

## Opportunities and risks of Blockchain Technologies in payments— a research agenda

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### Abstract

*Blockchain technologies offer new open source-based opportunities for developing new types of digital platforms and services. While research on the topic is emerging, it has thus far been predominantly focused on technical and legal issues. To broaden our understanding of blockchain technology based services and platforms, we build on earlier literature on payments and payment platforms and propose a research agenda divided into three focal areas of 1) organizational issues; 2) issues related to the competitive environment; and 3) technology design issues. We discuss several salient themes within each of these areas, and derive a set of research question for each theme, highlighting the need to address both risks and opportunities for users, as well as different types of stakeholder organizations. With this research agenda, we contribute to the discussion on future avenues for Information Systems research on blockchain technology based platforms and services.*

### 1. Introduction

Blockchain technologies are touted as one of the most significant technical innovations in digitalization of asset ownership<sup>1</sup>. Blockchain has been demonstrated to be a versatile programmable platform for managing contracts and ownership and providing an audit trail that cannot be easily tampered with, but can be distributed in real time [1]. Pervasive market penetration of novel cloud-connected mobile devices - including wearables - in combination with cloud-based data storage and analytics enable new types of distributed payment and transaction platforms that can be built as an overlay on top of traditional financial services and banking systems. In extreme cases – as

with distributed cryptocurrencies – not even a trusted third party such as a central bank is required.

These novel transaction and payment platforms allow for the development of a range of innovative financial instruments, such as micro-payments, peer-to-peer lending or non-regulated money enabling banking for the about 2.5 billion “non-banking” population<sup>2</sup>, while at the same time they can potentially simplify and lower the cost of transactions for example in cross-border payments<sup>3</sup>. Any digital representation of money is relative to the underlying computing technology and the digital payments we have seen so far have reflected a transactional computing model of manipulating rather stable entities. Thus, the current transformation is related to “money” and “cash” adapting to the decentralized nature of computing, which allow for different industrial and societal trust arrangements, for example distributed peerless and anonymous international money transfer services and even marriages<sup>4</sup> based on smart contracts.

These decentralized platforms offer new possibilities for anonymity, as they offer a vision of anonymous digital currencies, which can be a bit exaggerated. At the same time, these platforms also challenge the existing identity management systems and suggest new ones. To better understand these opportunities and challenges, research on mitigating risks and leveraging opportunities of digitalization and decentralization of payment platforms enabled by blockchain technologies is clearly called for. We also need deeper theoretical understanding of both how these platforms and services are designed, developed and organized, as well what is acceptable for users and how they perceive trust in the digital and decentralized world.

So far, the studies on the fairly recently introduced blockchain technology have predominantly focused on

<sup>1</sup> <https://www.weforum.org/reports/the-future-of-financial-infrastructure-an-ambitious-look-at-how-blockchain-can-reshape-financial-services>

<sup>2</sup> <http://mckinseysociety.com/half-the-world-is-unbanked/>

<sup>3</sup> <http://www.economist.com/news/special-report/21650295-orit-next-big-thing>

<sup>4</sup> <http://www.coindesk.com/prenup-ethereum-marriage-obligations/>

technology issues; aimed at addressing different technical challenges that such distributed systems pose [2, 3]. Another main research area has been the legal frameworks and their applicability (see e.g. [4, 5]). Now as the number of users of services based is increasing, more research on payment and asset management systems and service platforms in the disciplines of Information Systems and Management is called for [6, 7].

In what follows we first review the key literature that has addressed blockchain technology so far. We also provide a review on the essential literature on digitization of payments and payment platforms as the primary context for utilization of blockchain technologies. We will then identify a research gap by pinpointing where our understanding is still undeveloped.

As our main contribution, we outline a more holistic research agenda for studying the development and utilization of blockchain technology, with particular emphasis on digital payments and payment platforms. Furthermore, we suggest possible research problem areas and derived research questions for IS researchers to seek answers to.

## 2. Literature review

In this section, we will begin by providing an introduction to blockchain technology including definitions, after which we will discuss the growing body of literature on the first serious application of it, Bitcoin cryptocurrency. We will then provide a brief overview of the earlier literature on the broader context of payments and payment platforms, and conclude with a summary of the identified research gaps. For the purposes of this paper, the literature review presented is intentionally concise, while number of systematic literature reviews can be found on various areas of digital payments (see e.g. [8]).

### 2.1. Key definitions

Digital payments are simply payments that are conducted through digital means, for example as near field communication transactions between electronic wallet and a cash register, or through digital money [9]. Consequently digital platform is “a *proprietary or open modular layered technological architecture that support efficient development of innovative derivatives*, which are embedded in a business or social context.”[10] Blockchain can be seen as one such platform.

Blockchain technology is a sequential distributed database where the entire earlier transaction history is stored and shared in a (block) chain in a public ledger

[6]. Blockchains are normally used with cryptocurrencies i.e. currencies that use public-key cryptography as security measure and to prevent counterfeiting transactions. Blockchain can be seen both as a technical and as an economic innovation [11]. As a technical innovation, it is a new version of database transaction technology especially for decentralized environments of limited or imperfect trust. As an economic innovation it offers novel tools to any problem domain where there exists a need for a reliable record of transactions – a ledger - in a decentralized environment where not all parties, whether humans or machines can be fully trusted.

### 2.2. Bitcoin

Bitcoin is the initial distributed transaction system (bitcoin protocol) and a coupled currency (bitcoin as an unit of account). Bitcoin “infrastructure” consists of network of users, who have a client software running on their computer. Bitcoin was first suggested in 2008 and implemented as an open source project in 2009 by a person - or a group - calling himself or themselves Satoshi Nakamoto [12].

Initial application of blockchain technology is the original public ledger of bitcoin, which has later inspired other implementations called altchains. These kinds of networks also provide trust-based services that are not limited to currency transactions: Bitnation.co – decentralized “*Non-Geographically Contingent Governance Service Aggregators*”<sup>5</sup> offering a “*full range of services traditionally done by governments*”<sup>6</sup> with blockchain as its core technology - even aims ambitiously to become a future legislative entity.

The idea of the bitcoin system is that the entire earlier transaction history is verified by solving a cryptographic computation. This “work” – or computation time is extremely difficult to fake. This method is called “proof-of-work” (PoW). In a process called mining, blocks are created in about 10 minutes each, after which the solvers of the computation challenges are rewarded currency.

Users of the system use the bitcoin protocol to send and receive payments to “wallets”, which are anonymous (however, see [13] on identifying IP addresses). Bitcoin protocol verifies each transaction. Bitcoin protocol development is an open source project supported by the Bitcoin Foundation, and the development efforts are supported by a global community of developers and entrepreneurs [3].

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<sup>5</sup> <https://blog.bitnation.co/what-is-bitnation-the-googlement/>

<sup>6</sup> <https://bitcoinmagazine.com/articles/qa-ceo-bitnation-1412110033>

Lack of faith on established financial institutions, largely fueled by the financial meltdown of 2008 [14] has been established as one of the main drivers for development and proliferation of Bitcoin [3]). Another identified driver is the aim at frictionless payment systems [13, 15].

One prevailing question is whether Bitcoin should be understood primarily as a financial asset or as a system of payments (see for example [16] for more thorough discussion on their differences). If it is seen primarily as a financial asset, then the key issue is its financial performance and returns it provides as an asset. If it is considered mostly as a payment system, key is then its scalability for very large transaction volumes.

Brezo and Bringas [17] analyzed different risks related to Bitcoin and found that systems such as Bitcoin are quite vulnerable to speculation and misinformation. It has been contemplated that the lack of coordination entity (e.g. central bank) is at the same time a strength and a weakness of this kind of decentralized payment and trust infrastructure, as there is less inertia to try new ideas, but users' trust on the platform can rapidly erode, if for example forks occur in the development, as is currently happening in the case of Bitcoin<sup>7</sup>. In the area of open source research [18], different meanings of forks have been investigated, but forks usually refer to a situation where the developer community disagrees on the development roadmap (or other focal issues) and this results in a situation where several different competing versions of the code base are in use. In most open source projects forks are seen both as a safeguard of openness and as detrimental to the development efforts if they dilute contributions.

Bitcoin continues to capture the interest of academics, practitioners and the public, and the uncertainties resulting from its decentralized nature as well as wide misconceptions surrounding it render Bitcoin an excellent target for academic enquiry.

### 2.3. Potential of Blockchain technology

Blockchain technology and the underlying distributed database technologies are the key technological enablers of recent developments in distributed transaction and ledger systems.

Financial instruments, such as payments, trading records and smart contracts can be built on blockchain technology, which then prevents adverse behavior and repercussions, such as double-spending, forgeries and

false disputes [15]. Furthermore, the technology can be used for legal and public records, such as titles, birth certificates, voting or court records. It can also be used for creation of "smart property" in which case blockchain becomes an inventory, tracking and buy-sell mechanism for hard assets like diamonds or cars. It can also be used for tracing the product creation for socially responsible business. Blockchain can be utilized as a transactional mechanism for "sharing economy" services [19], as it naturally solves trusted recording of large-scale peer-to-peer activities. The importance of such a transactional mechanism increases with the emerging "Programmable World"<sup>8</sup> where an increasing amount of physical things become programmable and get connected to the Internet.

While the technical community (including both computer science scholars and practitioners) have addressed and continue to address blockchain as a technology, our knowledge on its application beyond descriptive accounts and anecdotal evidence is quite thin. Particularly the opportunities and risks from business and societal (rather than technical) perspectives are not well understood.

### 2.4. Payment systems and platforms

In the development of digital payments, trust has remained a focal conundrum [20-22]. Mobile payment literature has argued for the need for trusted service manager (TSM) that handles authentication, authorization and account settlement [23], especially in the presence direct and indirect network effects [24]. Distributed transaction platforms are answering this challenge by radical decentralization based on peer-to-peer networks. These are called "decentralized digital currencies" (Dccy) or "cryptocurrencies" and decentralized consensus systems (DCS) [25]. The first and most widely recognized decentralized cryptocurrency Bitcoin is a premier example, but there is a host of other alternative currencies ("altcoins"), including Litecoin, Peercoin, and Namecoin.

IS studies on open platforms [26, 27] and openness in general [28] are highly useful in understanding the development of new payment platforms. Open platforms literature focuses on boundary resources and ways to increase third party participation to the design. Openness research has discussed governance of open source development communities [18]. Governance in this context is seen as the means of achieving the direction, control, and coordination of wholly or partially autonomous individuals and organizations on behalf of an OSS (open source software) development project to which they jointly contribute [29]. Open

<sup>7</sup> For more detailed explanation and discussion on Bitcoin forks, see <https://blog.blockchain.com/2016/02/26/a-brief-history-of-bitcoin-forks/>

<sup>8</sup> <http://www.wired.com/2013/05/internet-of-things-2/>

source research has addressed governance in three different ways: 1) different incentives for independent developers to participate in open efforts [30, 31] 2) as well as the efforts to provide support for the necessary coordination activities [32], and 3) encourage building a culture that welcomes open contributions [29]. Open source communities that produce implementations of blockchain technologies seem to invite actors not so common in more traditional open source communities, but many of the governance challenges seem similar.

Even though distributed payment platforms are still a maturing technology, they are on the verge of becoming more widely accepted. This is demonstrated by, for example, the fact that in February 2016, Japan was considering legal changes that would define Bitcoin and other cryptocurrencies to be treated as currencies.<sup>9</sup>

While there are still a host of unresolved question related to digital payments and payment platforms in general – ranging from the trust issues to payment ecosystems – the decentralized nature of blockchain technology create a new set of so-far unaddressed research challenges that emerge when different platforms and services are designed, developed, introduced and eventually used.

## 2.5. Research gap

Based on our review of the extant literature, we conclude that there are clear research gaps in the state of the art related to these decentralized systems building on blockchain technology. There is an urgent call for research on both theoretical and practical perspectives on the blockchain technology.

Many critical issues are related to the inherently decentralized nature of these payment systems and platforms. For example, how can both trust and anonymity be guaranteed in such a platform-mediated network, and how can the risks be identified and mitigated? Only a better understanding of these risks and opportunities will lead to better, more trustworthy and more efficient services for citizens, consumers, as well as the range of organizations with interest in development of blockchain technologies.

To understand the operation logic and ensuing opportunities and risks of blockchain technology services and platform, we propose focusing on organizational, environmental and technology factors. Organizational factors include the organization and management of the focal service or the platform,

including issues such as financial structure (the cost structure and profit potential [33] of the service) and the related pricing strategies, or in other words the underlying business model [34, 35].

Market environment, in turn, includes the demand – that is, the users - as well as the competition, in terms of both the direct competitors offering similar services, and the companies offering substitute services. With technology factors we refer to the details of the ICT used, with a special interest in the design issues related to developing these systems.

Information Systems Science research builds on a wide range of possible lines of enquiry and theories adopted most often from the disciplines of marketing, management and economics, but also others including sociology and law. Thus, we will refrain from formulating the research issues in the light of any specific theory or approach, but rather provide areas for further investigation and possible research questions.

## 3. Research agenda

In essence, the distributed payment systems and platforms and other service enabled by blockchain technology can be conceptualized as service innovations. These service innovations can be expected to either improve services productivity or to develop new service models [36]. A widely accepted definition of service innovation states that “*a service innovation is a new service experience or service solution that consists of one or several of the following dimensions: new service concept, new customer interaction, new value system/business partners, new revenue model, new organizational or technological service delivery system.*” [37]. Hence, we can understand service innovations as combination of technology innovation, business model innovation, social-organizational innovation and demand innovation with the objective to improve existing service systems (incremental innovation) or to create new value propositions (offerings) or create new service systems (radical innovation) [38]. Service innovations are, in general and in financial industry in particular often technology-based: either the introduction of a new technology or a different use of existing technology. Whether decentralized digital currencies, such as bitcoin, are viewed as new-to-the-market or service line extension; or technology innovation or demand innovation; or some other type of service innovation, depends on the perspective adopted. Regardless of the perspective, the opportunities as well as risks are distinctly different from, for example, banks’ and legislators’ perspective to those of individual consumers or merchants. We

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<sup>9</sup> <http://www.theguardian.com/technology/2016/feb/25/japan-to-make-bitcoin-legal-currency>

utilize concepts from service innovation literature [37, 38]; together with the conceptualization of decentralized payments systems as platform-mediated networks in two (or many) sided markets [39-42] in drafting a research agenda.

We will next outline a research agenda divided into three focus areas of 1) organizational issues; 2) issues related to the competitive environment; and 3) technology design issues. We will discuss several salient themes within each of the focus areas, and derive a set of research question for each theme, highlighting the need to address both risks and opportunities for citizens as consumers, as well as different types of organizations with a stake on the development or utilization of blockchain technologies.

### 3.1. Organizational issues

With blockchain technology, the most critical organizational issues for the time being are related to the digital payment platforms and in more detail, the network effects these kinds of platforms are subject to. Another set of organizational key questions can be derived from the new business models enabled and facilitated by blockchain technology.

**Digital payment platforms.** Due to the nature of financial transactions, the maturation of the technology and more wide spread use will raise new organizational, legal and institutional issues. For example, while the ledgers are assumed to keep full histories and all the transactions are presumed “final” when settled, the processes are not unproblematic. For instance, there can be disputes over the finality of the transactions, or technology glitches and transaction delays can create a need for third parties and legal settlement. Several questions for research remain:

- What novel technical and legal issues are related to blockchain technology service and platform contracts, ledgers and transactions?
- How do these new institutional arrangements without central authority function? What are the implications to the users, different stakeholder organizations and societies in large?
- How open are these platforms for contributions and participation? What incentives are there for third party developers?

**Network effects.** Success of platform-mediated networks and services depends highly on the size of the user network [43]. Network effects are those positive

or negative effects that one user’s actions have on another user’s valuation of the network [44]. In other words, the value of membership to one user is positively affected by another user joining and enlarging the network [45]. Decentralized payment platforms operate in many-sided markets, where the platform’s value to any given user depends also on the number of users on the network’s other side(s), and the value grows as the platform matches demand from different sides [39, 40]. To put it simply, the primary two sides related to payment platforms are the payers (e.g. consumers) and the payees (e.g. merchants). Both same-side effects (i.e., how valuable is the growth of the network for the users in the same side of the market) and the cross-side network effects (i.e., how valuable is the growth of the network on the other side) are highly relevant in the context of decentralized payments.

In industries characterized by strong, positive network effects, a single platform can rise to dominance, locking out competing services [41]. Transaction and payment platforms are such that we can assume that there will be geographic and market differences that lead into a situation where there are several different players, but at the same time this is a volume business and together with the needed trust this will lead into situation, where a few dominant players will emerge and in many markets there will be only one platform available. This winning platform will not necessarily or very likely be owned or operated by a single player (such as a bank or a technology provider). Rather, the platform will be the *de facto* technical standard, similarly to for example mobile telecommunication, allowing for interoperability between different service providers. It should be a key research theme to try to understand how this will play out in different markets.

Pricing strategy is a very interesting topic in this area. In two- or many-sided networks, pricing is complicated, as the platform providers have to choose a price for each side, factoring in the impact of the other side’s growth and willingness to pay [42]. The platform incurs costs in serving both groups of users and can collect revenue from each, although one side is most often subsidized [39]. A key issue here is to determine which side receives a discount. In credit card industry, for example, the industry norm is to subsidize consumers (even though not fully) and charge credit card accepting merchants more. Thus, it seems reasonable to expect that new entrants will compete on prices and speed of transactions. The ability to compete along these parameters will define the success and even survival of many of the actors in the industry. Host of research questions remain, including:

- Where are the networks effects on blockchain technology based payment platforms derived from and how strong are they?
- How strong are the same-side and cross-side network effects on different market sides, including (at least) consumers and businesses accepting new types of payments?
- What are the risks related to market power? What is the likelihood of a particular cryptocurrency becoming the dominant one, even to the extent of a monopoly?
- What are the viable pricing strategies for decentralized services building on blockchain technology? Are they different from pricing strategies of other platform-mediated services in financial industry, and if so, how and why?
- What are the possible viable strategies for the incumbent companies such as banks and telecommunications operators? Will they disrupt or be disrupted?

**New Business models.** Decentralization, blockchain technology and the underlying distributed database technologies offer possibilities also for new business models. For example, currency exchanges have emerged as an important gatekeeper role as clearinghouses taking care of conversion of cryptocurrencies to more traditional currencies. The risks of such operations have been known for long, but became very noticeable when Mt. Gox, which handled around 70% of Bitcoin traffic dramatically filed for bankruptcy in 2014. To make matters worse, initially Bitcoin worth of around \$450 million was found stolen from the bank in the process [46].

Moore and Christin [47] analyzed the defaults of these exchanges finding that their popularity and transaction volume reduce the risk of default (i.e., credit risk) [48]. Host of questions remain:

- What kind of new business models decentralization and blockchain technology enable or facilitate? Who will be able to develop and benefit from these new business models, various incumbents or new players?
- What are the sustainable business models for the new intermediaries? How to provide viable revenue stream to the company while maintaining users' trust of the intermediary?

- What are the business and financial risks related to currency exchanges and who bears them? How can the risks be mitigated and managed?
- What happened to Mt. Gox and how can such events be prevented in the future?

### 3.2. Issues Related to Competitive Environment

Financial services industry consists of a large number of long established incumbents, banks and credit card companies being traditionally the strongest players. Now, however, their dominance over payment services is increasingly challenged by entrance of various technology providers, both established (e.g. telecom operators) and totally new ones (e.g. mobile payment service providers, such as, iZettle<sup>10</sup>). It remains to be seen, how the incumbents and the new players will divide the market, and who will provide the services that the consumers are willing to accept and adopt. A closely related set of questions arise from the changes in consumers' payment behavior, driven by the proliferation of new payment technologies and systems.

**Actors in the financial industry.** New digital payment systems are not introduced to fill a previously nonexistent need, but instead in the heavily contested banking service landscape. Earlier research has noted that it is notoriously difficult to compete with the established incumbents in banking and telecom sectors, which are heavily protected by laws and regulations in most countries and regions [8, 49]. Reuver et al. [49] provide an interesting historical example of what could happen in such an institutional environment: banks viewed new payment systems as a way to reduce cash payments, but at the same time to protect their existing handling of consumer payments. Mobile operators on the other hand wanted to generate further revenues by using SIM cards for payer identification. The conflicting goals directly affected the negotiations on pricing, openness etc. of the platform strategy. Thus, new digital payment platforms face an uphill battle in the heavily regulated financial sector. This the institutional arrangements can be studied at least from the following viewpoints:

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<sup>10</sup> <https://www.izettle.com>

- Which actors will emerge as the key players in the development of new payment systems and services?
- What will be the different roles of the incumbents and the new entrants in the changing financial services industry?
- What are the characteristics of new payment and trust systems that can radically alter the economics of payments?

**Consumers' payment behavior.** When examining the use of different information systems or technologies, IS research has traditionally focused on technology acceptance and adoption by the users (see e.g. [50, 51]), in circumstances usually (ideally) involving large paradigmatic shifts in use behavior. Can we understand the adoption – or non-adoption, for that matter – of new payment technologies with the help of earlier tested technology acceptance models? If not, how the adoption should be theorized and understood in this context?

For consumers, trust and context issues related to payments have been found to be of paramount importance [52]. By and large, consumers are reluctant and slow to change their payment behavior, but if the context is such that they find the new payment systems more convenient and/or cheaper than the old ones, the change can be quite rapid [52]. Most of the early adopters of Blockchain based cryptocurrencies have been technology enthusiasts, as expected. When the systems become more mainstream, the users need to be able to trust that there will not be significant volatility in the value of the currencies. Furthermore, the probability of any large-scale disruptions in the platform operations that can have instant negative effects must be substantially decreased before large scale adoption by the consumers is likely.

Also understanding the homing costs of different decentralized payment systems is of great importance. If we are to see wider proliferation of one or more new cryptocurrencies, whether the consumers are likely to prefer mono-homing, that is, become a user of only one particular cryptocurrency, or are they more likely to prefer multi-homing, that is, the ability to use various payment methods is of great significance. This is largely dependent on the costs of adopting and using (and when necessary, terminating the use) of one or multiple alternatives. While homing costs of cryptocurrencies are relevant for the merchant side as well, the question is more crucial for the consumers with more limited resources.

Interestingly, earlier studies have found evidence of the role of social influences in consumer behavior in

different contexts [53, 54]. Also, fashion and trends have an effect on consumers' buying behavior [55, 56]. Technology industry has seen its share of fashions and fads, throughout the years: some have been more persistent (e.g. social media, that was originally branded as a trend to die out soon), while some have disappeared before becoming more widely accepted (e.g. WAP services on early mobile (or feature) phones. Some interesting questions related to consumers' payment behavior remain:

- How the diffusion and adoption of blockchain technology based systems unfold among the consumers in different markets?
- What technological or psychological characteristics affect the use of blockchain technologies and how?
- What are the contextual issues that lead users to change their established trust providers or financial institutions?
- What are the costs related to using one (or more than one different) new payment method?
- What is the role of different social factors in proliferation of decentralized payment systems and cryptocurrencies?
- What operational performance changes lead to adoption of the new systems?

### 3.3. Technology Design Issues

Instead of focusing on the technical developments of distributed transaction technology, we look at the design decisions and issues and provide avenues for building new service prototypes through design research. As this is new technology that changes long established patterns of user behavior in sensitive areas - such as, changing ownership of goods and monetary transactions - it is important to conduct trials in different kinds of settings and with different prototypes. This would naturally lead into using design research in forms such as Action Design Research that promote testing designs in real world settings and adjusting the artifacts during their testing [57].

In a setting where the software platform has a clear owner, boundary resources are the resources provided by the platform owner to facilitate third-party development efforts [26]. These efforts aim at inviting additional contributions to the design and increased

access to the platform. These resources also provide means for the governance of contributions. More research is needed on the role of boundary resources for the different platforms which lack a clear owner or have a set of different actors jockeying for the design decisions, resources and governance power.

Possible research questions related to the technology design issues are:

- What are the possible new application areas for blockchain technology based computing platforms?
- How are design decisions made in different systems relying on blockchain technology?
- What are the features of these systems that enhance and/or decrease the trust of users towards the economic or regulatory systems that they implement?

#### 4. Discussion

In this paper, we have outlined an initial research agenda and a set of questions for information systems research on blockchain technologies in payments. We reviewed the relevant (but still scarce) extant literature to identify and classify the challenges related to blockchain technology based platforms and services, with a particular focus on new decentralized payment systems, and developed a research agenda to support future research in this emergent area.

To this end, we have provided a host of possible research questions related to different aspects of blockchain technologies. Even though the list is diverse, covering a large area of topics and domains, we do not claim it includes all relevant questions. On the contrary, we believe that many more are needed, and these need to be addressed from a multitude of perspectives, by researchers from different disciplines. Nevertheless, we are confident that the research agenda presented in this paper can serve as an inspirational starting point into an area that is likely to be important for research and for practice beyond our current comprehension.

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