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# ABSTRACT

This work provides a systematic literature review of blockchain-based applications across multiple domains. The aim is to investigate the current state of blockchain technology and its applications and to highlight how specific characteristics of this disruptive technology can revolutionise “business-as-usual” practices. To this end, the theoretical underpinnings of numerous research papers published in high ranked scientific journals during the last decade, along with several reports from grey literature as a means of streamlining our assessment and capturing the continuously expanding blockchain domain, are included in this review. Based on a structured, systematic review and thematic content analysis of the discovered literature, we present a comprehensive classification of blockchain-enabled applications across diverse sectors such as supply chain, business, healthcare, IoT, privacy, and data management, and we establish key themes, trends and emerging areas for research. We also point to the shortcomings identified in the relevant literature, particularly limitations the blockchain technology presents and how these limitations spawn across different sectors and industries. Building on these findings, we identify various research gaps and future exploratory directions that are anticipated to be of significant value both for academics and practitioners.

# INTRODUCTION

Almost a decade ago Satoshi Nakamoto, the unknown person/group behind [Bitcoin](https://www.sciencedirect.com/topics/computer-science/bitcoin" \o "Learn more about Bitcoin from ScienceDirect's AI-generated Topic Pages), described how the blockchain technology, a distributed peer-to-peer linked-structure, could be used to solve the problem of maintaining the order of transactions and to avoid the double-spending problem ([Nakamoto, 2008](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1470)). Bitcoin orders transactions and groups them in a constrained-size structure named blocks sharing the same timestamp. The nodes of the network (miners) are responsible for linking the blocks to each other in [chronological order](https://www.sciencedirect.com/topics/computer-science/chronological-order), with every block containing the hash of the previous block to create a blockchain ([Crosby et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0435)). Thus, the blockchain structure manages to contain a robust and auditable registry of all transactions.

Blockchains introduced serious disruptions to the traditional business processes since the applications and transactions, which needed centralised architectures or trusted third parties to verify them, can now operate in a decentralised way with the same level of certainty. The inherent characteristics of blockchain architecture and design provide properties like transparency, robustness, auditability, and security ([Greenspan, 2015a](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0730), [Christidis and Devetsikiotis, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0395)). A blockchain can be considered a [distributed database](https://www.sciencedirect.com/topics/computer-science/distributed-databases) that is organised as a list of ordered blocks, where the committed blocks are immutable. One can see that this is ideal in the banking sector as banks can cooperate under the same blockchain and push their customers’ transactions. This way, beyond transparency, blockchain facilitates transactions’ auditing. Companies invest in this technology as they see the potential of making their architectures decentralised and minimising their transaction costs as they become inherently safer, transparent and in some cases faster. Therefore, blockchains are not just a hype.

The number of [cryptocurrencies](https://www.sciencedirect.com/topics/computer-science/cryptocurrency" \o "Learn more about cryptocurrencies from ScienceDirect's AI-generated Topic Pages) illustrates Blockchain’s importance, currently exceeding 1900 and growing ([CoinMarketCap, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0420)). Such a growth pace could soon create interoperability problems due to the heterogeneity of cryptocurrency applications ([Tschorsch and Scheuermann, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2070), [Haferkorn and Quintana Diaz, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0755)). Furthermore, the landscape is rapidly evolving as blockchain is being used in other fields beyond cryptocurrencies, with [*Smart Contracts*](https://www.sciencedirect.com/topics/computer-science/smart-contract) (SCs) playing a central role. SCs defined in 1994 by Szabo as: “a computerised transaction protocol that executes the terms of a contract” ([Szabo, 1994](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1990)), allow us to translate contractual clauses into embeddable code ([Szabo, 1997](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1995)) thus minimizing external participation and risks. So, a SC is an agreement between parties which, although they do not trust each other, the agreed terms are automatically enforced. Therefore, within the blockchain context, SCs are scripts running in a decentralised manner and stored in the blockchain ([Christidis and Devetsikiotis, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0395)) without relying on any trusted authority. In particular, blockchain-based systems supporting SCs enable more complex processes and interactions so they establish a new paradigm with practically limitless applications.

As a result, Blockchain technology is becoming increasingly relevant ([Zhao et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2305)). Almost 1000 (33%) of C-suite executives declare that they are considering or have already been actively engaged with blockchains ([IBM, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0880)). Researchers and developers are already aware of the capabilities of the new technology and explore various applications across a vast array of sectors ([Christidis and Devetsikiotis, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0395)). Based on the intended audience, three generations of blockchains can be distinguished ([Zhao et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b2305)): Blockchain 1.0 which includes applications enabling digital cryptocurrency transactions; Blockchain 2.0 which includes SCs and a set of applications extending beyond cryptocurrency transactions; and Blockchain 3.0 which includes applications in areas beyond the previous two versions, such as government, health, science and [IoT.](https://www.sciencedirect.com/topics/social-sciences/internet-of-things" \o "Learn more about IoT. from ScienceDirect's AI-generated Topic Pages)

While there are several reviews regarding blockchain technology ([Tama et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2005), [Brandão et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0250)), we argue that the state-of-the-art of blockchain-enabled applications has received limited attention. Even in [Zheng et al. (2016)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2315) the applications of blockchains are not covered to their full extent nor applicability. There are indeed some reviews focused on the particular role of blockchain including the development of decentralised and data-intensive applications for the IoT ([Conoscenti et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2105), [Christidis and Devetsikiotis, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0390)), and managing big data in a decentralised fashion ([Karafiloski and Mishev, 2017a](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0980)). Other reviews focus on security issues of the blockchain ([Khan and Salah, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1005), [Li et al., 2017a](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1250), [Meng et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1395)) and on its potential to enable trust and decentralisation in service systems ([Seebacher et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1850)) and P2P platforms ([Hawlitschek et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0785)). Some technical aspects of the blockchain design such as its consensus protocol ([Sankar et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1830)), the vulnerabilities of SCs ([Atzei et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0085)) and other technical characteristics like its size and bandwidth, usability, data integrity, and scalability have also been studied in [Yli-Huumo et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2250), [Koteska et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1090). Moreover, there are other surveys such as [Bonneau et al., 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0210), [Tsukerman, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2075), [Mukhopadhyay et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1450), [Khalilov and Levi, 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1000), [Conti et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0430) which are more focused on the currency aspect of blockchains and the offered security and privacy.

Evidently, the literature lacks a concrete and [systematic review](https://www.sciencedirect.com/topics/social-sciences/systematic-review) of the current blockchain-enabled state-of-the-art applications, a limitation which was the primary driver for conducting this research. In particular, we try to address this by answering the following three questions: (i) How blockchain-based applications develop over time? (ii) How certain technical limitations of the blockchain architecture affect procedures/processes in particular domains? Which are these limitations? (iii) What is the suitability of blockchain technology across different domains and thematic areas?

Our work contributes towards a thorough understanding of the blockchain features and provides a snapshot of current blockchain-enabled applications across sectors. Based on a content analysis approach, we highlight the growing interest from the academic [community](https://www.sciencedirect.com/topics/social-sciences/community) and identify three key research streams: (i) classification of the range of blockchain-based applications across a vast array of sectors (ii) suitability of the blockchain technology to create value in these sectors taking into account the various limitations this technology presents, and (iii) guiding researchers by providing a roadmap of promising research avenues, challenges and opportunities for which further research is needed. It is worth noting that this review cannot by any means be considered as exhaustive since blockchain technology is continuously growing at a very fast pace.

# OVERVIEW OF BLOCKCHAIN

In principle, a blockchain should be considered as a distributed append-only timestamped [*data structure*](https://www.sciencedirect.com/topics/computer-science/data-structure). Blockchains allow us to have a distributed peer-to-peer network where non-trusting members can verifiably interact with each without the need for a trusted authority ([Christidis and Devetsikiotis, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0395)). To achieve this one can consider blockchain as a set of interconnected mechanisms which provide specific features to the infrastructure, as illustrated in [Fig. 1](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "f0005). At the lowest level of this infrastructure, we have the signed transactions between peers. These transactions denote an agreement between two participants, which may involve the transfer of physical or digital assets, the completion of a task, etc. At least one participant signs this transaction, and it is disseminated to its neighbours. Typically, any entity which connects to the blockchain is called a node. However, nodes that verify all the blockchain rules are called full nodes. These nodes group the transactions into blocks and they are responsible to determine whether the transactions are valid, and should be kept in the blockchain, and which are not.

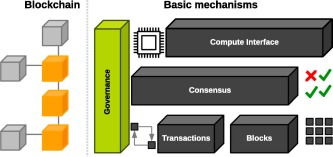


Figure 1

A valid transaction means, for instance, that Bob received one [bitcoin](https://www.sciencedirect.com/topics/computer-science/bitcoin" \o "Learn more about bitcoin from ScienceDirect's AI-generated Topic Pages) from Alice. However, Alice may have tried to transfer the same bitcoin, as it is a digital asset, to Carol. Therefore, nodes must reach to an agreement on which transactions must be kept in the blockchain to guarantee that there will be no corrupt branches and divergences ([Vukolić, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2120), [Christidis and Devetsikiotis, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0395)). This is actually the goal of the second *Consensus* layer. Depending on the blockchain type, different [Consensus mechanisms](https://www.sciencedirect.com/topics/computer-science/consensus-mechanism) exist ([Mingxiao et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1425)). The most well-known is the *Proof-of-work (PoW)*. PoW requires solving a complicated computational process, like finding hashes with specific patterns, e.g. a leading number of zeroes ([Antonopoulos, 2014](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0060)), to ensure [authentication](https://www.sciencedirect.com/topics/computer-science/authentication) and verifiability. Instead of splitting blocks across proportionally to the relative hash rates of miners (i.e., their mining power), *Proof-of-Stake (PoS)* protocols split stake blocks proportionally to the current [wealth](https://www.sciencedirect.com/topics/social-sciences/wealth) of miners ([Pilkington, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1660)). This way, the selection is fairer and prevents the wealthiest participant from dominating the network. Many blockchains, such as [Ethereum](https://www.sciencedirect.com/topics/computer-science/ethereum" \o "Learn more about Ethereum from ScienceDirect's AI-generated Topic Pages) ([Dannen, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0445)), are gradually shifting to PoS due to the significant decrease in power consumption and improved scalability. Other consensus approaches include [*Byzantine Fault*](https://www.sciencedirect.com/topics/computer-science/byzantine-fault)*Tolerance (BFT)* ([Castro and Liskov, 2002](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0325)) and its variants ([Zheng et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2315)).

An additional layer, the *Compute Interface*, allows blockchains to offer more functionality. Practically, a blockchain stores a state which consists e.g. of all the transactions that have been made by the users, thereby allowing the calculation of each user’s balance. However, for more advanced applications we need to store complex states which are updated dynamically using [distributed computing](https://www.sciencedirect.com/topics/computer-science/distributed-computing), e.g. states that shift from one to another once specific criteria are met. This requirement has given rise to [SCs](https://www.sciencedirect.com/topics/computer-science/smart-contract) which use nodes of the blockchain to execute the terms of a contract.

Finally, the [*Governance*](https://www.sciencedirect.com/topics/social-sciences/governance) layer extends the blockchain architecture to cover the human interactions taking place in the physical world. Indeed, although blockchains protocols are well defined, they are also affected by inputs from diverse groups of people who integrate new methods, improve the blockchain protocols and patch the system. While these parts are necessary for the growth of each blockchain, they constitute off-chain social processes. Therefore, blockchain governance deals with how these diverse actors come together to produce, maintain, or change the inputs that make up a blockchain.[1](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "fn1)

Current literature categorises blockchain networks in several ways ([Buterin, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0295), [Zheng et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2315), [Eris Industries, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0585), [Christidis and Devetsikiotis, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0395), [Kravchenko, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1115), [Wood, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2155)). These categories are formed according to the network’s management and permissions as *public*, *private* and *federated*. In public blockchains (*permissionless*) anyone can join as a new user or node miner. Moreover, all participants can perform operations such as transactions or contracts. In private blockchains; which along with the federated belong to the *permissioned* blockchain category, usually, a whitelist of allowed users is defined with particular characteristics and permissions over the network operations. Since the risk of [Sybil attacks](https://www.sciencedirect.com/topics/computer-science/sybil-attack) is almost negligible there ([Swanson, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1980)), private blockchain networks can avoid expensive PoW mechanisms. Instead, a wider range of consensus protocols based on disincentives could be adopted. A federated blockchain is a hybrid combination of public and private blockchains ([Buterin, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0295), [Zheng et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2315)). Although it shares similar scalability and privacy protection level with private blockchain, their main difference is that a set of nodes, named *leader* nodes, is selected instead of a single entity to verify the transaction processes. This enables a partially decentralised design where leader nodes can grant permissions to other users. In this article, we provide a more fine-grained blockchain network classification than current the state-of-the-art ([Buterin, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0295), [Zheng et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2315), [Christidis and Devetsikiotis, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0395), [Kravchenko, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1115)) because, in addition to classical features such as the ownership and management of the information shared in the blockchain, we consider features such as [transaction approval](https://www.sciencedirect.com/topics/computer-science/approval-transaction) time, or security aspects such as anonymity. [Table 1](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "t0005) summarises the main characteristics of each blockchain network regarding efficiency, security and consensus mechanisms.

Well-known implementations of public blockchains include Bitcoin, Ethereum, [Litecoin](https://www.sciencedirect.com/topics/computer-science/litecoin" \o "Learn more about Litecoin from ScienceDirect's AI-generated Topic Pages) and, in general, most [cryptocurrencies](https://www.sciencedirect.com/topics/computer-science/cryptocurrency" \o "Learn more about cryptocurrencies from ScienceDirect's AI-generated Topic Pages) ([Nakamoto, 2008](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1470), [Haferkorn and Quintana Diaz, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0755)). One of their main advantages is the lack of infrastructure costs: the network is self-sustained and capable of maintaining itself, drastically reducing management overheads. In private blockchains, the main applications are database management, auditing and, in general, performance demanding solutions ([Zheng et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2315)). Multichain ([Greenspan, 2015b](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0735)) is an example of an open platform for building and deploying private blockchains. Finally, federated blockchains are mostly used in the banking and industry sectors ([R3, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1720)). This is the case of the Hyperledger project ([Hyperledger Project, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0870)) which develops cross-industry permission-based blockchain frameworks. Recently, Ethereum has also provided tools for building federated blockchains. Other projects such as [Cardano (2018)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0310) are rather ambitious trying to provide more functionality. For more on blockchain categorisation, the interested reader may refer to [Walport, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2125), [Swanson, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b1980).

# RESEARCH METHODOLOGY

To provide a transparent, reproducible and scientific literature review of blockchain-based applications, the process suggested by [Briner and Denyer (2012)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0255) as well as some features of the PRISMA statement ([Moher et al., 2009](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1430)) have been adopted. The overall methodological approach includes the following steps:

* 1. Identify the need for the review, prepare a proposal for the review, and develop the review protocol.
* 2. Identify the research, select the studies, assess the quality, take notes and extract data, synthesise the data.
* 3. Report the results of the review.

## Locating studies

To address our primary research question, a systematic literature search was carried out during January 2018 without timeframe restrictions and the results were subsequently updated during April 2018. Scopus was used as the main scientific database in which the term “*blockchain*” was searched in all articles’ titles. Additional searches using the referenced works of relevant articles were also conducted (snowball effect). Relevant “grey literature”, including unpublished research commissioned by governments or private/public institutions was also identified through [electronic](https://www.sciencedirect.com/topics/computer-science/electronics) searches. To identify the published grey literature, we evaluated the first 200 hits from Google. Alternate terms for “blockchain” and “application” were used during the search. The hand-search reference list in several reports resulted in additional grey literature, particularly research and committee reports or policy briefs from both private and public sector institutions/organizations. A flowchart of the strategy implemented is presented in [Fig. 2](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "f0010). In addition, several refinement features of Scopus were extensively used (multiple refinements of results following the context of specific articles, related documents search, etc.). When the abstract of a particular study was not available, the full article was retrieved and assessed for relevance. All potentially relevant articles were retrieved in full text.

# LITERATURE REVIEW

The study analyzes 260 research papers published between 2014 and April 2018 (for conformity, grey literature has been excluded from the descriptive analysis). The purpose of the descriptive analysis is threefold: (i) it provides interesting insights regarding current research trends in blockchain technology, and its applications (ii) it helps to visualise the multidisciplinary research approaches developed so far in the scientific literature, and (iii) it further supports the classification structure presented in Section [5](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "s0040). For classifying the available literature, the descriptive analysis is based on two key-criteria: (i) distribution of publications over time and thematic area and (ii) distribution of type of publication over time.

A year-wise analysis of the selected papers is illustrated in [Fig. 3](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "f0015). It is worth noting that during 2017 the number of publications has sky-rocketed. Until 2016 just a little more of 40 publications existed related to blockchain-enabled applications whereas during 2017 their number reached almost 180. Therefore, research has slowly, yet significantly, picked up in the area of blockchain-enabled applications during the last couple of years. This upward trend highlights the emerging and growing nature of the blockchain technology and the growing academic interest. Even though blockchain technology was first introduced with Bitcoin as its core underlying technology, it took several years to the research community to become fully aware of blockchain’s potential and to take advantage of its possible applications. Unsurprisingly, during its first years, blockchain was considered a synonymous to Bitcoin, and in principle, researchers were trying to create the infrastructure rather than use this new technology for application purposes. Therefore, journal-oriented content related to blockchain-enabled applications has been notably published from 2016 onwards.

# TAXONOMY OF BLOCKCHAIN-BASED APPLICATIONS

Most authors classify blockchain applications into financial and non-financial ones ([Crosby et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b0435)) since cryptocurrencies represent a considerable percentage of the existing blockchain networks. Others classify them according to blockchain versions (i.e., 1.0, 2.0 and 3.0) ([Swan, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1975), [Zhao et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b2305)). In this work, we propose an application-oriented classification, similar to the one proposed in [Zheng et al. (2016)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2315). Our approach, however, differs from other similar works in that it uses a rigorous statistical methodology based on the literature (see Sections [3 Research methodology](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "s0015), [4 Descriptive analysis](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "s0035)), and thus it fits better to current blockchain developments and illustrates with high fidelity the future blockchain trends. Therefore, taking into account the actual and forthcoming heterogeneity of blockchain solutions, we present a more comprehensive and in-depth classification of blockchain-based applications, which is graphically represented in [Fig. 5](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "f0025). In the following subsections we provide a sound classification of the available blockchain-enabled applications based on the analysis of the available literature.



## Financial applications

Currently, blockchain technology is applied to a wide variety of financial fields, including business services, settlement of financial assets, prediction markets and economic transactions ([Haferkorn and Quintana Diaz, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0755)). Blockchain is expected to play an essential role in the sustainable development of the global economy, bringing benefits to consumers, to the current banking system and the whole society in general ([Nguyen, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1485)).

The [global financial system](https://www.sciencedirect.com/topics/computer-science/global-financial-system) is exploring ways of using blockchain-enabled applications for financial assets, such as securities, fiat money, and derivative contracts ([Peters and Panayi, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1640), [Fanning and Centers, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0615), [Nijeholt et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1495), [Paech, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1585)). For example, blockchain technology offers a massive change to capital markets and a more efficient way for performing operations like securities and derivatives transaction ([Van de Velde et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2095), [Wu and Liang, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2165)), digital payments ([Papadopoulos et al., 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1590), [Beck et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0130), [Min et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1420), [Yamada et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2235), [English and Nezhadian, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0580), [Lundqvist et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1305), [Gao et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0680)), loan management schemes ([Gazali et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0695)), general banking services ([Cocco et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0400)), financial auditing ([Dai and Vasarhelyi, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0440)) or cryptocurrency payment and exchange (i.e., e-wallets) ([Cawrey, 2014](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0330), [Rizzo, 2014](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1755)). Notably, a set of the world’s biggest banks, including Barclays and Goldman Sachs have joined forces with R3 ([R3, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b1720)) to establish an operating blockchain-based framework for the financial market ([Crosby et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b0435)). Another example of bank cooperation is the Global Payments Steering Group (GPSG) ([Ripple, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1745)), whose members include Santander, Bank of America and UniCredit, among others. The cryptocurrency behind GPSG is XRP, created by Ripple ([Britto et al., 2012](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0260)) which implements an interoperable and scalable open-source infrastructure enabling global payments and currency exchanges.

## Integrity verification

One of the most emerging blockchain-related fields is integrity verification ([Bhowmik and Feng, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0150), [Dupont, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0560), [Xu et al., 2017a](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2205), [Jamthagen and Hell, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0945), [Zikratov et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2330)). Blockchain integrity verification applications store information and transactions related to the creation and lifetime of products or services. The possible applications are: (i) provenance and counterfeit, (ii) insurance; and (iii) [intellectual property](https://www.sciencedirect.com/topics/social-sciences/intellectual-property) (IP) management.

An integrity verification subset of blockchain applications are those oriented to IP protection ([Kishigami et al., 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1040), [Kitahara et al., 2014](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1045), [Fujimura et al., 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0665), [De La Rosa et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0470)). As stated in [Swan (2015)](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b1975), the term digital art refers to IP and not just to online artworks, so blockchain technologies can be considered to cover all such scenarios ([O’Dair and Beaven, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1535), [McConaghy et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1355), [Zeilinger, 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2280)). Mature solutions like Ascribe ([Ascribe, 2014](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0075)) and Mediachain ([Labs, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1165)) use Bitcoin blockchain to link digital content with their creators. Ascribe uses it to transfer ownership and loan digital assets, while Mediachain tries to store metadata on the blockchain to allow [media recovery](https://www.sciencedirect.com/topics/computer-science/medium-recovery) and querying. Monetisation approaches such as Monegraph ([Monegraph Inc., 2014](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1435)) enable sharing of revenue across the value chain of media distribution for online [broadcasts](https://www.sciencedirect.com/topics/social-sciences/broadcast), video clips, image reels, and other licensed or brand-sponsored content, previously verified in the blockchain. Factom ([Snow et al., 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1905)) is another blockchain solution for storage and validation of digital assets. SilentNotary ([Silent Notary, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1900)) is a blockchain-based service for confirmation of event existence, recorded in a digital format such as communication in messenger, image, video file, and e-mail. Kodakcoin ([Kodak et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1075)), is a novel a payment method used to acquire photo licenses and image rights from a the kodakOne platform, which stores the works of registered photographers. Another example of network media’s digital [rights management](https://www.sciencedirect.com/topics/social-sciences/rights-management) can be found in [Xu et al. (2017b)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2210). [Herbaut and Negru (2017)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0795) propose a user-centric approach that helps the necessary reshaping of the content delivery ecosystem.

## Governance

Governments throughout years are entrusted with managing and holding official records of both citizens and/or enterprises. Blockchain-enabled applications might change the way governments at local or state level operate by disintermediating transactions and record keeping ([Reijers et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1735), [Hou, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0825)). The accountability, automation, and safety that blockchain offers for handling public records could eventually obstruct corruption and make government services more efficient. In particular, blockchain could serve as a secure communication platform for integrating physical, social, and business infrastructures in a smart city context ([Ibba et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0875), [Jaffe et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0940), [Biswas and Muthukkumarasamy, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0165), [Sharma et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1865)). Blockchain governance aims at providing the same services that are offered by the state and its corresponding public authorities in a decentralised and efficient way while maintaining the same validity. Examples of such services include registration or legal documents, attestation, identification, marriage contracts, [taxes](https://www.sciencedirect.com/topics/social-sciences/taxation) and voting ([Swan, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b1975)).

The World Citizen project ([McMillan, 2014](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1365)) is an example of a decentralised passport service to identify citizens all over the world. Blockchains can also be used to other public services such as marriage registration, [patent](https://www.sciencedirect.com/topics/computer-science/patent) management, and income taxation systems ([Akins et al., 2013](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0040)). Other projects focus on ideas such as delegative democracy, where delegates (instead of parliamentary representatives) take the voting power ([Swan, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b1975)). Similarly, Holacracy ([Robertson, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1770)) is a customisable self-management practice for organisations where authority and decision-making are distributed throughout self-organising teams instead of relying on a typical hierarchical organisation setting.

## Education

Blockchain can solve issues of vulnerability, security, and privacy in the case of ubiquitous learning environments ([Bdiwi et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0125)) and can be used for storing educational records related to reputational rewards ([Sharples and Domingue, 2016a](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1875), [Turkanović et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2085)). [Sharples and Domingue (2016b)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1880) propose the use of a blockchain-based distributed system for educational record and reputation. Similar reputation systems are shown in [Carboni, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0305), [Dennis and Owen, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0490). In [Devine (2015)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0505), teachers add blocks into the blockchain storing the learning achievements of students. Educational certificate management can also be enhanced by blockchain improving data security and trust in digital infrastructures ([Xu et al., 2017d](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2220)), and for credit management (for instance, relevant to the European Credit Transfer and Accumulation System-ECTS) ([Turkanović et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2085)). Moreover, blockchain-based applications could enhance the digital accreditation of personal and academic learning ([Grech et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0725)). Blockchain-enabled school information hubs could also be established for collecting, reporting, and analysing data about school systems for supporting decision-making ([Bore et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0215)). Finally, in the case of scholarly publishing, blockchain can be used either for better handling manuscript submissions and for conducting suitable reviews in a [timely fashion](https://www.sciencedirect.com/topics/computer-science/timely-fashion) ([Spearpoint, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1915)) or for manuscript verification ([Gipp et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0705)).

## Data management

Data management is one of the most indisputable properties of the blockchain. Implementations and applications based on this technology have not only enhanced data management ([Asharaf and Adarsh, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0080)) but have also facilitated by default auditability ([Sutton and Samavi, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1965), [Neisse et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1480)) since all of their operations are verifiable. In this last blockchain-based applications section we cite relevant literature that aims at efficient, secure and verifiable data management ([Zhang, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2285), [Jin et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0960)).

Although cross-organisational management has not yet reached a level that enables full interoperability between parties, several examples of cross-organisational data management can be found in the literature. In [Fridgen (2018)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0645) the authors, in a joint effort with a German Bank, follow the Design Science Research approach ([Hevner and Chatterjee, 2010](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0810)) to design, implement, and evaluate a blockchain prototype for cross-organisational workflow management. The results are encouraging and demonstrate that Blockchain has the potential to serve as an infrastructure for cross-organisational workflow management. Hawk ([Kosba et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1085)) is a framework for building privacy-preserving SCs that enables privacy-aware intermediate computations to avoid or minimise several types of disclosures, such as transactional privacy. Authors also provide an algorithmic framework to enable coding functions that will be parsed intro private and blockchain compliant protocols.

## Business and industrial applications

Blockchain has the potential to become a significant source of disruptive innovations in business and management through improving, optimising, and automating business processes ([Tapscott and Tapscott, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2025), [Bogner et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0200), [Ying et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2245)). Many e-business models based on IoT and blockchain are emerging. One example can be found in [Zhang and Wen (2015)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2290) where authors propose a business model in which transactions between devices are performed using SCs on a blockchain-based [distributed database](https://www.sciencedirect.com/topics/computer-science/distributed-databases). In [Hardjono and Smith (2016)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0770) the authors propose a privacy-preserving system that uses an IoT network and blockchain to prove provenance manufacturing without the third party [authentication](https://www.sciencedirect.com/topics/computer-science/authentication).

Blockchain applications appear to offer considerable performance enhancement and commercialisation opportunities ([White, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2145), [Klems et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1055), [Kogure et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1080)), improving credibility in e-commerce and enabling IoT companies to optimise their operations ([Xu et al., 2017b](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2210), [Yoo and Won, 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2255)) while saving time and cost ([IBM Corporation, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0890)). Blockchain-based applications could serve as decentralised business process management systems for several enterprises. In such cases, each business process instance may be maintained on the blockchain, and the workflow routing could be performed by SCs, thereby streamlining and automating intra-organisational processes and reducing cost ([Weber et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2140), [López-Pintado et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1295), [Prybila, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1710), [Rimba et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1740), [Mendling et al., 2018](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1385)).

# OPEN ISSUES AND FUTURE TRENDS

From the analysis of the selected literature, a series of insights can be derived concerning the limitations of the blockchain technology and its usability across a wide area of domains. As described in Section [5](https://www.sciencedirect.com/science/article/pii/S0736585318306324#s0040), blockchain is nowadays adopted in many research fields and business areas, providing limitless opportunities for exploration. However, like any other emerging technology, issues and challenges arise. In this section, we discuss certain limitations of the blockchain technology, and we develop several avenues of fruitful areas for further research directions.

## Suitability of blockchain

Companies across different sectors are excited about blockchain technology and its potential to drive their digital transformation while solving real-life problems ([Umeh, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2090)). Nevertheless, while several IT specialists envisage the usage of blockchain in almost every project, they do not quite understand the fundamental reasons for using it, particularly from a data management perspective. For instance, if no data needs to be ever stored, blockchain will not add any value to already established technical solutions. Similarly, if only one writer in a given system is foreseen, a blockchain will not provide additional guarantees compared to a regular database which would most probably be a more appropriate choice, particularly from a performance perspective (transactions speed) ([Greenspan, 2015c](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0740)). On the other hand, blockchain is suitable when one requires a transaction between trustless sources or a permanent historical record. For instance, if there is a need for multiple mutually mistrusting entities to interact and change the state of a system, then blockchain may be a viable solution ([Wüst and Gervais, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2175)).

Therefore, before adopting blockchain-enabled solutions one should examine the suitability of the blockchain technology against the use cases requirements ([Lo et al., 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1285)). A limited number of frameworks have been developed in the scientific literature for assessing the suitability of blockchain-enabled applications. For example, in [Lo et al. (2017)](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b1285) the authors propose an evaluation framework for blockchain-enabled applications in specific industrial domains like [supply chain](https://www.sciencedirect.com/topics/social-sciences/supply-chain-management), EHRs, identity management, and the stock market. In [Wüst and Gervais (2017)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2175) an analysis is provided related to the properties of different blockchain types (i.e., permissioned and permissionless) and a methodological framework is developed for identifying the suitability of blockchain-enabled applications across several domains.

Databases are by their very nature *mutable* where a predefined set of entities have access and may insert or update data. These entities may have specific roles, but their identities are known. However, there are administrative roles which may completely alter the contents and structure of the hosted information regardless of whether they are centralised or not.

## Latency and scalability

Most cryptocurrencies have a low transactions’ rate. For instance, Bitcoin transactions[2](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "fn2) cannot by any chance compare to systems like VISA’s credit card processing network that constantly handles up thousands of transactions per second. Undoubtedly, the broad adoption of cryptocurrencies needs to address this latency issue as well ([Swan, 2015](https://www.sciencedirect.com/science/article/pii/S0736585318306324#b1975)). Note that each Bitcoin block is processed in approximately 10 min which, along with the associated security checks (e.g. to avoid the double-spent attack in the subsequent transactions), results in each transaction confirmation to last up to several minutes[3](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "fn3). Therefore, blockchain architectures face serious latency issues which may be proved more significant as they evolve. Private blockchains, on the other hand, although they are indeed far more efficient, they have not reached the required standards.

Data storage optimisation examples may also be found in the literature. In [Bruce (2013)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0265), authors propose a scheme where old transaction records are removed by the network and a tree-structured database balances all non-empty addresses. Hence, the number of transactions stored by the nodes is decreased, thereby improving the transaction validation step. In [Eyal et al. (2016)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0600), the authors proposed Bitcoin-Next Generation where the core idea is to decouple a block into two parts: the key block for leader election and microblock to store transactions. So, miners compete to become a leader, which is the responsible role for microblock generation. Moreover, the authors improved the longest chain strategy to enhance the trade-off between block size and [network security](https://www.sciencedirect.com/topics/computer-science/network-security).

## Sustainability of the blockchain protocol

One of the main drawbacks of blockchain technology, especially affecting public blockchains, is the waste of resources of the mining network. Such concern generates two main questions: (i) how to reduce energy consumption and, (ii) whether to apply the computational power to useful [data processing](https://www.sciencedirect.com/topics/computer-science/data-analysis).

Bitcoin mining, which is lead by China ([Blockchain hash rate distribution, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0180)), consumes more electricity than 159 countries of the world ([Digiconomist, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0515)). Nevertheless, the real power consumption could be even worse, since there may be cases where users are mining without their knowledge due to [malware infections](https://www.sciencedirect.com/topics/computer-science/malware-infection) ([Malwarebytes, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1315)).

As already discussed, several consensus mechanisms and procedures could be adapted to decrease energy waste. Besides the energy consumption problem, current [consensus algorithms](https://www.sciencedirect.com/topics/computer-science/consensus-algorithm) like PoW or PoS may face the “rich get richer phenomenon” ([Zheng et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b2315)). Many efficient consensus mechanisms related to cryptocurrencies and bitcoin have been proposed. In [Sompolinsky and Zohar (2013)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1910) the authors propose the GHOST chain selection rule, which weights branches according to some parameters, easing the selection task for miners. In [Chepurnoy et al. (2016)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0380), the authors present an alternative consensus protocol for Bitcoin-like P2P systems where a party receives permissions to generate a block providing non-interactive proofs of storing a subset of the past state snapshots. Therefore, a network using such protocol is safe if nodes prune full blocks, which are not needed for mining. The PeerCensus system ([Decker et al., 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0460)) enables strong consistency in Bitcoin and similar systems. Moreover, Discoin, which acts on top of PeerCensus, decouples the block creation and transaction confirmation operations so that consensus efficiency can be increased. In [Kraft (2016)](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1110), the authors proposed a new consensus method to avoid multiple hash-rate scenarios. This way, the system guarantees stable average block times.

## Big data and artificial intelligence

The broad adoption of [artificial intelligence](https://www.sciencedirect.com/topics/computer-science/artificial-intelligence) solutions could be tuned, utilising SCs, to manage particular characteristics or behaviours, autonomous drones or cars. Moreover, intelligent transactions between entities and/or devices may also enable real-time implementations and a wide range of possibilities.

The race of data acquisition, increases the effectiveness and accuracy of data across many AI domains ([Halevy et al., 2009](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0760)). In the case of public blockchain systems standardisations and interoperability will improve AI algorithms and market prediction solutions since data will be available via a public ledger. The above pave the way for scalable and more accurate solutions and better AI models ([McConaghy, 2016](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1350)) within multiple contexts, enhancing the possibilities of [data analytics](https://www.sciencedirect.com/topics/social-sciences/data-analytics).

The secure and verifiable blockchain structure may be used to ease big data management ([Karafiloski and Mishev, 2017b](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b0985)). However, data analytics using blockchain structure imply too much overhead. Despite this, in most cases processing all transactions will not be necessary and, hence, intermediate or efficient auxiliary structures may be implemented, increasing thereby the overall efficiency. Therefore, solutions must be adopted ad hoc. Nevertheless, there already exist blockchain-based architectures for big data storage ([Kumar and Abdul Rahman, 2017](https://www.sciencedirect.com/science/article/pii/S0736585318306324" \l "b1145)).

# CONCLUSION AND REFERENCE

While blockchain applications are being widely deployed, many issues have yet to be addressed. By doing so, blockchains will become not only more scalable and efficient but more durable as well. The features they offer are not unique if judged individually, and the bulk of the mechanisms they are based on are well-known for years. However, the combination of all these features makes them ideal for many applications justifying the intense interest by several industries.

As blockchains become more mature, their applications are expected to penetrate more industries/domains than the ones covered in our survey. However, while many try to propose blockchains as a panacea and an alternative to databases, this is far from true. As already discussed, there are many scenarios where traditional databases should be used instead. Moreover, we identified the individual characteristics that are mostly required per each application domain. This facilitates the choice of the proper blockchain and the corresponding mechanisms to tailor the blockchain to the actual needs of the application.

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