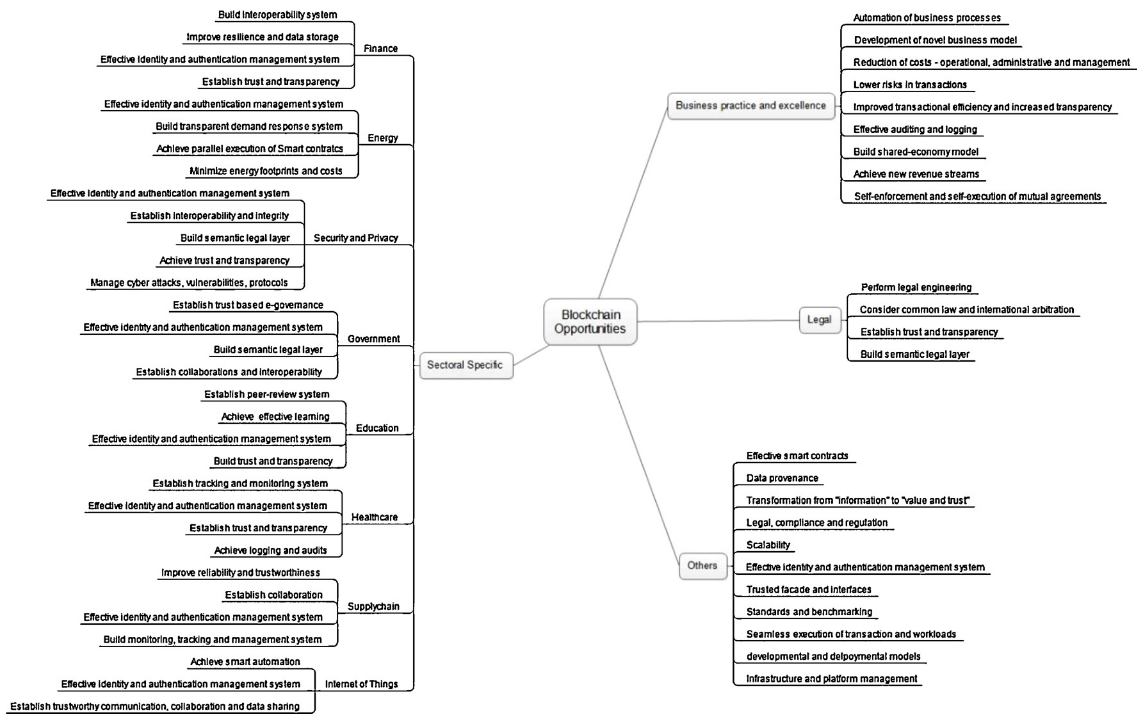

Fig. 7. (*continued*)

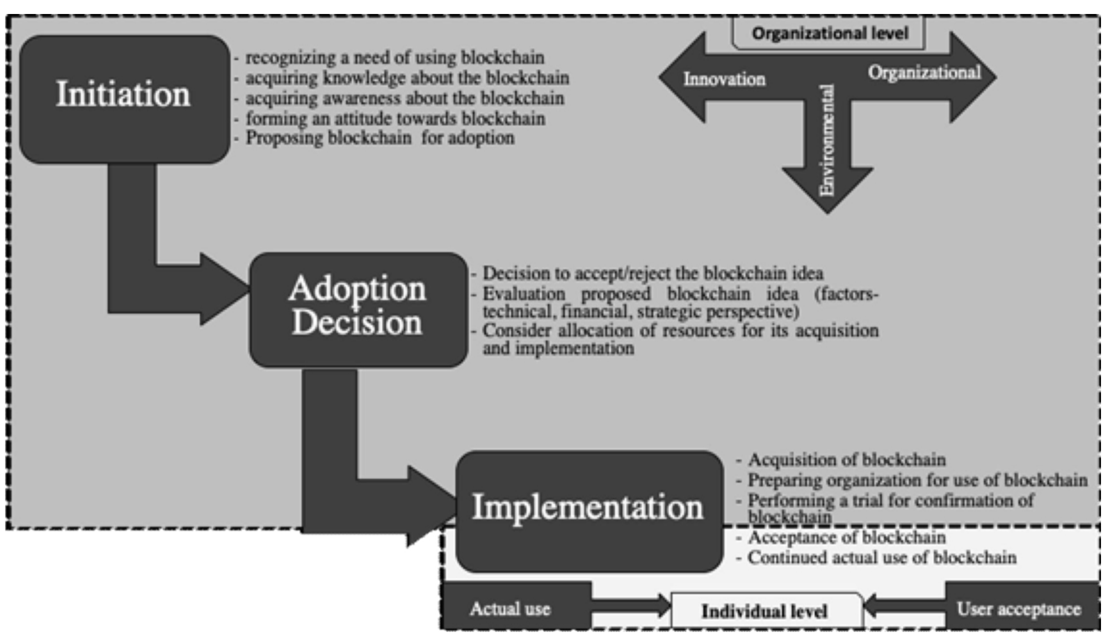

Fig. 8. Blockchain innovation adoption framework (BIAF).
Adapted from Hameed et al. (2012).

dimensions, namely "*the customer relationship, information quality, service quality, supply uncertainty, mass customization, and delivery reliability*" related to blockchain perceived benefits in supply chains. On the contrary, Wong, Leong, Hew, Tan, and Ooi (2019) perform analysis of blockchain adoption in the context of small and medium enterprises (SMEs) in Malaysia by using technology, organization and environment framework to study the blockchain adoption. They argue that technology acceptance model or united theory of acceptance and use of technology ignores the organizational and environmental factors. Frizzo-Barker et al. (2019) argue that the mainstream discussion of the blockchain is still within the scope of innovators and early adopters. Thus, more in-depth exploration is required to broaden the research study towards understanding organizational spectrum and decision-making around the adoption of blockchain technologies (Frizzo-Barker et al., 2019; Warkentin & Orgeron, 2020). Such studies will not only help to understand the blockchain adoption enterprise-wide but also to explore the diffusion of a new innovation (Ligaya, 2017). Gopalakrishnan and Damanpour (1997) claim that innovation adoption is successful only when the innovation is accepted, embraced and integrated into the organization, and individuals continue to use it over a period of time. To ensure successful adoption and user acceptance of innovation, it is of utmost important to precisely and elaboratively utilize the framework that depicts, explains and document the innovation adoption process and user acceptance of innovation in the

Table 4
3-stage process of innovation adoption.

3-stage Process	Activities	Purpose
Stage 1 Pre-adoption	- recognizing a need of using blockchain - acquiring knowledge about the blockchain - acquiring awareness about the blockchain - forming an attitude towards blockchain - proposing blockchain for adoption	To understand the utility, benefits and desired consequences of blockchain to develop and retain sustained leadership and market space
Stage 2 Adoption-decision	- performing decision to accept/reject the blockchain idea - evaluating proposed blockchain idea (factors- technical, financial, strategic perspective) - considering allocation of resources for its acquisition and implementation	To understand and explore the potential ideas and evaluation strategies considering technical, financial and strategic perspectives for the blockchain adoption decision.
Stage 3 Post-adoption	- preparing for acquisition of blockchain - preparing organization for use of blockchain - performing a trial for confirmation of blockchain - accepting blockchain - continuing actual use of blockchain	To acquire, deploy blockchain and prepare organization accordingly. Also, establish user acceptance and actual use of blockchain for use cases.

organization (Tidd, Bessant, & Pavitt, 1997). The process of adoption of innovation has been considered as the stage-based process (Hage & Aiken, 1970; Kwon & Zmud, 1987; Pierce & Delbecq, 1977; Rogers, 1995; Zaltman, Duncan, & Holbek, 1973). IT innovation adoption has been widely considered as a 3-stage process of initiation, adoption-decision, and implementation (Pierce & Delbecq, 1977; Rogers, 1995; Tornatzky & Fleischer, 1990). In the IS literature, these 3-stage processes are commonly referred to as pre-adoption, adoption-decision, and post-adoption.

The study by Hameed, Counsell, and Swift (2012) present an innovation model with an interactive perspective. The model presented in Hameed et al. (2012) outlines the 3-stage process for IT innovation adoption and also elaborates on two-level analysis, firstly, from the organizational perspective which considers organizational level analysis, and secondly, from the user acceptance (individual level) perspective performing user acceptance analysis. This study theoretically constructs an integrated framework of the blockchain innovation adoption process in organizations by considering the organizational level adoption of blockchain and user acceptance of blockchain at an individual level.

By applying the 3-stage process and key elements of IT innovation adoption model presented in Hameed et al. (2012), this study presents a framework, Blockchain Innovation Adoption Framework (BIAF) Fig. 8, that can guide organization to adopt blockchain. The 3-stage process activities are summarized in the Table 4. Slappendel (1996) advocates the utility of interactive process perspective to describe and explain the complex IT innovation adoption in organization in multiple contexts. The interactive process perspective deals with innovation adoption by considering factors such as individuals or structural involving their interconnection analysis. The proposed framework incorporates the characteristics of the organization and behaviors of individuals and thus considers interactive process perspective.

Further, the framework will help key stakeholders to strategize and act to perform organizational and individual level analysis to understand organizational level and individual (user acceptance) level adoption. In addition, a number of research propositions have been set out in Table 5. Each of these research propositions is aligned with one or more elements within a framework and is developed from the literature review. The research propositions are broadly categorized into:

- *organizational level analysis*: It measures the organizational level adoption of the blockchain. In the 3-stage process of the blockchain innovation adoption framework, it appears when an organization seeks knowledge of the blockchain innovation until the acquisition of the blockchain.
- *individual level analysis*: It measures the individual level adoption of the blockchain. In the 3-stage process of the blockchain innovation adoption framework, it covers the user acceptance and actual use of the blockchain.

5.2. Propositions of blockchain innovation adoption

In the BIAF, the blockchain innovation adoption is identified as passing through the 3-stage process – initiation, decision-adoption, and implementation employing an interactive process approach considering two levels of adoption – organizational and individual (Hameed et al., 2012). The organizational level is further categorized into innovation characteristics, environmental characteristics, organizational characteristics (Hameed et al., 2012; Ven & Rogers, 1988; Wong et al., 2019). The individual level driven by user acceptance characteristics is further categorized into perceived usefulness, performance expectancy, effort expectancy, social influence, facilitating conditions, behavioral intention and use behavior (Hameed et al., 2012; Tornatzky & Klein, 1982; Dwivedi et al., 2017).

5.2.1. Innovation characteristics

The literature has mentioned various factors of innovation that influence IT adoption in the organization. In the work of Rogers (2003), the innovation-diffusion process is described as "an uncertainty reduction process" (p. 232). The author has also proposed five innovation attributes - relative advantage, compatibility, complexity, trialability, and observability, all having the potential to reduce uncertainty about the innovation (Rogers, 1995). Kapoor, Dwivedi, & Williams, 2014) review the usage of innovation diffusion attributes and their work identify the gaps in the innovation diffusion. Further, they claim that their meta-analysis will help the scholars and practitioners to understand the prevailing trends of Rogers' five innovation attributes. Mallat, Rossi, Tuunainen, and Oorni (2006) argue that innovation diffusion theory has now been considered critical in the IS adoption research. Venkatesh, Morris, Davis, and Davis (2003) emphasize that for organization to enhance the productivity, acceptance of technologies and systems must be streamlined and materialized. Moreover, they consider IS and modern technologies as vital part of the effective operational and functional aspects of the organization. Thus, it is paramount for the organization to have clarity on the user acceptance of the new technologies and the factors influencing the acceptance of such technologies. It is necessary for the managers to understand the influence of innovation attributes to steer the diffusion of the given innovation in the organization (Kapoor et al., 2014b).

Relative advantage: Rogers (2003) defined relative advantage as "*the degree to which an innovation is perceived as being better than the idea it supersedes*" (p. 229). Lee and Kim (2007) observe that there exists a direct impact on the implementation and performance of the innovation, for example an internet-based IS system, when staff appreciate the

Table 5
Research Propositions.

3-stage Process	Propositions
Stage 1 Pre-adoption	- P8: blockchain adoption can be affected by the availability of skilled and expert resources. - P9: blockchain adoption can be affected by the availability of the infrastructure, standards, protocols, and functionality to integrate and interoperate within and across the business ecosystem. - P10: blockchain adoption can be affected by the level of sufficient knowledge and awareness of blockchain
Stage 2 Adoption-decision	- P1: relative advantage positively impacts the blockchain adoption decisions in organizations. - P2: compatibility positively impacts the blockchain adoption decisions in organizations - P3: complexity negatively impacts the blockchain adoption decisions in organizations. - P4: trialability positively impacts the blockchain adoption decisions in organizations. - P5: observability positively impacts the blockchain adoption decisions in organizations. - P6: blockchain solution offering great levels of relative advantage, compatibility, simplicity, trialability, and observability (complexity) is likely to have a positive (negative) impact on blockchain adoption decisions in organizations - P7: blockchain adoption can be affected by different cultures. - P8: blockchain adoption can be affected by the availability of skilled and expert resources. - P9: blockchain adoption can be affected by the availability of the infrastructure, standards, protocols, and functionality to integrate and interoperate within and across the business ecosystem. - P10: blockchain adoption can be affected by the level of sufficient knowledge and awareness of blockchain - P11: blockchain adoption can be affected by the level of organization readiness. - P12: blockchain adoption can be affected by the level of operational readiness - P13: blockchain adoption is reduced if the information is not shared by the partners - P14: development in storage, computing and cloud infrastructure will affect the blockchain adoption and positively improve the data-intensive processes and practices. - P18: blockchain adoption increases collaborative performance and likely to transform the strategic collaborations.
Stage 3 Post-adoption	- P13: blockchain adoption is reduced if the information is not shared by the partners - P14: development in storage, computing and cloud infrastructure will affect the blockchain adoption and positively improve the data-intensive processes and practices. - P15: blockchain adoption changes the governance structure characteristics and cost - P16: blockchain innovation solution adoption is increased by favorable government and regulatory policies and frameworks - P17: blockchain adoption reduces opportunistic behavior - P18: blockchain adoption increases collaborative performance and likely to transform the strategic collaborations. - P19: perceived usefulness positively impacts the behavioral intention of using blockchain - P20: effort expectancy positively impacts the behavioral intention of using blockchain - P21: social influence positively impacts the behavioral intention of using blockchain - P22: facilitating conditions positively impact the behavioral intention of using blockchain - P23: behavioral intention positively impacts the use behavior of blockchain and affects the blockchain adoption

relative advantage of the new system. Kishore and McLean (2007) while investigating their research work on the software reuse infusion find that the relative advantage has a positive influence on the infusion behavior. The decision-maker in the organizational context will have better visibility of the desirable consequences of the innovation as compared to the alternatives and thus will have a better chance of its adoption (Kapoor, Dwivedi, & Williams, 2014; Premkumar, 2003).

Proposition 1 (P1). relative advantage positively impacts the blockchain adoption decisions in organizations.

Compatibility: Rogers (2003) stated that "*compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters*" (p. 15). An innovation that is more compatible in the desired context results in reduced uncertainty of its adoption (Kapoor et al., 2014a). Huh, Kim, and Law (2009) suggest that compatibility is a significant predictor of the attitude contributing to the innovation adoption. They studied the innovation adoption acceptance behavior of hotel IS in upscale hotel and recommended compatibility attribute of significant nature. Slyke, Johnson, Hightower, and Elgarah (2008) argue that other scholars in the IS field consider studying risks of scale reuse in discussing compatibility and focus on the dimension that is closely related to the current work style (Moore & Benbasat, 1991). The greater level of compatibility means that the innovation can be seamlessly integrated within the desired context of the organization considering its processes, practices, resources, and infrastructures and thus positively influence the adoption decision (Jeon, Han, & Lee, 2006). The compatibility attribute is therefore positively related to any innovation adoption decision.

Proposition 2 (P2). compatibility positively impacts the adoption decisions in organizations

Complexity: Rogers (2003) defined complexity as "*the degree to which an innovation is perceived as relatively difficult to understand and use*" (p. 15). Kapoor et al. (2014b) argue that a higher degree of complexity renders an equally higher degree of difficulty in understanding and using any given innovation. IT innovation having intrinsic complexity to understand and its usage will have a negative impact on assessing the net benefits of the desirable consequences (Dwivedi, Venkitachalam, Sharif, Al-Karaghouli, & Weerakkody, 2011; Jan & Contreras, 2011). Moreover, innovation having great level of complexity, results in increased uncertainty of the desired outcomes and thus negatively impacts the adoption decision (Kapoor et al., 2014a; Thong, 1999).

Proposition 3 (P3). complexity negatively impacts the blockchain adoption decisions in organizations.

Trialability: According to Rogers (2003), "*trialability is the degree to which an innovation may be experimented with on a limited basis*" (p. 16). Teo and Lim (1996) explore the trialability attribute for trying different PC applications considering both opportunity and accessibility as the factors. In another study by Turner and Turner (2002) is was found that due to lack of trialability the uptake for computer supported co-operative working was affected and resulted into significant low uptake. The availability of the innovation on the trial basis help decision-maker to asses and evaluate potential capabilities of the innovation and resolve any issues before adopting it fully (Kapoor et al., 2014a). Innovation having great level of trialability results in reduced uncertainty of the desired outcomes and thus impacts positively the adoption decision.

Proposition 4 (P4). trialability positively impacts the blockchain adoption decisions in organizations.

Observability: Rogers (2003) defined observability as "*the degree to which the results of an innovation are visible to others*" (p. 16). It helps the decision-maker to assess the positive features and benefits of the innovation. Moreover, great level of observability offers decision-maker to understand and explore the innovation which in turn positively impacts the decision-maker decision of adoption (Hashem & Tann, 2007). For example, applications like energy management as a shared economy is completely unfeasible in the presence of intermediaries and since blockchain fundamentally works for the transaction of any value and promotes disintermediation, its benefits are visible.

Proposition 5 (P5). observability positively impacts the blockchain adoption decisions in organizations.

Kapoor et al. (2014b) study 226 articles and claim that out of the Rogers' five innovation attributes, two attributes, observability and trialability, were the least used. However, it is believed that for an immediate impact assessment and early adoption studies attributes such as – observability and trialability are important. For example, Li, Troutt, Brandyberry, and Wang (2011) emphasize that, while studying the innovation adoption on the use of online sales channels, due to the presence of the peer adopters the trialability does not make sense and thus the attribute can be avoided for further study. However, they argue that trialability attribute should be considered when peer adopters are not present. Sia, Teo, Tan, and Wei (2004) suggest that when the organization is undergoing restructuring, having limited scope of the adoption and when it is impossible to reverse the impact of the innovation adoption then it is advisable to eliminate observability and trialability attribute. Ramdani and Kawalek (2009), argue that in IS innovations-adoption research, observability depicts a component of result, known as demonstrability, which is regarded as an individual innovation attribute and which can be used to study different technological adoptions (Moore & Benbasat, 1991). Along similar lines, Rijsdijk, Hultink, and Diamantopoulos (2007) and Plouffe, Hulland, and Vandenbosch (2001) state that observability and trialability become significant when the consumers have less experience of using the innovation. As blockchain innovation adoption is still in the early adoption phase and not many potential proof-of-concept (deployed and tested) cases for the peer adopters are present in the literature (Frizzo-Barker et al., 2019), it is decided to include trialability and observability attribute.

Proposition1 (P6). blockchain solution offering great levels of relative advantage, compatibility, simplicity, trialability, and observability (complexity) are likely to have positive (negative) impact on blockchain adoption decisions in organizations

5.2.2. Organizational characteristics

The characteristics of the organization are the frequent attributes examined by scholars with regard to IT innovation adoption. Many research studies recognized culture as an influential factor in technology adoption. Moreover, culture has also been considered as an organizational factor (Alam, 2009; Costello & Prohaska, 2013). Veiga, Floyd, and Dechant (2001) suggest that the perceived usefulness and perceived ease of use of IT are connected with an individual's cultural beliefs. It is unknown to what and how culture will influence the adoption of the blockchain innovation solution (Upadhyay, 2019b) and thus the following proposition is formulated:

Proposition 7 (P7). Blockchain adoption can be affected by different cultures.

The resource and infrastructure are the two important constructs that help the organization to make it ready to deal with complex innovations (Vaccaro, Jansen, Bosch, & Volberda, 2012). The availability of skilled and expert resource to work with blockchain technology is scarce. The perceived immaturity of the blockchain technology creates a barrier for the businesses to adopt it (Avital, 2018; Beck & Muller-Bloch, 2017). Besides, the unavailability of skilled human resources to develop, manage and control blockchain solutions limits the extent to which blockchain solutions may be developed, deployed and utilized.

Proposition 8 (P8). Blockchain adoption can be affected by the availability of skilled and expert resources.

Moreover, the infrastructure to deal with blockchain solutions is immature and due to the lack of standards and protocols, it is difficult to integrate and interoperate within and across the business ecosystem (Glaser, 2017; Hashem & Tann, 2007). Organization need to invest in new hardware and software solutions to work with blockchain technology, which is costly for several organizations and network partners (Mougayar, 2016; Tsai, Yu et al., 2017).

Proposition 9 (P9). Blockchain adoption can be affected by the availability of the infrastructure, standards, protocols, and functionality to integrate and interoperate within and across the business ecosystem.

Lack of sufficient knowledge, awareness, and potentials of blockchain technology restricts its widespread adoption (Daniel & Zhu, 2018). It has been identified that due to lack of awareness and commitment to the management in IT innovation, organization face challenges related to resource allocations and financial decisions (Fawcett, Wallin, Allred, Fawcett, & Magnan, 2011). Considering the importance of the resource and infrastructure requirements, the following propositions are formulated:

Proposition 10 (P10). Blockchain adoption can be affected by the level of sufficient knowledge and awareness of blockchain

Iacovou, Benbasat, and Dexter (1995) consider 'organizational readiness' as one of the prime factors that may influence the adoption of EDI. It indicates the relationship between people, processes, systems and performance measurement. It requires synchronization and coordination without which no implementation will be successful. Considering the importance of 'organization readiness' it is worthwhile to understand how it affects the blockchain adoption. It is possible to automate some business processes with blockchain that currently involve a human intervention or a third-party involvement. Such automation will provide efficiency gains. For example, involvement of a trusted third party performing intermediated data synchronization and concurrency control in a supply chain can be removed (Avital, 2018; Beck & Muller-Bloch, 2017). Following proposition is formulated:

Proposition 11 (P11). Blockchain adoption can be affected by the level of organization readiness.

Operational readiness has also been considered as an important factor in IT adoption. It is not uncommon that without the support of the management the adoption is likely to stall, but despite having management support the adoption fails due to the lack of 'operational readiness'. Operational readiness refers to the engagement that is institutionalized: (1) one can witness the available budgets and funds to pursue the project, (2) have the skilled workforce and relevant infrastructure, (3) maintain ties with customers and stakeholders and (4) have good governance in place. More research is needed to understand and explore the importance of operational readiness in the context of blockchain adoption and thus the following proposition is formulated:

Proposition 12 (P12). Blockchain adoption can be affected by the level of operational readiness.

One of the key contributions of blockchain technology is to remove the information asymmetry between stakeholders and partners. Although information verifiability, transparency, integrity are the important characteristics to drive the performance of the organization, several stakeholders and partners are hesitant to share the information considering it as a competitive advantage thereby limiting the adoption of the blockchain (Kshetri, 2018). This leads to the next proposition:

Proposition 13 P(13). Blockchain adoption is reduced if the information is not shared by the partners

In scholarly research works, system readiness has also been considered as an important factor that influences IT adoption. Organizations and partners have to deploy and utilize new IT tools and solutions and this can be a challenge for some of the partners (Fawcett et al., 2011; Goranovic et al., 2017). Moreover, due to the surge of big data in real-time usage, it is not practical to use the blockchain considering its scalability, size and number of blocks that could impact the data-intensive practices and process (Swan, 2015). Considerable developments in storage, computing and cloud infrastructure are required which will influence the blockchain adoption decision. It is important to investigate how the organization will be system ready and thus the following proposition is formulated:

Proposition 14 P(14). Development in storage, computing and cloud infrastructure will affect the blockchain adoption and positively improve the data-intensive processes and practices.

The organizational governance mechanisms and structure are core constructs of the transaction cost theory (Boland & Hirschheim, 1992; Rindfleisch & Heide, 1997). In the blockchain-based solutions, there is no central authority and thus the role of governance for managing information, policies, rules, and structures are unclear and yet very important. There exist different governance structures such as- market, modular, captive, relational and hierarch. It is important to understand and investigate how and which governance structure will prevail in the organization considering blockchain adoption. This leads to the next proposition:

Proposition 15 (P15). Blockchain adoption changes the governance structure characteristics and cost

5.2.3. Environmental characteristics

Research studies have shown that the external environment plays a great role in the adoption of IT innovation (Damanpour & Schneider, 2006; Tornatzky & Fleischer, 1990). Wang, Li, and Qi (2020) have considered various factors such as external stakeholders, governments, competitive pressure, trading partners support, vendor support as environmental aspects. Lack of government and industry policies and regulations and willingness to support the blockchain initiatives limits the blockchain adoption. Hughes et al. (2019) suggest that favorable government and regulatory policies and frameworks in the business ecosystem promotes adoption of the innovation and also reduce the demand uncertainty of the IT solutions. It is of utmost importance that government, industries, NGOs, communities and professional organizations exploit and develop co-exist, co-collaborate environments to promote blockchain technology. Following proposition is formulated:

Proposition 16 (P16). Blockchain adoption is increased by favorable government and regulatory policies and frameworks

The businesses and stakeholders are unclear about the way blockchain technology operates and its long-term market development potential. This area is related to long-term agreements and potential collaborations (Ketchen, D. J., & Hult, 2007). In constructs of transactional cost economics, 'opportunism' is considered as a critical aspect of the environmental factors. It deals with the self-interest of the participating parties involved in trade and exchanges (Ketchen et al., 2007). For example, an organization can make its partners depend on them by harnessing the opportunistic behavior and then take advantage of their power (Grover & Malhotra, 2003; Ketchen et al., 2007). Organization exploits 'opportunism' to keep track of inappropriate opportunistic behavior of their partners, which imposes costly transaction costs in terms of audits, traceability, trackability, and accountability (Carter & Koh, 2018). Blockchain technology promotes disintermediation which is responsible to remove interaction point frictions, cut down the transaction costs, increase transparency and thereby help to mitigate the opportunistic behavior. Also, at all time the single truth is shared and is made available to all the potential participants which can be used by smart contracts to determine the potential exchange parameters, legal bindings, execution enforcements contexts, thereby reducing the opportunistic behavior (Lu & Weng, 2018). Considering 'opportunism' as an important factor to investigate, the following proposition is formulated:

Proposition 17 (P17). Blockchain adoption reduces opportunistic behavior.

The participating parties need to showcase 'trust' to engage themselves in effective business and professional relationships (Ireland & Webb, 2007). The 'trust' signifies that the potential partners will act positively to benefit the organization and will not do anything negative to affect it (Anderson & Narus, 1990). Several researchers have promoted 'trust' as an important factor for long term effective and strategic collaborations and improved performance (Ketchen et al., 2007; Kwon & Suh, 2005; Schorsch, Wallenburg, & Wieland, 2017). The foundation of the blockchain technology is the trust-free environment, where participating parties can register, exchange and trade assets of value (Upadhyay, 2019b). The consensus mechanism drives the transactions of value on the blockchain. Moreover, smart contracts on blockchain reduce bias, human interventions, delays, and resource plus time-intensive processes. This leads to the next proposition:

Proposition 18 P(18). Blockchain adoption increases collaborative performance and likely to transform the strategic collaborations.

5.2.4. User acceptance characteristics

Researchers have also addressed and studied the individual attributes that affect the adoption of IT innovation in the organization. Some of the critical factors for user acceptance of the technology innovation are – perceived usefulness, performance expectancy, effort expectancy, social influence, facilitating conditions, behavioral intention and use behavior (Dwivedi, Rana, Jeyaraj, Clement, & Williams, 2019; Hameed et al., 2012; Venkatesh et al., 2003).

Perceived usefulness: Employees at an organization constantly work hard to improve the performance and are comfortable with those IT innovations that they perceive to be helpful in increasing their performance. Blockchain solutions reduce information asymmetry and allow participants to track and trace information and assets leading to establish trust and transparency (Upadhyay, 2019b). Also, smart contracts executing a pre-defined code of business rules help an individual to improve processes and tasks at hand. This leads to the next proposition:

Proposition 19 (P19). Perceived usefulness positively impacts the behavioral intention of using blockchain

Effort expectancy: It deals with the degree of ease of use of technology. Employees think that they take little effort to use technology to get their job done. Trackability, traceability, integrity, and execution of SLAs help workforce to work efficiently as the blockchain technology ease out complex processes and practices to achieve the same as compared with the conventional technologies. Following proposition is formulated:

Proposition 20 (P20). Effort expectancy positively impacts the behavioral intention of using blockchain

Social influence: It deals with the degree to which an employee perceives the technology important as others in the workplace believe the technology should be used. Literature has shown several pieces of evidence of pilot projects demonstrating the benefits of the use of blockchain technology and researchers also claim that the blockchain technology with the increased network effects will affect the higher intention of use (Upadhyay, 2019a). This leads to our next proposition:

Proposition 21 (P21). Social influence positively impacts the behavioral intention of using blockchain

Facilitating conditions: It refers to the degree where an individual believes that organizational infrastructure, technical resources, and support are available to use the technology (Osch & Steinfield, 2018; Venkatesh et al., 2003). Blockchain technology requires new IT tools and systems, and technical resources and management support for its effective use. This leads to our next proposition:

Proposition 22 (P22). Facilitating conditions positively impacts the behavioral intention of using blockchain

Behavioral intention and use behavior: Behavior intention deals with the degree to which an individual believes in engaging with a certain behavior (Webb & Sheeran, 2006). It is a function of attitudes and researchers have claimed that the acceptance and usage of IT innovation are determined by the individual's attitude towards the IT innovation. Use behavior refers to the individual's actions in the physical and mental context to incorporate information found in the individual's existing information base (Wilson, 2000). Moreover, behavioral intention has a positive association with the actual choice of behavior. This leads to our next proposition:

Proposition 23 (P23). Behavioral intention positively impacts use behavior and affects the blockchain adoption

5.3. Research agenda, implications, and limitations

This research study is aimed at understanding the challenges, opportunities and applications associated with the blockchain. Moreover, it also explores the blockchain adoption process in an organization by developing the blockchain innovation adoption framework and various propositions considering the organizational level and individual level adoption. It is important to note that the blockchain is in the nascent stage of development and the availability of scholarly literature is limited thus it is difficult to predict the evolution of blockchain space. However, it opens more research questions than it actually solves and thus, a future research agenda is presented here which is categorized into three dimensions- application, management, and impact. It is believed that various stakeholders of the blockchain would find value in this research study. Table 6 presents the potential future research questions for blockchain research.

5.3.1. Implications

The fast-growing interest of scholars and practitioners in the blockchain area signify the timeliness of this research study. This study provides a wide array of implications:

5.3.1.1. Managerial perspective. Firstly, it highlights high-value challenges related to the blockchain, as well as scholarly work in which managers can find suitable information about these technologies in their respective industries. Secondly, it presents the prospective contexts or domains for the blockchain applications, while focusing on the impact, issues and business value. Thirdly, it showcases that organizations adopting blockchain need to invest more effort both in research and development in bringing product and services to the market quickly, but should not compromise on security and privacy. Moreover, managers need to realign the organizational structure and resources considering aspects of system integration, development of business models, generation of new revenues. And they also need to achieve improved transactional efficiency and increased transparency. Furthermore, developments of robust blockchain standards and legal structure will help organizations to minimize risks, uncertainties and encourage new entrants to embrace blockchain. Finally, decision makers can utilize the integrated framework (BIAF) to address the blockchain adoption in the organization.

5.3.1.2. Research perspective. In this study, researchers and scholars will find great value with the developed ontological artifact related to challenges, opportunities, and applications. The descriptive analysis provides the supplement contributions of the research study. Some pertinent details are – yearly publication, types of publication, geospatial coverage and classification of research. Moreover, the classification of publication and key elements within each category significantly extend and complement other findings within the research area. Apart from this, the research propositions and research agenda can enhance the research spectrum and trigger academic discussions to

Table 6
Research agenda for Blockchain.

Dimension	Future research questions for Blockchain
Management	- How can an organization ensure business alignment, business process transformation, and strategic decisions? - How can organization incorporate functional differences in developing blockchain based culture? - How organizations achieve security and privacy when conducting blockchain based transactions? - How an organization can establish trust and accountability and increase participation of its stakeholders? - What factors influence the adoption of the blockchain? - How blockchain can be used in a better way to receive operational excellence? - How can governance ensure blockchain adoption and affordance? - How an organization builds new business models? - How resources and assets are aligned for effective utilization? - How to manage accountability related to responsibilities and terms of use for participants? - What are the organization capability dimensions for working with blockchain?
Impact	- What is the impact of blockchain in various sectors? - What factors influenced the customer-perceived value of blockchain? - What type of training and skill sets at all levels impact working with the blockchain? - How do organizations capitalize on blockchain at their disposal and extract value? - How to assess the impact of new business models? - How incorporating smart contracts impacts organizational performance? - What is the impact of restructuring systems, processes and legacy IT structures? - How do blockchain adoption and implementation vary by different firms and in different domains?
Application	- Which sectoral application is most viable regarding usage and penetration? - How to monetize on the application? - How to identify the feasible scenarios for blockchain? - What channels and platforms to be used for the applications? - How to integrate sematic legal layer with smart contracts? - How to manage scalability? - How do specific application induce affordance? - What factors influence the application life cycle and what are their implications at different stages? - What offerings are more profitable and which segments are more attractive?

explore, exploit and understand blockchain adoption.

5.3.1.3. Practitioner perspective. It offers critical insights into understanding the blockchain challenges, applications, and opportunities and thus practitioners need to take cognizance of the challenges and the opportunity space to strategize the adoption and deployment of the blockchain. Practitioners will be able to place challenges and benefits in the context or domain while discovering the potential opportunities for business regarding value and impact.

As the users and adopters are gaining interest in diverse applications of the blockchain, it is important to investigate several issues such as –

- Factors affecting the adoption of the blockchain
- Impact analysis of the blockchain on individual life, organizational operations, and social activities
- Cost-benefit analysis of the timeline of the adoption of the technology
- Organization readiness and ease of use
- Security and privacy issues
- Value creation
- Scale and economics of transactions
- Legal, compliance and regulatory structure
- Development of robust standards
- (Re)Alignment of resources, and organizational structure
- Management of infrastructure

5.3.2. Limitations

The study was limited by the used method, and thus readers should be aware of the limitations and interpret the findings within the context of the limitations. Since the field is still in the nascent stage, and it is possible that the research related to blockchain happened in the industry is published as reports or white papers, this study has not undertaken any such research work. Moreover, the limitations are also due to publication bias and selection bias. To reduce the publication bias, high-quality Scopus scientific data based was targeted for the search and the study. The literature search was limited to the Scopus Scientific database and therefore some papers which have been published elsewhere in other academic journals may have been ignored even though they might contribute to the research questions. To reduce the selection bias, the pilot search was performed by undertaking different combinations of the terms/keywords and then final search protocol was developed. Although a strong search protocol was adopted to perform the search for the good quality articles, it might happen that some research papers have been dropped due to the absence of the search keywords in the papers.

6. Conclusion

This paper presents a systematic review of the scholarly research work published on blockchain, with respect to perceived challenges, potential opportunities, and application focus. It also specifies significant insights for practitioners to assess their requirements and resources to adopt and deploy blockchain and for researchers to charter new research focus. The findings affirm that the blockchain technology is still in nascent stage and is evolving, and organizations are considering to embrace it to gain the competitive advantage. Taking cognizance of the undertaken research study, the paper proposes an integrated framework, an ontological construct and a set of research questions that hold the potential to drive and contribute to the future research studies. This study theoretically constructs an integrated framework of the blockchain innovation adoption process in organizations by considering the organizational level adoption of blockchain and user acceptance of blockchain at an individual level. However, to achieve full potential and benefits of blockchain, it is necessary to address the research agenda by leveraging the blockchain innovation adoption framework with the ontological constructs including challenges, applications and opportunities. To the best of author's knowledge, the current research study is a first detailed review of blockchain challenges, applications and opportunities. Additionally, it proposes a comprehensive blockchain innovation adoption framework.

Author statement

Nitin is the only author of the paper and has contributed to the full paper.

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Appendix A

3-Stage Process for Systematic Literature Review

Planning the review process: It comprises three steps:

A1.1 Defining the research aim and objectives (A1.1)

To achieve the aims and identification of the challenges, opportunities and applications following research questions are framed:

RQ1: What challenges have been addressed in the current research on Blockchain?

The blockchain is nowadays considered to be a novel and mainstream technology. Understanding the challenges will help to mitigate the risks and barriers associated with the Blockchain technology.

RQ2: What opportunities have been addressed in the current research on Blockchain?

Acknowledging the opportunity is a critical pathway to build Blockchain applications and market leadership. The answer to this question helps to understand the opportunity space for utilizing Blockchain.

RQ3: What applications have been addressed in the current research on Blockchain?

Most often Blockchain is referred about Bitcoin cryptocurrency, but it is not the only application of the Blockchain. Thus, identification of the focus of the potential applications help to understand other directions and ways to use Blockchain.

It is noticeable that the consequence of the RQ1-RQ3 leads to the identification of the future research directions for the blockchain. It will help the key stakeholders of the blockchain in developing new applications, embracing new opportunities and acknowledging and resolving challenges.

A1.2 Formulating the research proposal (A1.2)

The Blockchain discipline is continuously evolving by targeting multiple applications in various sectors. Thus, a comprehensive understanding of the challenges, opportunities and application space is necessary to work with blockchain. There is a huge gap in the research studies that elaborately and comprehensively address the challenges, opportunities, and applications in the blockchain discipline. For example, Yli-Huumo et al. (2016) provided the technical perspective of the blockchain. Although their research study provide a worthy discussion of the technical perspective, it does not cover the elaborative and comprehensive understanding of the blockchain challenges, opportunities, and applications.

Furthermore, in this research study, an attempt is made *to broaden the perspective and scope of their reviews by extending the investigation and assessment of the pertinent challenges, opportunities, and applications.* This research paper explicitly contributes to the attainment of the following aim:

Analyze, synthesize and present a deep, comprehensive and elaborative understanding of the state-of-art structured analysis of normative literature on Blockchain to establish the signposting of future research directions

This research paper deploys the systematic SLR by employing suitable profiling of the research to investigate and analyze various challenges, opportunities, and applications. As a key requirement to perform robust, effective and reliable research study, the rigorous research protocol is followed.

A1.3 Developing the research protocol (A1.3)

A detailed review protocol is adopted to perform the systematic search based on the directions and procedures elaborated in the SLR (Afroz & Navimipour, 2017; Kitchenham & Charters, 2007).

It is decided to include both the conceptual and empirical (covering quantitative, qualitative and mixed method) papers. As followed by Delbufalo (2012) and Kamal and Irani (2014), the research protocol focuses on the two major points

- Conceptualization of the discipline considering the challenges, opportunities, and applications
- Development of the typology of the research studies and the relevant measures.

To attain the robust search protocol results based on the typology of the research studies following conditions (inclusion and exclusion) measures are formulated (Duan, Edwards, & Dwivedi, 2019; Ismagilova, Hughes, Dwivedi, & Raman, 2019; Kuttimani, Rana, Prakasam, & Dwivedi, 2019):

1 The review is conducted by searching Scopus scientific database. The total coverage of the database is huge and is anticipated that the majority of the research papers relevant to the review study are included.
2 Only peer-reviewed, high-quality scholarly work published in conferences, workshops, symposiums, and journals related to the review research study are included.
3 Only those scholarly work appeared and published between 2008 and 2018 (September) are included.
4 Only articles in the English language covering the subject areas – Business, Computer Science, Management, Information Science, Information Systems, Decision Sciences, and Social Sciences are included.
5 The articles selection was not limited to empirical research but also targets the conceptual papers to focus on the research questions and objectives.
6 The articles selected and included are based on the robust search criteria covering the key phrases, see sub-section A1.4, throughout the paper that includes – title, abstract, keywords and after that the complete paper. More specifically, the article selection is also subjected to the appearance of key phrases in the sections or sub-sections of the papers focusing on the key research questions and objectives.
7 Finally, to attain the robustness, reliability, and quality of the selected papers a thorough reading of the paper is attained to map the research with the research questions and objectives.

To conduct an effective and reproducible database search and selection aforementioned seven listed conditions and measures are deployed.

Conducting the review process: It comprises four steps:

A1.4 Identifying the research articles (A1.4)

As all research articles do not contribute to answering the research questions thus, they needed to be assessed on the actual relevance. To identify the papers related to the blockchain, the following search query is utilized:

Blockchain OR Blockchain Technology AND Challenge OR Challenges OR issue OR issues OR Barrier OR Barriers OR Obstacle OR Obstacles OR Impediment OR Impediments OR Problem OR Problems AND Opportunity OR Opportunities OR Solution OR Solutions AND Application OR Applications

The aforementioned search term is chosen after performing the several pilot searches. A search including *Bitcoin* in a search term has also been performed under the pilot project, but it was found that a large number of papers related to Bitcoin fall under the economic periphery in cryptocurrencies and do not contribute to the knowledge corpora related to the research questions and objectives. It may be noted that any Bitcoin paper that did not address or places blockchain anywhere in its meta-data then the paper was not targeted the proposed research objectives (and thus excluded from the research study).

The research study also supplements the yearly contribution in the identification of the knowledge corpora related to blockchain between 2008 and 2018 covering the geo-location details of the contributory authors. The study also adds information on the type of paper.

The paper comprehensively addresses the research questions and objectives and is predominantly descriptive and inductive. The paper aims to provide a state-of-the-art understanding of the blockchain by focusing on three main aspects – challenges, opportunities, and applications.

A1.5 Selecting the appropriate research articles (A1.5)

Considering the conditions and measures for the typology of the research studies the search was deployed. However, in cases where the title was not significant in addressing the suitability of the paper for the research study, a next selection step covering the reading of keywords and abstracts was performed. Total 805 papers were retrieved. Also, as outlined in sub-section A1.3 the measures for the inclusion and exclusion were executed to screen each paper. Further, 716 papers were discarded according to the barring conditions thereby leading to 89 articles for further investigations catering to the research questions.

A1.6 Studying and evaluating the research articles (A1.6)

To attain a robust, effective and quality evaluation of the research study, it is decided to follow the quality matrix as adopted by Pittaway, Robertson, Munir, Denyer, and Neely (2005). In this step, the articles evaluated were subjected to the conditions mentioned in sub-section A1.3. By performing such evaluation, the articles were categorized as challenges, (BC_CH) opportunities (BC_OP), and applications (BC_AP). Also, there are few articles which overlap the different categories

- BC_CH: All the articles treated under this category were based on the coverage related to the blockchain challenges. Almost 12 articles proposed or discussed blockchain challenges
- BC_OP: All the articles treated under this category were based on the coverage related to the blockchain opportunities. Almost 23 articles proposed or discussed blockchain opportunities
- BC_AP: All the articles are treated under this category based on the coverage related to the blockchain applications. Almost 37 articles proposed or discussed blockchain applications.
- BC_CH_OP: All the articles treated under this category were based on the coverage related to the blockchain challenges and opportunities. Almost 10 articles proposed or discussed blockchain challenges and opportunities
- BC_CH_AP: All the articles treated under this category were based on the overlapping coverage related to the blockchain challenges and applications. Only 1 article proposed or discussed blockchain

challenges and applications

- BC_AP_OP: All the articles treated under this category were based on the overlapping coverage related to the blockchain applications and opportunities. Almost 4 articles proposed or discussed blockchain applications and opportunities
- BC_CH_OP_AP: All the articles treated under this category were based on the overlapping coverage related to the blockchain challenges, applications and opportunities. Almost 2 articles proposed or discussed blockchain challenges, applications and opportunities

A1.7 Synthesizing the appropriate research studies (A1.7)

In this step, the typology artifact is developed for each of the desired research objectives – challenges, opportunities, and applications. Moreover, synthesis is achieved after thoroughly reviewing the papers to identify and documenting the challenges, opportunities, and applications by different domain and sector organization.

Reporting and Disseminating the findings: It consists of two steps

A1.8 Descriptive reporting of the appropriate results (A1.8)

Later, descriptive analysis is also conducted to provide the supplement contributions of the research study. The standard template mentioned in the works of Delbufalo (2012) is adopted to streamline the descriptive analysis. Some pertinent details are – yearly publication, types of publication, geo-spatial coverage and classification of research.

A1.9 Thematic reporting and addressing implications covering suggestions and future directions (A1.9)

In this step, the major findings, suggestions and future directions are addressed. Also, theoretical formulations of the framework, propositions and research agenda are described. The limitation of the study is subjected to the publication bias, selection bias, inaccuracy in the extraction, and misclassification.

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