On the Design and Management of Blockchain-Based Information Systems

Dissertation

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As for the future, your task is not to foresee it, but to enable it.

Antoine de Saint-Exupéry

Abstract

Blockchain is said to bring disruptive changes to the business environment of many industries. However, empirical evidence shows that very few blockchain-based systems have been deployed operationally to date. The gap between the potential of blockchain for organizations and the actual use of the technology is correspondingly large. To help organizations further close this gap, this dissertation aims to support organizations in designing and managing blockchain-based information systems.

I structured my dissertation around three research goals: Identifying the technological boundaries of blockchain (RG1), guiding organizations in designing blockchain-based information systems (RG2), and guiding organizations in managing blockchain-based information systems (RG3). Intending to delineate the technological boundaries of blockchain (RG1), Essay 1 clarifies the scalability of blockchain and which factors play an important role in this regard. Essay 2 draws on the findings of Essay 1 and analyzes attack vectors on blockchain systems and presents a future research agenda. Building on this technical understanding, Essays 3-5 address how blockchain can be used to design effective information systems (RG2). To this end, the essays each examine one of the application areas of finance (Essay 3), supply chain management (Essay 4), and identity management (Essay 5), present a concrete solution design, and discuss abstract design principles. Finally, Essay 6 and Essay 7 study how companies manage blockchain-based information systems (RG3). Essay 6 takes a project management perspective and elaborates on which criteria play a role in evaluating the success of blockchain implementation projects. Essay 7 takes a broader view and describes how organizations innovate and interact within ecosystems that arise from the use of blockchain.

Consequently, my dissertation offers new theoretical insights into the technical properties of blockchain-based systems, the ways in which these systems can be designed, and the ways that companies manage related projects and ecosystems. Thus, the essays span the entire field of blockchain research, covering the technical and social subsystems as well as their interplay.

Keywords: Blockchain, distributed ledger technology, decentralization, information systems, design, management.

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Tobias Guggenberger

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Introduction to On the Design and Management of Blockchain-Based Information Systems

Abstract

This dissertation aims to support organizations in developing and managing blockchain-based information systems. It comprises seven essays, which are structured according to three research goals. Following these research goals, this dissertation informs about the technical boundaries of blockchain, how blockchain-based information systems are designed, and how blockchain-based applications are carried out in organizations and ecosystems. In the introduction of this dissertation, I motivate the topic of blockchain-based information systems (Section 1), provide background to blockchain with a focus on an information system perspective (Section 2), derive and justify the three guiding research goals (Section 3), describe the research methodology of the essays (Section 4), summarize the results of the essays (Section 5), and conclude and discuss the findings of this dissertation, describe its limitations, and outline future opportunities for research (Section 6).

Keywords: Blockchain, distributed ledger technology, decentralization, information systems, design, management.

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1 Motivation

On September 14th, 2008, The New York Times reported: “Lehman Files for Bankruptcy; Merrill Is Sold” (Sorkin, 2008, para. 1). The bankruptcy of Lehman Brothers marked the climax of the subprime mortgage crisis, which was a major contributing factor to the global financial crisis. In the United States alone, the economic impact of the global crisis was disastrous. Between 2007 and 2009, U.S. stock markets lost nearly USD 8 trillion in value (Merle, 2018). However, the impact of the crisis was not restricted to financial markets. Within ten years, nearly 10 million Americans had lost their homes due to the crisis's direct or indirect effects (Shalby, 2018). It was in the midst of the financial crisis that the idea of Bitcoin emerged. A person whose identity remains unknown used the pseudonym Satoshi Nakamoto to publish a whitepaper describing a computer system that would allow secure financial transactions without the need for central intermediaries (Nakamoto, 2008). To this day, the Bitcoin community continues to discuss whether the development of Bitcoin was a direct result of the financial crisis of 2007-2009 (Brennecke, Guggenberger, Schellinger, & Urbach, 2022). However, it stands to reason that distrust in financial intermediaries fueled the adoption of the cryptocurrency (Dodd, 2018). Today, the Bitcoin network holds over USD 350 billion in value (coinbase, 2022). While the emergence of the Bitcoin network alone can be considered an important development, the introduction of the underlying technology is equally significant (Xu et al., 2019). Bitcoin does not rely on a centrally governed ledger, as do normal banks, but uses a distributed ledger made possible by blockchain technology. The adoption of blockchain technology has led to the emergence of other similar networks over the years, and a plethora of blockchain systems exist today (Zheng et al., 2017).

While blockchain systems are a relatively novel phenomenon, the basic idea of creating alternatives to centralized systems predates the introduction of blockchain by several decades. As early as 1964, computer engineer and researcher Paul Baran divided computer networks into centralized, decentralized, and distributed computer systems (Baran, 1964). The thinking behind Baran’s (1964) classification was heavily influenced by the Cold War between the USA and Russia and the aim of developing a communication network that could withstand a nuclear attack. Baran (1964) observed that centralized communication networks incorporate a central processing unit that stands in the middle of a network but also presents a single point of failure. And while decentralized communication networks do not rely on a single processing unit, they incorporate several hubs through which at least a small number of the connected participants must send their data. Only in distributed systems is the dependence on individual hubs and processing units entirely eliminated, making such systems more resilient than centralized and decentralized designs. Interestingly, according to Baran's (1964) definition, Bitcoin – or, to be more precise, the underlying technology of blockchain – would be described as a distributed rather than decentralized communication network. However, to understand Bitcoin in its entirety, an organizational perspective is required. Baran (1964) used the example of the U.S. military, which has always been the sole owner and controller of its communication network. This is not the case for Bitcoin, where there is no single actor who controls the network (Nakamoto, 2008). In other words, control of the Bitcoin network is decentralized. With this organizational perspective, the term 'decentralized' has become the common adjective used to refer to the Bitcoin network and many alternative blockchain systems (Atzori, 2015).

In the above discussion, my goal is not simply to clarify the different definitions of distributed and decentralized systems relating to blockchain. Rather, the discussion also introduces two different views that can be taken of blockchain. On the one hand, blockchain represents a distributed information technology (IT). Consisting of distributed hardware and software, it provides various technical functions and processes. On the other hand, there is also a social component which includes individuals and organizations in contact with the technical subsystem. The interplay between technology and its social environment is at the heart of an information system (IS) perspective (Chatterjee et al., 2020), which allows for a broader understanding of blockchain.

In my dissertation, I apply this IS perspective to the phenomenon of blockchain. Although blockchain technology is said to have great potential, there are only a few use cases currently in operation (Al-Shamsi et al., 2022). In part, this is a consequence of the complexity of blockchain technology. The use of distributed networks and cryptographic techniques makes it difficult for organizations to grasp the technology and its capabilities (Du et al., 2019). But the lack of use-cases is also the result of the difficulties many organizations face in adapting their processes and control structures to the decentralized governance of blockchain (Batubara et al., 2018).

Thus, in order to holistically understand blockchain and to support organizations in leveraging the potential of this technology, I define the overall research goal of my dissertation as follows:

Guiding organizations in designing and managing blockchain-based IS

This research aim guides this dissertation toward answering diverse and exciting questions around blockchain as an IS. I focus on enriching the IS discourse by looking at both the technical and social subsystems and their interactions. Thus, I follow several research calls for a more detailed investigation of blockchain and provide a holistic perspective on this exciting phenomenon. Specifically, my dissertation consists of seven essays that cover the technical characteristics, design, and management of blockchain.

The rest of the introduction to my dissertation is structured as follows: First, I discuss the technical and conceptual foundations of blockchain as an emerging IS. I then introduce three Research Goals (RGs), which provide structure for the seven essays of my dissertation. Next, I describe the research methods used to address the research questions and summarize the findings of my essays. The introduction concludes with a discussion of the findings, describes the limitations, and highlights the potential for future research. The seven essays follow this introduction.

The findings of the essays are the result of joint work undertaken with co-authors. Accordingly, I use the plural formulation *we* when referring to the contents of these essays in subsequent sections. I have refrained from the usual labeling of these citations to improve readability.

2 Blockchain-Based Information Systems

2.1 Technical Fundamentals of Blockchain

Satoshi Nakamoto laid the foundation for blockchain technology. In the Bitcoin whitepaper, they described for the first time the structures and functions of blockchain technology (Nakamoto, 2008). In recent years, organizations and individuals have adopted this core concept to develop a variety of different blockchain implementations.

Walport (2016) describes a blockchain as a kind of database that groups transactions into blocks. These blocks are linked in chronological order by cryptographic fingerprints. A consensus ensures the authentication of transactions and the integrity of blocks, even if they are shared in a peer-to-peer network (Walport, 2016). Walport (2016) also notes that blockchain is similar to distributed ledger technology (DLT) but differs in the way transactions are stored. While blockchains group entries in the aforementioned blocks, distributed ledgers store transactions in a single ongoing ledger (Walport, 2016). Panwar and Bhatnagar (2020) offer a more nuanced perspective on the difference between blockchain and DLT. The authors define blockchain as a subcategory of DLT with peculiarities that distinguish it from other DLTs such as hashgraphs or directed acyclic graphs (DAGs). Thus, to be as precise as possible and avoid ambiguity with other DLTs, I have chosen the specific term *blockchain* in the introduction to my dissertation.

To this end, I follow Guggenberger et al. (2020) and define blockchain as a technology that:

- uses interlinked blocks to store transactions in an ongoing manner
- enables distributed data storage and computing by employing peer-to-peer technology
- ensures consensus among the nodes of the network
- makes use of cryptographic techniques to guarantee the authenticity, integrity, and validity of data

The unique structure of blockchain technology offers a number of key attributes. Firstly, blockchain systems are considered particularly resilient thanks to their decentralized and distributed nature (Gimenez-Aguilar et al., 2021), which protects against failure due to technical problems or malicious attacks (Fraga-Lamas & Fernández-

Caramés, 2019). Secondly, a blockchain system operates on a consensus mechanism which ensures that, despite decentralized storage of the ledger, there is always a common agreement on the state of the ledger (Lashkari & Musilek, 2021). Thirdly, the use of hash references makes retroactive changes to entries either completely impossible or only possible after extreme amounts of effort (Lashkari & Musilek, 2021). Finally, the use of public key infrastructure ensures that actors must authenticate themselves to the system. As a result, actors can only alter the state resources in the system for which they are authorized (Monrat et al., 2019).

The above aspects describe the key attributes of every blockchain system. Beyond these, researchers and practitioners are constantly seeking to evolve the functional scope of blockchain technology (Bhutta et al., 2021). For example, the introduction of smart contracts through their first appearance in the Ethereum blockchain has been particularly relevant to the development of new blockchain applications (Khan et al., 2021). Smart contracts allow programmable code to be executed on the blockchain and, therefore, offer additional services beyond those made possible by simple transactions. With the introduction of smart contract-specific high-level languages, it became possible to run applications on a blockchain (Khan et al., 2021). Therefore, smart contracts laid the foundation for decentralized applications (dApps) (Wessling et al., 2018). These applications are similar to regular web applications but operate in the background, with a blockchain as the underlying infrastructure. Smart contracts allow the implementation of arbitrary business logic and, thus, further expand the application of blockchain (Khan et al., 2021).

Blockchain technology is a very young concept, particularly compared to central and even many distributed databases. Accordingly, blockchain still faces several technical challenges. In particular, enabling data protection and ensuring privacy, both important requirements for many blockchain-based applications, are in contrast to the core features of blockchain (Schellinger et al., 2022). The shared world state means that, in many blockchain systems, all information can be read by any party at any time, which is especially concerning in business settings or when dealing with personal data (Tatar et al., 2020). This tension is further exacerbated by the fact that blockchain's immutability prevents data from being deleted retrospectively. As a result, discussions continue about how to design blockchain applications that comply with the European General Data Protection Regulation (Schellinger et al., 2022; Tatar et al., 2020).

Another challenge is the scalability of blockchain systems. Due to the significant effort required to find a secure common world state, blockchain systems scale worse than comparable centralized applications. Thus, efforts to optimize the scalability and performance of blockchain systems continue (Zhou et al., 2020).

2.2 Conceptualizing Blockchain as an Information System

As previously mentioned, an IS perspective is necessary to understand blockchain in its entirety. Chatterjee et al. (2020) define an IS as “a superordinate system composed of social and technical subsystems, with information playing a key role that captures the state and behavior of these superordinate systems” (Chatterjee et al., 2020, p. 13). Chatterjee et al. (2020) follow A. S. Lee et al. (2015) in conceptualizing the social subsystem as individuals and structures – and their relationships – that shape organizations, shared norms, values, and symbols. On the other hand, Chatterjee et al. (2020) use a description by Sykes et al. (2014) that defines the technical subsystem as a set of tools, devices, and techniques that help to enhance the performance of an organization by transforming inputs into outputs. Both the social and technical subsystems are open systems with fluid and permeable boundaries. This allows them to interact with their environment and exchange with other subsystems. It is important to understand that Chatterjee et al. (2020) do not consider information as a subsystem in its own right. Rather, they describe it as a “property of the superordinate system that shapes, and is shaped by, how the social and technical subsystems interact” (Chatterjee et al., 2020, p. 14).

For the conceptualization of blockchain as an IS, I follow Brennecke, Guggenberger, Sachs, and Schellinger (2022), who apply the sociotechnical system framework developed by Bostrom and Heinen (1977). The framework allows researchers to describe blockchain’s social and technical subsystems in more detail (see Figure 1). The technical subsystem contains the physical system and tasks. The physical system comprises the internet infrastructure, computer hardware, and the software that runs on it. Tasks refer to computational processes, such as the execution of protocols. In particular, for blockchain systems, tasks mainly relate to the consensus algorithm and the logic embedded in smart contracts. The social subsystem is made of people and structures. People in a blockchain-based IS comprise researchers, developers, and other related stakeholders who are important sources for the development and growth of the system.

These individuals are part of structures, e.g., in the form of organizations or projects, which, in turn, govern how people work together.

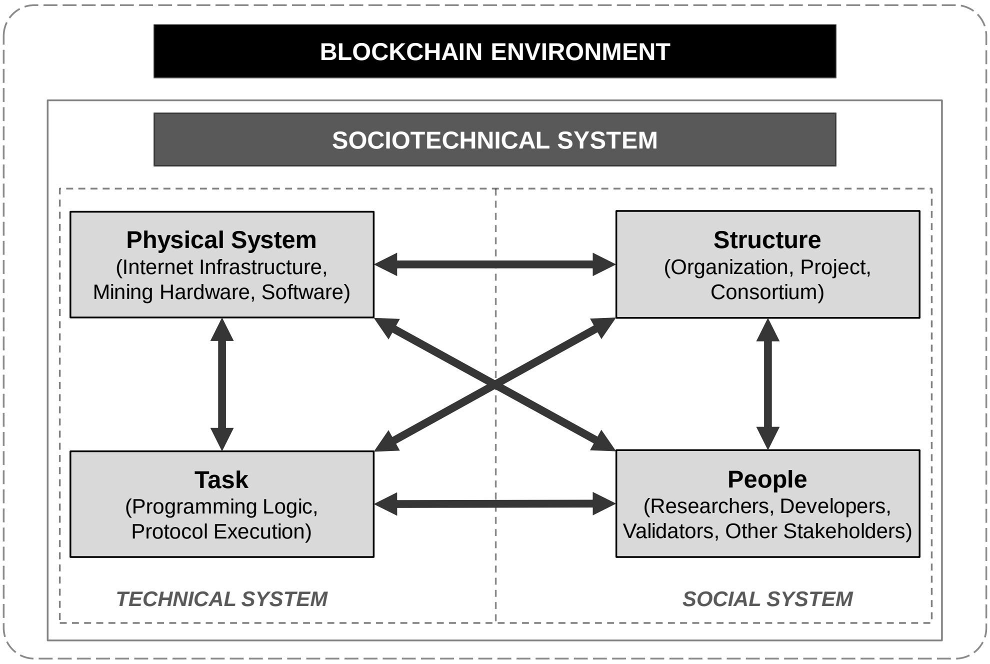

Figure 1: Blockchain as a Sociotechnical System,
adapted from Brennecke, Guggenberger, Sachs, and Schellinger (2022)

2.3 Emergence of Blockchain-Based Information Systems

The interest in blockchain technology has grown continuously in recent years (Berneis et al., 2021; Feulner et al., 2022). This trend is not exclusively due to the rise of Bitcoin and other cryptocurrencies. Practitioners and researchers have also discovered blockchain's potential as an infrastructure for various applications that fundamentally disrupt existing business processes, thus providing value to individuals, organizations, or society as a whole (Konstantinidis et al., 2018). Consequently, blockchain-based applications for finance (Schweizer et al., 2017), supply chain management (Berneis et al., 2021), and identity management (Liu et al., 2020) – among others – are being discussed. In all these applications, blockchain technology serves as an infrastructure that enables secure, decentralized, and direct collaboration in untrusted environments.

Many early applications of blockchain technology were undertaken in the financial sector. As blockchain evolved and smart contracts were introduced, the use of blockchain for financial applications quickly became more diverse (Risius & Spohrer, 2017). Decentralized blockchain-based applications now extend beyond the simple processing of transactions. In particular, token-based approaches to the financing of ventures or the trading of digital goods, and early-stage venture funding, have been established as suitable use-cases (Fridgen, Regner, et al., 2018; Schweizer et al., 2017). The concept of decentralized finance is even being pursued as an alternative financial system (Chen & Bellavitis, 2020), with the aim of making all financial instruments from the traditional world of finance – such as borrowing and lending – available via the blockchain. We are now at the point where decentralized central banks are being developed and, in some contexts, already being used (Brennecke, Guggenberger, Schellinger, & Urbach, 2022).

Blockchain, however, is not exclusively focused on financial applications and is expanding to other industries. Blockchain technology promises transparency, responsiveness, and resilient infrastructure for decentralized environments (Gimenez-Aguilar et al., 2021), which makes the technology well-suited for use in supply chain management (Berneis et al., 2021). blockchain is often touted as a potential solution to the problem of end-to-end transparency. For example, blockchain can track food from farm to fork throughout the supply chain; from the origin of resources to their ultimate consumption (Kamilaris et al., 2019). Blockchain provides a single point of truth across all participants in a supply chain, allowing all parties to view the remaining raw materials or resources at any time and, therefore, optimize their processes accordingly. For customers, blockchain-based provenance can strengthen trust in the origin of products (Kamilaris et al., 2019). Thus, the technology provides a solution that can effectively reduce information asymmetries in complex supply chain relationships (Longo et al., 2019).

Another example of emerging applications are blockchain-based identity management systems (IdMs), which have recently become a focus of research (Frizzo-Barker et al., 2020; Liu et al., 2020). IdMs are systems used to manage identities. Generally speaking, they include the tasks of authentication, authorization, issuance of identity attributes, and management of the lifecycles of identities or individual attributes (Liu et al., 2020). With the increasing relevance of digital identities, the problems of existing approaches to identity management are becoming ever more apparent. Often, existing centralized IdM approaches are poorly scalable, operated by single authorities, or not very convenient to use (Preukschat & Reed, 2021). With the use of blockchain technology, it becomes possible to develop new decentralized forms of IdM. Here, the properties of blockchain – e.g., decentralization, interoperability, and a high level of security – are relied upon to improve existing IdMs (Preukschat & Reed, 2021; Zambrano et al., 2018). Often, blockchain-based IdMs also aim to hand control over identities back to the user. In contrast to single sign-on approaches, whereby a centralized provider holds the identity, with blockchain-based IdMs the user can manage their identity entirely on their own (Mühle et al., 2018).

Despite the value propositions and the apparent potential of blockchain, blockchain-based applications remain few in number (Al-Shamsi et al., 2022). While blockchain has been successfully adopted for some token-based business models (see the *initial coin offering* (ICO) and *non-fungible token* (NFT) waves (Bao & Roubaud, 2022)), companies are still struggling to successfully integrate the technology into their system landscapes and processes (Al-Shamsi et al., 2022). The reasons given for this are diverse: On the one hand, designing decentralized applications requires new knowledge and different paradigms to develop effective IS (Udokwu et al., 2020). On the other hand, blockchain presents companies with additional managerial challenges. The decentralized nature of blockchain-based applications means new approaches are required for managing implementation projects or even entire ecosystems (Zavolokina et al., 2020). In addition to the technical challenges already mentioned, these design challenges and open questions about the effective management of blockchain applications are important motivations for my dissertation.

3 Derivation of Research Gaps and Research Questions

Aiming to address the overall research aim (i.e., guiding organizations in designing and managing blockchain-based IS), I developed three specific research goals:

(RG1) *Identifying the technological boundaries of blockchain*
(RG2) *Guiding organizations in designing blockchain-based IS*
(RG3) *Guiding organizations in managing blockchain-based IS*

Meeting RG1 required the adoption of a technical perspective to identify the baseline technological potentials of blockchain and define its technical boundaries. RG2 led me to build upon the insights from RG1 and address how organizations can use blockchain technology to design effective IS artifacts. Finally, RG3 led me to investigate how blockchain-based applications are carried out in organizations and ecosystems. In summary, these three RGs guide this dissertation, furthering our understanding of both the technological and managerial perspectives of blockchain.

3.1 RG1: Identifying the Technological Boundaries of Blockchain

Digital technologies can be seen as the tools of the 21st century. Just as the tailor in the Middle Ages had to understand what his needles were capable of doing, we now need to understand the capabilities of modern digital technologies. This imperative is especially the case for systems, such as blockchain, where novelty and complexity limit the value of previous experience when it comes to estimating the system's capabilities.

Blockchain systems are very complex – increasingly so since the introduction of smart contracts and novel consensus mechanisms (Lashkari & Musilek, 2021). Consequently, many parameters have to be considered when implementing a blockchain network. It is well known that different architectural parameters – e.g., the number of nodes, consensus mechanisms, and complexity of operations – significantly impact the performance of distributed systems and blockchain, in particular (Fan et al., 2020). However, there are still significant gaps in the knowledge on the performance of blockchain systems, especially private-permissioned blockchains. The reasons for these gaps are many. First, blockchain frameworks are developing rapidly (Melo et al., 2022). Blockchain frameworks frequently introduce new features that need to be understood and considered when implementing a respective network. For example, Hyperledger Fabric introduced private data collections, which will be an essential feature in many enterprise-level applications because they allow access control (Ma et al., 2019). At this point, we can only assume that the load on the system will be higher due to the additional transaction overhead, and, thus, performance will be worse. However, there is no reliable evidence or actual data in the literature on the use of this new type of transaction. Second, existing studies focus on only a few influencing factors when evaluating performance. Nevertheless, authors seldom use standardized tools to measure performance, and few reveal sufficient information about their methodology. This means that many among these observations would be hard to replicable and the results do not yield a holistic view (Sedlmeir et al., 2021). Consequently, the literature still lacks a complete understanding of how various factors impact the performance of blockchain systems. We formulate the following research questions in order to fill this gap in the research:

What are the relevant design parameters and how do they impact the performance of blockchain systems? What are the performance limits of blockchain systems? (Essay 1)

In addition to performance, we identified cybersecurity as an important design goal for those considering implementing a blockchain system. We understand that cybersecurity and performance often stand to conflict with one another (Kannengießer et al., 2020). For example, more nodes may provide additional resilience against unforeseen events or attacks. However, such additional nodes increase demand on the consensus mechanism of a network and, thus, may also result in lower performance (Kannengießer et al., 2020). This example demonstrates that the cybersecurity of blockchain is neither absolute nor perfect (Taylor et al., 2020). Past events support this assumption; for example, The DAO – reportedly the first fully decentralized organization to operate on blockchain – became the victim of a hack in 2016. The incident resulted in a $50 million loss for The DAO's investors (Mehar et al., 2019). Given the ever-increasing value embedded in blockchain systems, it becomes even more important that IS researchers and practitioners consider cybersecurity threats to blockchain systems when designing, building, and evaluating their applications (Warkentin & Orgeron, 2020). Consequently, several researchers have begun to call for a more critical and holistic view of the security of blockchain-based systems (Gimenez-Aguilar et al., 2021; Nilufer & Yeni Erol, 2020; Taylor et al., 2020). Heeding these calls, some recent articles provide a descriptive technical perspective on the security of blockchain-based systems. However, a systematic overview of attack vectors and related research opportunities remains woefully lacking. Aiming to fill this gap in the research, we ask the following question:

What are the known attack vectors of blockchain systems, and which IS research avenues on the cybersecurity of blockchain-based systems should be established in response? (Essay 2)

3.2 RG2: Guiding Organizations in Designing Blockchain-Based Information Systems

Technology should not be an end in itself but rather a means of facilitating new value-adding applications. Similarly, it is not enough to merely understand the technical characteristics of blockchain. It is also necessary to understand how blockchain can be put to use to add value to organizations, individuals, and society (Rossi et al., 2019). However, the design of such applications often poses particular challenges for researchers and practitioners (Beck et al., 2017). The reason for this is not only related to the novelty of the blockchain itself but also to industry-specific requirements (Al-Jaroodi & Mohamed, 2019).

Early-stage funding is an exemplary area where blockchain offers opportunities for improvement. During the early stages of entrepreneurship, funding is often crucial to drive forward and implement an idea or a project (Estrin et al., 2018). In an attempt to advance early-stage funding, equity crowdfunding has evolved as a financing tool, amassing a total of over USD 1.5 billion globally in 2018 (Cambridge Center for Alternative Finance, 2020). Equity crowdfunding is a crowd-based form of issuing company shares, in which equity-like rights are issued to investors, via an internet platform, in exchange for capital. Although equity crowdfunding improves on previous types of early-stage funding, it lacks broad liquidity. It also involves significant bureaucracy and high administrative costs and depends on trusted intermediaries, such as centralized platform providers (Buerger et al., 2018; H. Zhu & Zhou, 2016).

An alternative approach to traditional crowdfunding was proposed by using ICO via blockchain technology. The goal was to democratize early-stage funding and enable more efficient crowdfunding processes (Chen, 2018). However, unclear regulations, limited configurability, and insufficient investor protection led to a decline in investment in ICOs. More recently, stagnating development in the traditional funding process and a lack of regulatory compliance in ICOs have led to the development of

Security Token Offering (STO). A Security Token is a digital representation of a security, issued and managed on a blockchain (Lambert et al., 2022). Security Tokens aim to meet regulatory requirements, provide an underlying value to the token holder, and, eventually, promise a more mature form of token sale (Kranz et al., 2019). Thus, STOs offer a novel alternative to equity crowdfunding platforms. While researchers recognize the value of blockchain for equity crowdfunding, design theory in this area is limited (Hartmann et al., 2019). However, this knowledge is a prerequisite for understanding how such systems can be effectively implemented to add value (Beck et al., 2017). In order to address this knowledge gap, we pose the following research question:

How can blockchain be incorporated as an alternative infrastructure for equity crowdfunding? (Essay 3)

Another area that has faced rising challenges over the last few decades is supply chain management (Berneis et al., 2021). Product life-cycles have become shorter, product variants more numerous, and corresponding ramp-up and ramp-down phases more intensive. Supply chains are no longer formed through bilateral relationships between original equipment manufacturers (OEMs) and suppliers. Nowadays, such chains typically encompass an extensive ecosystem of companies at multiple levels (Wu & Cheng, 2008). Intending to overcome the challenges of increasingly complex supply chains and provide better coordination between actors, researchers have highlighted the need to ensure the seamless flow of information as a critical supply chain management task (Gavirneni et al., 1999; Wu & Cheng, 2008). In recent decades, technology has effectively supported the flow of information in the supply chain (H. L. Lee & Whang, 2000). As a result, the recent understanding of supply chain management embraces a digital perspective (Dehning et al., 2007), which emphasizes the importance of IT infrastructures for integrating supply chain processes and, ultimately, for business performance (Rai et al., 2006). Typically, companies now use electronic data interchange (EDI) to exchange data between different systems in different organizations (Jardini et al., 2015). Yet, while EDI provides proven standards for data transfer, it is not fully aligned with the distributed character of modern supply chains due to its unicast nature (Jardini et al., 2015). In fact, EDI implementations are costly and severely limit the feasibility of transmitting information across a network as extensive as an entire supply chain (Neubert et al., 2004).

Researchers suggest that blockchain can improve transparency, cybersecurity, and integration between supply chain actors (Berneis et al., 2021). Kristoffer Nærland et al. (2017) explore the use of blockchain technology to mitigate risk in environments with a high rate of decentralization. The research team introduced an Ethereum-based prototype for managing documents during the shipping process. They propose four design principles for blockchain-based applications: digitization, tamper-proof storage, accessibility, and user authentication. However, the authors also note that we still lack a deeper understanding of blockchain in terms of design principles and underlying theories. Similarly, Babich and Hilary (2020), in their research agenda, highlight the theoretical potential of blockchain to facilitate information sharing in supply chains. However, they also emphasize the need for a better understanding of the design of blockchain-based IS. They argue that research must provide blueprints to enable companies to effectively exploit blockchain's full potential for information sharing in supply chains. In summary, we follow the call of Nærland et al. (2017) Babich and Hilary (2018) and state our research question as follows:

How and to what extent can blockchain facilitate information sharing in a supply chain? (Essay 4)

While supply chain management often only indirectly affects the end consumer, for example, in the form of cheaper products, digital identities directly shape our modern, networked society. Many digital services in our personal and professional lives require identification and identity verification (Cao & Yang, 2010). When handling the identities of their customers and employees, organizations use IdM. Various forms of IdM have been developed, of which centralized and federated are the most commonly used. In a centralized IdM, a user creates an identity in the system by registering an account with an application, typically providing a username and a password (Cao & Yang, 2010; Preukschat & Reed, 2021). With federated IdM, instead of creating an account directly with an application provider, the user registers with an identity service provider (IDP). When the user accesses an application, the IDP relays a portion of their identity information to this application (X. Zhu & Badr, 2018). Both concepts still suffer from drawbacks, including a lack of interoperability between identity providers, poor privacy, and low portability (Preukschat & Reed, 2021).

New blockchain-inspired models have emerged to address the above-mentioned challenges accompanying centralized and federated IdM (Frizzo-Barker et al., 2020; Liu et al., 2020). Among these models is self-sovereign identity (SSI)[1]. SSI is an approach that places the identity-holder at the center of all activities. It promises novel avenues to promote comfortable, connected, and secure identity services (Bernal Bernabe et al., 2019). In 2021, the European Commission presented a proposal for a new pan-European identity network driven by blockchain and SSI. The idea at the heart of the proposal is to shift away from a closed identity system. Instead, future exchanges of identity data between public institutions and private companies should be facilitated (European Commission, 2021). However, the high potential SSI holds for the EU is counterbalanced by high implementation and operating costs. The European Commission (2021) expects that the initial deployment of a new pan-European IdM based on SSI will cost over 600 million euros. A comprehensive understanding of SSI – and, in particular, how it can be designed to maximize value – is needed in order to make well-educated investments in this area. However, the respective research is still in its early stages. Very few studies have been published and, of these, most focus on either hypothetical advantages that SSI offers to wider society or on specific technical features (Liu et al., 2020). There is a lack of knowledge as to how these technical features could be implemented in real-world use-cases. Therefore, approaches to designing effective blockchain and SSI-based IS, especially in cases that span multiple identity domains and have high transferability requirements, remain largely unexplored (Preukschat & Reed, 2021; X. Zhu & Badr, 2018). To address this research gap, we pose the following question:

How can blockchain-based SSI be incorporated for decentralized identity management spanning multiple organizations? (Essay 5)

3.3 RG3: Guiding Organizations in Managing Blockchain-Based Information Systems

Even with an understanding of the benefits that digital technologies can offer, there is still a long way to go before the technology is effectively implemented in organizations and adopted by the market. In particular, the decentralization often associated with blockchain leads to major challenges in the deployment of applications (Al-Shamsi et al., 2022). Such considerations are relevant for both the implementation of individual

[1] I would like to note that the discussion as to whether SSI requires a blockchain is ongoing (Mahula et al., 2021). Within this dissertation, all descriptions of SSI follow the assumption of SSI being a blockchain-based system. Thus, all SSI systems described herein make use of blockchain in some way.

projects and the emergence of entire ecosystems.

Through IT projects, companies can adopt new technologies, thus, helping them to transform and grow their business in the digital age (Miterev et al., 2017; Turner & Müller, 2003). To this end, companies aiming to adopt and integrate blockchain-based applications into their corporations undertake blockchain implementation projects. In 2017, most blockchain-based applications were still in strategic starting or early proof-of-concept phases. However, these applications have matured significantly in the last few years, and companies have started transitioning their prototypes to pilots or operative implementations (Du et al., 2019). With rising complexity and limited resources, effective management of such projects becomes more important to ensure their success. However, the intrinsic characteristics of blockchain as an emerging digital technology introduce new challenges and require businesses to develop new ways of handling such implementation projects (Fridgen, Radszuwill, et al., 2018). In particular, decentralization efforts leading to cross-organizational collaboration in many blockchain implementation projects require organizations to adapt (Zavolokina et al., 2020). Therefore, Du et al. (2019) and Labazova (2019) state that it is essential to clearly define the goals and boundaries of blockchain projects. Early project management literature suggests the use of the iron triangle, which is composed of time, budget, and scope (Wit, 1988). However, recent literature proposes that these success criteria are insufficient to holistically evaluate the success of a project. Heeding Shenhar et al.'s (2001) argument that success criteria differ for technologies of different complexity, it can be argued that blockchain implementation projects require a more differentiated approach. The need for research in this area is further emphasized by the fact that recent studies still fail to address the effects of intra- and inter-organizational projects on project management. In summary, existing research does not address how to appropriately measure the success of blockchain projects. Aiming to fill this research gap, we pose the following questions:

Which success criteria can be used for the evaluation of blockchain projects? How do success criteria differ in their relative importance? (Essay 6)

The goal of using blockchain is often to pave the way for new digital ecosystems (Zavolokina et al., 2020). In digital ecosystems, independent organizations interact with one another through the use of digital technologies (Adner, 2017). In this way, organizations bring their specialized expertise to the ecosystem, providing complementary products and services that a single company cannot offer (Baldwin & Clark, 2000). With the emergence of SSI, new forms of digital identity ecosystems are beginning to develop. In order to advance the development of these novel digital identity ecosystems, projects have recently been undertaken in both the private and public sectors (DLR Projektträger, 2019). The literature argues that a fundamental understanding of the underlying interactions within and between ecosystems is needed to enable innovation and value realization (West & Wood, 2014). However, the study of digital identity ecosystems is still in its infancy (Soltani et al., 2021). As a result, a multitude of interactions and structures are not sufficiently understood. This comes at a cost to both the public and private sectors, as well as to end users, and, thus, negatively impacts the growth potential of those ecosystems. To this end, we propose that Wang's (2021) information ecology theory of digital innovation ecosystems provides a useful theoretical framework for capturing the underlying interactions and value-creation functions of digital identity ecosystems. This theory is based on research in digital innovation and ecosystems. It recognizes that previous literature in IS and organizational research tends to favor the analysis of parts of ecosystems rather than looking at them in their entirety. For this purpose, Wang (2021) borrows the holon as an ecological concept of entities in part-whole relationships among ecosystem participants. This novel theory promises to provide a whole-of-entity view of digital identity ecosystems, thus, offering new insights into the interaction of ecosystems. On this basis, our research aims to answer the following questions:

H*ow can a digital identity ecosystem be structured, understanding them as a holarchy? How do organizations in digital identity ecosystems interact with each other within and across ecosystem levels/their holarchy? (Essay 7)*

4 Dissertation Structure and Research Design

This dissertation consists of seven research essays that address the research goals derived in Section 3. Essays 1 and 2 address RG1, Essays 3 to 5 RG2, and Essays 6 and 7 RG3. The essays follow this introduction, with the structure of the dissertation reflecting its cumulative nature. Table 1 provides an overview of the essays, their publication outlets, and their publication status. Please find my other publications, which are not part of this dissertation, in Appendix B.

Table 1: Essays on the Three Research Goals of this Dissertation

Title	Publication outlet	VHB JQ3 ranking	Publication status
RG1: Identifying the technological boundaries of blockchain			
Essay 1: An In-Depth Investigation of the Performance Characteristics of Hyperledger Fabric	Computers & Industrial Engineering	B	Published as Guggenberger et al. (2022)
Essay 2: Attacking the Trust Machine: Developing an Information Systems Research Agenda for Blockchain Cybersecurity	International Journal of Information Management	C	Published as Schlatt et al. (2022)
Building upon: A Structured Overview of Attacks on Blockchain Systems	Proceedings of the 25th Pacific Asia Conference on Information Systems	C	Published as Guggenberger, Schlatt, et al. (2021)
RG2: Guiding organizations in designing blockchain-based IS			
Essay 3: Kickstarting Blockchain: Designing Blockchain-Based Tokens for Equity Crowdfunding	Electronic Commerce Research	C	Published as Guggenberger, Schellinger, et al. (2023)
Essay 4: Improving Inter-Organizational Information Sharing for Vendor Managed Inventory: Towards a Decentralized Information Hub Using Blockchain Technology	IEEE Transactions on Engineering Management	B	Published as Guggenberger et al. (2020)
Essay 5: Designing a Cross-Organizational Identity Management System: Utilizing SSI for the Certification of Retailer Attributes	Electronic Markets	B	Published as Guggenberger, Kühne, et al. (2023)

Title	Publication outlet	VHB JQ3 ranking	Publication status
RG_3: Guiding organizations in managing blockchain-based IS			
Essay 6: You Can't Manage What You Can't Define: The Success of Blockchain Projects Beyond the Iron Triangle	Proceedings of the 42nd International Conference on Information Systems	A	Published as Guggenberger, Stoetzer, et al. (2021)
Essay 7: Governing Digital Identity Ecosystems: Towards an Information Ecology Theory of Digital Innovation Ecosystems	n/a	n/a	In preparation for submission

In Essay 1, we started by conducting a structured literature review (SLR) to identify relevant testing parameters. These testing parameters formed the independent variables for the subsequent performance experiments, which aimed to investigate the parameters' effects on the technical performance (dependent variable) of Hyperleder Fabric. For the SLR, we first defined "Hyperledger AND Fabric" as a search string and then used this string to search in ACM Digital Library, AIS electronic Library, arXiv, IEEE Explore, and Web of Science. This returned a total of 1,085 papers. Through initial screening of their titles and abstracts, we excluded 1,007 papers for lack of relevance to our study. Subsequently, we performed a full-text analysis and removed papers that conducted their studies on a non-stock version of Hyperledger Fabric, as their results were not transferable to the publicly available version of the blockchain framework. After all elimination steps, we used 19 articles to identify relevant parameters for the performance of Hyperledger Fabric. We then moved on to setting up our benchmarking evaluation framework. We used an earlier version of the Distributed Ledger Performance Scan (DLPS) framework (Sedlmeir et al., 2021), which we further developed to cover all 15 identified test parameters and support Hyperledger Fabric 2.0. We then evaluated the performance of Hyperledger Fabric by conducting experiments, which were undertaken incrementally and interactively to ensure the validity and reliability of our results. A single benchmarking run in DLPS involves sending client requests to the network for a specified duration and at a specified rate. We began with a base configuration and iteratively altered one of the testing parameters. Each iteration was then analyzed with regard to performance characteristics, such as throughput and latency. In total, our experiments spanned nearly 2,000 hours of testing, during which we deployed about 1,500 Hyperledger Fabric networks involving a combined number of approximately 20,000 nodes and 40,000 clients, and sent more than 200 million transactions. This approach allowed us to gather 100 GB of log files to record factors such as the send and response times of transactions, along with resource statistics such as CPU, memory, disk usage, ping, and traffic for all nodes and clients.

In Essay 2, we performed an SLR to identify concrete attacks and attack vectors on blockchain systems. The SLR followed the widely accepted research approach developed by Webster and Watson (2002). Therefore, we started by determining search terms with reference to the research question. We then created a Boolean search string based on these terms, which we applied to relevant literature databases. We searched for titles, abstracts, and keywords in the ACM Digital Library, IEEE Xplore, arXiv, AISel, and Web of Science, to cover both IT and IS journals and conferences. The initial search resulted in 5,332 articles. After applying exclusion and inclusion criteria, we were left with 161 articles. In our subsequent analysis, guided by the principles of Nickerson et al. (2013), we aimed to derive a robust, comprehensive, concise, and explanatory systematization of attacks on blockchain systems. We examined shared features and characteristics to assign 87 relevant attacks to common attack vectors. Based on our findings, the essay proposes a research framework for studying the cybersecurity of blockchain systems. In conjunction with this research framework, the essay also discusses six propositions addressing the interplay between IT and human(s) in the cybersecurity of blockchain systems. This research framework led us to present a research agenda providing future avenues for IS researchers to investigate the cybersecurity of blockchain-based IS.

Essays 3-5 follow a design science research (DSR) approach and intend to contribute to design knowledge about blockchain-based IS. Design science research generally aims to solve problems with practical relevance (Hevner et al., 2004) by designing novel and innovative IT (March & Smith, 1995). Concerning the maturity of an artifact, the products of design science research can be (mid-range and grand) design theories, constructs, methods, or instantiations such as software or implemented processes (Gregor & Hevner, 2013; March & Smith, 1995). However, it is important to note in this context that design science research should simultaneously contribute to both research and professional practice (Gregor & Hevner, 2013). Thus, the development and application of the artifact involve a twofold task. First, it should provide information on building the artifact, i.e., expand prescriptive knowledge. Second, design science research should involve descriptive knowledge and, ultimately, contribute to our general understanding of laws and cause-effect relationships (Gregor & Hevner, 2013). Addressing the first requirement, Essays 3-5 present concrete IS artifacts, such as system architectures, processes, and program codes, as forms of instantiation. In striving to satisfy the second requirement, these essays also discuss design principles that provide generalizable higher-order knowledge.

In Essay 3, we designed a blockchain-based equity token with the goal of addressing the shortcomings of the traditional crowdfunding process and ICOs (Fridgen, Regner, et al., 2018). Our research was guided by Peffers et al. (2012), who advocate an iterative approach to the design process. In this context, we first explain the main challenges of traditional equity crowdfunding and analyze the drawbacks of ICOs, the first wave of blockchain-based solutions. In this context, our studies show that current crowdfunding approaches are characterized by high administrative costs, a lack of trust in central providers, and a lack of opportunities to operate in the secondary market. While ICOs offer the opportunity to address these challenges, they present regulatory hurdles of their own. Combining the identified challenges in these two areas, we determined design goals to be met by the improved solution. Based on these goals, we designed and implemented an equity token, including additional issuance and transaction protocols. To instantiate our design, we relied on Ethereum, the most mature platform for smart contract development. The developed artifact was then evaluated in the course of seven semi-structured expert interviews. This allowed us to gather important feedback from experts on our reference implementation and the use of equity tokens for crowdfunding. It also helped us to abstract insights from our instantiation. Based on our results, we propose seven design principles.

In Essay 4, we designed a blockchain-based information hub to improve vendor-managed inventory (VMI), an established approach to information sharing (Angulo et al., 2004). Again, we followed the widely accepted research approach of Peffers et al. (2012). As a first step, we conducted several interviews with employees of a healthcare company to identify and understand the issues relating to current IT solutions used to facilitate VMI. The interviews revealed that the current challenges are mainly related to IT security, in particular, the system's availability and lack of transparency regarding ongoing processes. Based on the problems identified, we established design objectives to guide the development of our design. Over the course of several development cycles, we developed a solution design based on Hyperledger Fabric. The design focuses primarily on demonstrating how information disclosure and privacy can be balanced by Hyperledger Fabric's privacy features, i.e., private data collections. Through regular contact with the healthcare company, we were able to ensure continuous development of the artifact. When we reached a sufficient level of maturity, we conducted semi-structured interviews with both the healthcare company and some of their suppliers. We concluded the research process by formulating our findings into higher-order knowledge during the research process. The results of the study propose the decentralized information node as an extension of H. L. Lee and Whang’s (2000) model. They also establish four design principles that contribute to the design theory of blockchain.

In Essay 5, we again followed the DSR approach of Peffers et al. (2012) and implemented a blockchain-based IdM. Specifically, the essay presents an SSI system that enables online retailers to maintain multiple verifiable credentials (VCs) to prove proper registration as taxpayers to an online platform (e.g., Amazon, eBay). Again, we were able to contextually embed our study in a real-world setting. The Bavarian State Taxation Office was our research partner throughout: from the definition of the problem to the evaluation of the artifact. The research project was structured as follows: As a first step, we conducted several interviews with employees of the taxation office to understand the current technical status quo and the legal situation. These insights helped us to establish the design goals in response to the problem definitions. We then developed an initial solution design and which was implemented by an IT service provider. Over the course of several weeks, we presented the prototype to the professional experts in the Bavarian State Taxation Office and iteratively refined the prototype’s architecture and implementation. Once we received confirmation from the tax authority that the application had reached a sufficient level of maturity, we moved on to the final evaluation, which involved a two-pronged approach. First, we conducted a criteria-based assessment with reference to the design objectives. The evaluation was then refined and supplemented using our findings from eight semi-structured interviews. Again, our goal was to provide higher-level design knowledge beyond that presented in the architecture and instantiation. Accordingly, we drew insights from the design and evaluation of our artifact and, based on these, formulated four design principles to guide future research in the development of blockchain-based SSI applications.

In Essay 6, we conducted an interview study to inductively determine the success criteria and dimensions of blockchain software development projects. The results of this study aim to improve the understanding of project evaluation and success criteria. (Myers & Newman, 2007). When conducting the study, we approached companies involved in the implementation of blockchain-based IS. We developed interview guidance based on the use of open-ended questions. This approach was intended to encourage interviewees to respond freely and to generate unanticipated insights (Bhattacherjee, 2012; Myers & Newman, 2007). Altogether, we interviewed professionals involved in 12 blockchain projects. Throughout, we engaged in interview debriefings, discussed newly identified themes, and cross-referenced with previous interviews. We held a final meeting to reflect on the entire data set before we began coding. We recorded and transcribed all interviews, resulting in 176 pages of transcripts. Within four weeks, we conducted three coding rounds, each ending with coding workshops where all authors discussed the results. Through coding the qualitative data and triangulating relevant research literature, we ended up with six success dimensions and 29 success criteria for blockchain development projects (Corbin & Strauss, 1990). Finally, we asked each of our interview participants to separately rate the identified success criteria regarding their relative importance. The eventual result is a quantitative assessment of the relevance of all success dimensions for each blockchain project in which the interviewees were involved.

In Essay 7, we performed an embedded single case study, which followed the guidelines and propositions made by Yin (2018). We also incorporated recommendations and ideas derived from methodological analysis of case study research by Eisenhardt (1989), Eisenhardt and Graebner (2007), as well as the quality criteria for research design proposed by Dubé and Paré (2003) and Gibbert et al. (2008). In particular, we studied the *showcase program secure digital identities* through the perspective of the information ecology theory of digital innovation ecosystems (Wang, 2021). Thus, our aim was to evaluate the information ecology theory of digital innovation ecosystems, apply this theory to a novel type of innovation ecosystem, and, eventually, present new theoretical insights. Throughout our research, we aimed to collect a wide range of qualitative data to allow for triangulation and take different perspectives to study the phenomenon at hand. Consequently, we collected public and internal documents, 20 transcribed interviews, 929 social media postings, and more than 18 hours of audiovisual sources. The data was then analyzed via a three-level coding system. First, we performed open coding to derive the part-whole interactions (first-order categories) present in the showcase program. Second, we broadly drew on the innovation tasks (second-order themes) as proposed by (Wang, 2021) and classified our first-order categories into these second-order themes. Third, we drew on the innovation tasks (aggregate dimensions) of integration, value realization, adaption, and moderation (Wang, 2021). Throughout our research, we continuously evaluated the data against the code system and adjusted it where necessary. Thus, we were guided by theory but without being constrained in our data analysis. Eventually we were able to validate most of the part-whole interactions proposed by Wang (2021) but were also able to integrate a new type of interaction, which we called *compiling*.

5 Summary of Results

In this section, I will summarize the results of the seven essays. The results provide insights into the technical boundaries, the design, and the management of blockchain-based IS.

5.1 Essay 1: An In-Depth Investigation of the Performance Characteristics of Hyperledger Fabric

In Essay 1, we examined the impact of a wide range of variables on the performance of blockchain systems, particularly Hyperledger Fabric-based applications. First, we conducted an SLR and presented an overview of the existing literature on Hyperledger Fabric performance. We described the methods and conditions under which existing studies investigate the performance of Hyperledger Fabric. We found that while the extant literature provides some important initial insights into the performance properties of Hyperledger Fabric, these insights are fragmented. Previous studies focus on analyzing individual parameters rather than providing a holistic picture (Fan et al., 2020). We noted further that the results presented to date have limited reproducibility. Many studies use proprietary tools to perform their measurements or do not adequately reference the configuration of their measurement systems (Sedlmeir et al., 2021). Accordingly, our SLR indicated that the results could be improved in terms of both their reproducibility and their insight. In a second step, we addressed this knowledge gap. We used the insights from the SLR relating to relevant performance-critical variables and configuration options to develop an extended version of the DLPS (Sedlmeir et al., 2021). This DLPS served as our test framework, which we then used to conduct a wide-ranging series of performance tests. With this effort, we validated and extended previous research by evaluating more than 15 network- and transaction-related parameters. These parameters include hardware and database selection, transaction payloads and privacy configurations, various network sizes from 5 to 128 nodes, geographic distribution, and analysis of the impact of node crashes. In summary, we demonstrated that Hyperledger Fabric is suitable to support the needs of many industrial blockchain applications. For example, even in large or intercontinental networks, Hyperledger Fabric can still achieve more than 1000 tx/s for public transactions with LevelDB. In this way, we revealed which features affect the performance of Hyperledger Fabric and defined the limitations of the blockchain framework under different conditions.

The contribution made by this essay is threefold. First, the essay reveals the impact of various parameters on blockchain performance. We anticipate that future research will profit from the expanded list of relevant factors, using them as a basis for performance analysis of Hyperledger Fabric and other blockchains. This should help optimize existing and future applications to enable higher network performance. Second, by discussing Hyperledger Fabric's potential, we provide a basis to understand better whether a private-permissioned blockchain meets the needs of applications at different scales. In this way, we contribute to the current understanding of blockchain system design by exploring the full potential of blockchains. Finally, researchers and practitioners can benefit from future use of our improved version of DLPS. They can use the developed framework to test and optimize their applications and advance their understanding of blockchain system performance.

5.2 Essay 2: Attacking the Trust Machine: Developing an Information Systems Research Agenda for Blockchain Cybersecurity

In Essay 2, we utilized an SLR to provide an overview of the existing literature on attacks on blockchain-based systems. This allowed us to identify a total of 87 different attacks. The attacks were mapped based on five attack vectors. The first and second attack vectors represent the P2P network of a blockchain system. This layer represents the basic functions for data storage and exchange (15 attacks) and the consensus mechanism (27 attacks) of the blockchain system. The third attack vector targets the virtual machine (VM) as well as the corresponding programming language of a blockchain system (10 attacks). The fourth attack vector aims at the infrastructure responsible for implementing application logic. This, in turn, can be broken down into the two subdomains of smart contracts (16 attacks) and off-chain programs (11 attacks). The final attack vector relates to the client applications and wallets (8 attacks), which the end-user employs to interact with the blockchain. Building on these findings, we then developed a framework for IS research on the cybersecurity of blockchain-based systems. In doing so, we abstracted the findings into higher-order cause-effect relationships between different actors. The identified actors include the human subsystem – which consists of users of blockchain applications, developers of blockchain-based systems, and attackers – and the IT subsystem – which consists of blockchain infrastructure and applications running on top of the protocol. In total, six cause-effect relationships were defined and formulated as propositions. Finally, we presented research opportunities for future endeavors with respect to the identified actors. By presenting these research opportunities along with the identified attacks, we answered the questions of which attack vectors of blockchain systems exist and which IS research avenues for the cybersecurity of blockchain-based systems hold promise.

This essay makes three main contributions: First, we use a comprehensive SLR to provide a structured overview and analysis of attacks on blockchain-based systems. By organizing these based on five attack vectors, researchers and practitioners can optimize future applications with respect to the different layers of blockchain systems and their cybersecurity. Second, we propose a comprehensive research agenda that can guide researchers in future cybersecurity research. Finally, we bring a socio-technical perspective to research on the cybersecurity of blockchain systems. This helps to better reveal and explain the interplay between humans and IT in blockchain-based applications. Thus, we lay an important foundation for future research that looks at the technical security of blockchain-based applications and also considers the human factor. In this way, we also embed ourselves in existing cybersecurity research, which has identified humans as a critical gateway for security vulnerabilities (Ghafir et al., 2018).

5.3 Essay 3: Kickstarting Blockchain: Designing Blockchain-Based Tokens for Equity Crowdfunding

In Essay 3, we designed, developed, and evaluated an equity token prototype for crowdfunding, following the DSR approach. We used a set of smart contracts to represent the relevant business logic of our equity funding system. Furthermore, to enable effective document sharing (e.g., for KYC/AML processes), we relied on the Inter-Planetary File System (IPFS) as a distributed storage technology (Daniel & Tschorsch, 2022). This allowed us to separate the storage of larger datasets from the business logic on the blockchain. The design was implemented in the form of a prototype as a real-world instantiation using Ethereum as the representative of a public-permissionless blockchain. We subsequently assessed the effectiveness of the artifact via an evaluation. We found evidence that the artifact enhances trust and mitigates adverse selection by reducing asymmetric information between interacting parties, aligning interests, and minimizing regulatory uncertainty related to equity tokens. Overall, the developed artifact reduces the transaction costs of acquiring and trading equities and provides investment seekers with global access to investors. In the long term, we proposed that our artifact could benefit countries with less-developed financing structures. Building on the findings from the design and evaluation of the artifact, we also proposed a refined crowdfunding model and derived seven design principles that contribute to the design theory of equity tokens. In doing so, we answered how blockchain could be used as an alternative way to foster equity crowdfunding.

This essay attempts to make several contributions to the body of knowledge. First, our artifact provides a concrete solution design and, thus, a blueprint for how to implement effective tokenization of equity for crowdfunding. Second, through our research process, we were able to show how equity crowdfunding, as a specific form of crowdfunding, can benefit from blockchain. Third, we present general design principles that future research can use as guidance for the development of blockchain-based equity crowdfunding applications. Fourth, we contribute to discussions on the use of blockchain for funding early ventures by extending the model of Schweizer et al. (2017).

5.4 Essay 4: Improving Inter-Organizational Information Sharing for Vendor Managed Inventory: Towards a Decentralized Information Hub Using Blockchain Technology

In Essay 4, we followed the design science research approach to develop a blockchain-based information hub. The system is intended to support VMI and enable the exchange of information between different actors in a supply chain. The design was implemented as a prototype and relied strongly on Hyperledger Fabric. Thanks to the use of Hyperledger Fabric, we were able to evaluate the application of private data collections in the system and, thus, build a blockchain system that provides essential access control capabilities. It is important to note that the prototype was developed in close collaboration with a leading German healthcare company, allowing us to demonstrate the blockchain-based prototype in a real-world use-case. In particular, we used the existing healthcare company's system as a baseline. In this way, we evaluated the blockchain system using a stand-alone approach and highlighted its relative strengths and weaknesses compared to the existing centralized solutions. During the interviews we conducted to evaluate the artifact, four features were emphasized as advantages over the old system: two-way communication, shipping information, interoperability, and multi-level supply chain transparency. With reference to the designed artifacts, we discussed the resulting system architecture and its implications for our understanding of IT solutions in the supply chain. In doing so, we eventually developed the decentralized information hub model, extending the information exchange models of H. L. Lee and Whang (2000). Finally, we proposed four design principles for building future decentralized information hubs. Overall, the essay answered how blockchain can facilitate information sharing in a supply chain.

The essay makes several contributions to the body of knowledge. First, it answers calls from Babich and Hilary (2020) and van Engelenburg et al. (2018) to show, based on a concrete design, how companies can use blockchain for information exchange between different parties in a supply chain. Second, it contributes to a better understanding of how permissioned-blockchains should be designed for the supply chain management. The essay is one of the first studies to instantiate and test the private data collection function of Hyperledger Fabric. Future research can build on these findings to build blockchain systems that technologically facilitate the balancing of information sharing and privacy. Third, the essay takes the system model for information sharing developed by H. L. Lee and Whang (2000) and extends it to include a fourth model, the decentralized information hub. Thus, it expands our theoretical understanding of what models of information exchange exist and how the blockchain-based decentralized information hub differs from legacy ones.

5.5 Essay 5: Designing a Cross-Organizational Identity Management System: Utilizing SSI for the Certification of Retailer Attributes

In Essay 5, we followed the DSR paradigm to design and present an SSI system that allows online retailers to manage multiple Verifiable Credentials (VC) to prove proper registration as a taxpayer toward an online platform (e.g., Amazon, eBay). We worked closely with the Bavarian State Taxation Office while conducting the study. Accordingly, the design was implemented on-site with an IT service provider at the Bavarian State Taxation Office. This allowed us to involve managers and potential users in workshops and prototype presentations to verify whether the design met their expectations. Subsequently, a mixed-method approach was used to evaluate the artifact. We first performed a criteria-based evaluation and assessed the artifact against specific design objectives using insights gained during the design and demonstration of the artifact. We then refined this initial evaluation with expert opinions. For this purpose, we conducted eight expert interviews, which lasted between 45 and 60 minutes. The evaluation showed that the developed IdM system largely fulfills the requirements we defined together with the Bavarian State Taxation Office. The system provides important functions for issuing credentials and deriving and verifying presentations. The system was particularly convincing in terms of IT security. While cryptographic signatures help to ensure the integrity of credentials, the blockchain can be used to ensure the availability of cross-organizational functions (e.g., the validity register). Finally, we proposed four nascent design principles derived from the final solution design. By presenting the design principles alongside our artifact, we revealed how blockchain-based SSI can be incorporated for decentralized identity management spanning multiple organizations.

In this essay, we make the following contributions: First, we provide a concrete solution design for an IdM that spans different organizations, allowing us to highlight underlying decisions that should support the realization of similar efforts in the e-government sector. This is especially relevant for future endeavors within the European Union and the use of SSI with respect to the EIDAS 2.0 regulation. We believe those insights into the design of the system will also help organizations outside of the public sector. Second, our evaluation of the system allows readers to better understand the strengths and weaknesses of blockchain-based SSI systems. For example, we argue that limitations regarding the auditability of processes might make SSI inadequate for some use-cases. Third, following calls by Nærland et al. (2017) and Janssen et al. (2018), we contribute design principles to the design theory of blockchain-based IdM, in particular, SSI. We hope these design principles will help in the development of more effective blockchain-based SSI applications.

5.6 Essay 6: You Can't Manage What You Can't Define: The Success of Blockchain Projects Beyond the Iron Triangle

In Essay 6, we identified success criteria for evaluating blockchain projects and presented these criteria in a framework. To this end, we conducted 12 interviews with project managers, IT consultants, and chief technology officers (CTOs) responsible for 12 blockchain projects in Germany and Switzerland. Building on the interviews, we then performed a multi-stage coding process to extract relevant success criteria and dimensions from our data. The results were then incorporated into the established framework for project success criteria by Shenhar and Dvir (2007) and, thus, adapted or extended specifically for blockchain. In total, we were able to identify six success dimensions and 29 success criteria. Building on the work of Shenhar and Dvir (2007), we expanded the model by one more dimension and identified several new criteria that were not mentioned in the original version. In doing so, we revealed which success criteria can be used for the holistic evaluation of blockchain projects. To provide additional insight into the relative importance of the success dimensions, we again contacted all interview partners and asked them to rate the success dimensions in order of importance. The interview partners rated success criteria from the dimensions *Impact on customer* and *Impact on environment* as particularly important. Interestingly, and in contrast to traditional project management literature (Wit, 1988), the *efficiency* dimension was accorded relatively low importance. We also noted that the relative importance of the *Business* and *direct success* dimensions increased the closer a project was aligned to the operative system. Thus, the essay also demonstrates how success criteria differ in their relative importance.

The contribution of this essay is multifold. First, we identified the new success dimension *Impact on environment* and extended the original model by Shenhar et al. (2001). The consolidated success criteria emphasize companies' need to think beyond established success criteria to carry out blockchain projects. Second, within the dimensions proposed by Shenhar and Dvir (2007), we identify several additional success criteria which we suggest are specific to blockchain projects. Thus, we show which adaptions need to be made to the understanding of legacy success dimensions with regard to blockchain projects. Third, we evaluate the identified success dimensions in terms of their relative importance and discuss the finding with reference to previous project management literature. In doing so, we reveal discrepancies between blockchain projects and traditional software implementation projects. In particular, we observe a generally lower rating for the dimension *Efficiency*. This contrasts with the literature on IT projects wherein adherence to budget and time is typically rated as a very important criterion (Joosten et al., 2011; Karlsen et al., 2005; Lech, 2013; Thomas & Fernández, 2008).

5.7 Essay 7: Governing Digital Identity Ecosystems: Towards an Information Ecology Theory of Digital Innovation Ecosystems

In Essay 7, we present an embedded single-case study of the *showcase program secure digital identities*, a collection of projects aiming to advance the development of digital identities in Germany. First, we applied the concept of understanding ecosystems as a holarchy (Wang, 2021) to the showcase program. In this way, we structure the digital identity ecosystem at hand and identify various different products, services, and industry ecosystems currently being developed within and by the showcase projects. In particular, we found a strong blurring of the roles of service and product providers, platform operators, and ecosystem customers. Although most organizations joined the showcase projects because they wanted to consume identities themselves, it turns out that they are often also very actively engaged in the development of the ecosystem. Therefore, many of these organizations simultaneously develop and operate the identity network (i.e., the platform), provide identity services, and consume identity credentials from other providers. Second, we analyzed the nature and intensity of interactions within and between ecosystems. Overall, the goal of interoperability of identity solutions is reflected in the collaboration between stakeholders, which in turn influences the shape of the observed interactions. In particular, the innovation task of *integration* is particularly pronounced in the showcase projects. For example, knowledge and expertise are shared intensively. As such, ecosystem actors measure the value of their solutions by their usefulness to the ecosystems. The actors eventually prioritize the added value for the ecosystem over the added value for themselves as individual actors. We find this consistent with the concept of ecosystem welfare, which describes the balance of "harmony, stability, and carrying capacity within an ecosystem" (Boley & Chang, 2007, p. 398).

This essay aims to contribute to our understanding of digital identity ecosystems in particular and to further the ecology theory of digital innovation ecosystems initially proposed by Wang (2021). First, we provide one of the first in-depth empirical studies to examine how digital identity ecosystems are structured and what interactions exist within and between respective ecosystems. Second, by applying the ecology theory of digital innovation ecosystems, we are able to evaluate and validate this only recently proposed theory extensively. Third, we found a new part-whole interaction in our empirical data, i.e., *compiling*. Compiling has been proposed in the literature in the past (Negoita et al., 2018) but lacked empirical evidence (Wang, 2021), which we now provide with our study.

6 Discussion and Conclusion

I will now end the introduction to my dissertation with a discussion and a final conclusion. For this purpose, I will briefly summarize the introduction of this dissertation (Section 6.1) and then present an overview of the contributions to theory and practice (Section 6.2). I will subsequently reflect on the overarching limitation of this work (Section 6.3) and suggest compelling avenues for future research (Section 6.4).

6.1 Summary

Motivated by the vast unrealized potential of blockchain technology, this dissertation aims to guide organizations in designing and managing decentralized IS.

I structured my dissertation around three research goals: Identifying the technological boundaries of blockchain technology (RG1), guiding organizations in designing blockchain-based IS (RG2), and guiding organizations in managing blockchain-based IS (RG3). The essays use a wide range of methods, including SLR, DSR, and qualitative empirical research. Strictly adhering to their methodologies, the essays provide information on the technical characteristics of blockchains, the design of blockchain-based IS, and how companies should manage these systems. Intending to delineate the technological boundaries of blockchain (RG1), Essay 1 clarifies the technical scalability of blockchain and which factors play an important role in this regard. Essay 2 builds on the insight from Essay 1 that performance and security are two opposing goals. Therefore, Essay 2 analyzes attack vectors on blockchain systems and presents opportunities for future research. Building on this technical understanding, Essays 3-5 address how blockchain can be used to design effective IS (RG3). To this end, the essays each examine one of the application areas of finance, supply chain management, and identity management, present a concrete solution design, and discuss abstract design principles. Finally, Essay 6 and Essay 7 show how companies manage blockchain. Essay 6 takes a project management perspective and shows which criteria play a role in evaluating the success of blockchain projects. Essay 7, on the other hand, takes a broader view and describes how organizations innovate and interact within ecosystems.

6.2 Contributions to Theory and Implications for Practice

The essays' results contribute to both theory and practice by answering questions that researchers have not answered yet and that are relevant to both academic discourse and industry.

Addressing RG1, Essay 1 and Essay 2 contribute to the technical understanding of blockchain. Essay 1 contributes to the academic discourse on the performance potentials – and the factors influencing the performance – of blockchain systems (Fan et al., 2020). Accordingly, I address the common question of the extent to which blockchain systems have the technical capabilities – in particular, the scalability – to support various applications (Xie et al., 2019). Similarly, Essay 2 strengthens our technical understanding of the blockchain by highlighting relevant attack vectors. Future researchers can use this knowledge to build secure blockchain-based IS or pursue the suggested research avenues.

Addressing RG2, Essay 3, Essay4, and Essay 5 contribute to the academic discourse on how to design effective blockchain-based artifacts (Kristoffer Nærland et al., 2017). In addition to detailed insights into the concrete design of the artifacts, all three essays provide broadly applicable design knowledge in the form of design principles (Gregor & Hevner, 2013). This answers calls from Beck et al. (2017) and Kristoffer Nærland et al. (2017) for research extending the design knowledge of blockchain. In particular, Essay 3 presents a design for a blockchain-based crowdfunding platform. Existing research in this area, such as Schweizer et al. (2017), is extended with insights into the factors relevant to bringing such a solution into compliance with regulatory requirements. Essay 4 contributes to our understanding of how blockchain can serve as an infrastructure for sharing information within a supply chain. This essay discusses the use of private data collection, a largely unexplored technique, to balance information sharing and privacy in supply chain management (Ma et al., 2019). Essay 5 takes up the novel concept of SSI (Preukschat & Reed, 2021). The solution contributes to a better understanding of how SSI can be used for the development of cross-organizational IdMs and, thus, allow for digitalization in the e-government sector.

Addressing RG3, Essay 6, and Essay 7 contribute to the managerial discourse on blockchain-based IS and the resulting ecosystems. Essay 6 contributes to both project management research (Shenhar & Dvir, 2007) and blockchain research (Zavolokina et al., 2020) by bringing together these two areas, which have, until now, been discussed separately. Specifically, the essay presents success criteria for evaluating the success of blockchain projects in the form of a framework. This builds on the established project management framework by Shenhar et al. (2001), to which it introduces a blockchain-specific perspective. Essay 7 validates and expands the ecology theory originally proposed by Wang (2021). Thus, it builds upon the ecosystem research strand and provides detailed insights into digital identity ecosystems, a novel form of digital ecosystems.

Consequently, my dissertation offers new theoretical insights into the technical properties of blockchain-based systems, the ways in which these systems can be designed, and the ways that companies manage related projects and ecosystems. The essays, thus, span the entire field of blockchain IS research, covering the technical and social subsystems as well as their interplay.

Finally, I take up Goldkuhl's (2004) suggestion that IS research should come with practical implications. Accordingly, the aim is that the essays herein are relevant to both research and practice. Essay 1 provides concrete numbers defining scalability and provides suggestions for optimizing blockchain systems. Essay 2 provides practitioners with a framework to assess the security of their blockchain applications. Essay 3, Essay 4, and Essay 5 demonstrate concrete solution designs that practitioners can use to develop their blockchain-based applications. Essay 6 presents specific evaluation criteria that can be used by organizations to improve the monitoring of their blockchain projects. Finally, Essay 7 describes which interactions in digital identity ecosystems are relevant for innovation and value realization.

6.3 Limitations

Exploring decentralized blockchain-based IS is a challenging endeavor. This is not only due to the complexity of blockchain (Lashkari & Musilek, 2021), the applications built on top of it (H. Zhu & Zhou, 2016), and the interactions between technology and organizations or individuals (Brennecke, Guggenberger, Sachs, & Schellinger, 2022; Zavolokina et al., 2020). It is also due to the constant evolution of blockchain technology and its understanding, which makes research in this area particularly challenging (Bhutta et al., 2021). Accordingly, the results of the essays must be viewed in light of limitations. In the next step, I will address the overarching limitations of this dissertation. The specific limitations of the individual essays will be discussed therein.

First, my results reflect the current state of technology. Blockchain is in constant flux, and the technology is expected to continue to evolve in the future (Bhutta et al., 2021). This means that certain technical assumptions will be of limited relevance or applicability in the future. For example, the performance evaluation of Hyperledger Fabric is based on the current version 2.0. However, it has already been shown that newer versions have different hardware requirements and performance characteristics (Dreyer et al., 2020). Consequently, what is not technically possible today may be feasible in the future. Hence, beyond concrete figures, I have always aimed to generate abstract, context- or time-independent knowledge. The result is that the essays present generalizable knowledge in the form of frameworks or design principles.

Second, the designed artifacts were implemented exclusively as prototypes and only evaluated as such. I have aimed to find valid insights for possible real-world applications by involving practitioners, yet, it cannot be ruled out that adaptations to the presented designs will be necessary for real-world applications. For example, one interviewee in Essay 5 suggested that the proposed SSI system in its current form is not sufficiently user-friendly. Whether end users will accept a real-world application based on the proposed design remains to be seen.

Third, empirical observations focus on prototype or pilot projects, as well as observations of large-scale research projects. Where possible, I have tried to cover a wide range of different projects. For example, in addition to prototype implementation projects, Essay 6 examines three projects that aim to deploy operational systems. Nevertheless, the empirical data set is limited and the possibility of bias remains. For example, projects aiming at a productive implementation may only be carried out by early adopters (Chesbrough & Crowther, 2006), fundamentally different from companies that will only carry out such projects in a few years. Thus, the results must also be considered in the context from which the data originate.

6.4 Future Research

This dissertation follows many calls for the study of blockchain and responds to a number of unanswered questions. Nevertheless, both the results and the limitations of my studies provide the impetus for future research.

The past has shown that blockchain systems are continuously evolving, and even some completely new architectures have been introduced (Bhutta et al., 2021). The set of characteristics presented in Essay 1 and the developed benchmarking tool DLPS provide a strong foundation for further research into the performance of future blockchains. For example, it would be exciting to explore how other blockchain architectures scale and how these systems differ from one another. In particular, the introduction of new designs, such as side chains, offers exciting possibilities for the use of the DLPS framework. Eventually, the goal could be to create even more precise statements about the future fit between blockchain and applications. Such insights could also help build more resilient and better-performing systems. However, this requires reliable and generalizable data, which DSLP promises to deliver.

New architectures not only require an assessment of their performance. As it is expected that future blockchain systems will have to secure increasingly more value (whether financial or as infrastructure for digital identities), it is imperative that they are also assessed in terms of their cybersecurity. The attack vectors identified in Essay 2 are mainly based on architectures used in public-permissionless systems, such as Ethereum. Looking at a Hyperledger Indy and Aries technology stack used for many SSI systems, the architecture is very different from Ethereum. Investigating whether this also results in new attack scenarios and, thus, new attack vectors is another promising research endeavor.

The introduction of newer technologies and architectures into blockchain systems not only represents an interesting object of research in itself but can also be used as an important tool for the further development of designs such as those presented in Essays 3 - 5. For example, Essay 3 shows how private data collection can balance information disclosure and privacy. However, the use of private data collections implies a high transaction overhead and greatly reduces scalability, making the design in its current form suitable only for medium-sized supply chains. Future designs could rely on modern cryptographic measures. For example, zero-knowledge proofs promise to increase both the performance and the security of future blockchain-based applications (Sun et al., 2021).

The extent to which certain technical solutions will prevail and lead to success in the long term is difficult to say, even from today's perspective. Essays 6 and 7 provide insights into real-world systems through their empirical work. However, only a few of these systems are operational, and it is hard to predict which will contribute to companies' success in a few years' time. The findings only represent the current best practices of companies in dealing with blockchain and blockchain projects. Future research should therefore continue to investigate real-world activities around blockchain. In the near future, it will slowly become clear which endeavors succeed in the market and why some endeavors fail.

Finally, while people, in the sense of individuals, and their roles in blockchain-based IS were considered to some extent, the focus of my dissertation, and thus my essays, was clearly on organizations and their interactions. Nonetheless, a more detailed analysis of people in blockchain-based IS would be a great addition to my dissertation and an exciting opportunity for future research. For example, there is already some research on technology acceptance and blockchain. In light of recent developments, e.g., SSI and DeFi, this would be a good research strand to further investigate individuals' acceptance of blockchain-based applications (Guggenberger, Neubauer, et al., 2023). Likewise, the interaction between people and structure could also emerge as an exciting area of research. For example, in Essay 7, we already found some first evidence that a few individual leaders are often highly responsible for the positive development of decentralized ecosystems.

We can see that the design and management of blockchain-based IS present us with many new challenges. Nevertheless, this is an exciting and dynamic field that promises great potential for organizations, individuals, and society in general. I hope that my dissertation will make an important contribution to further developing this potential and making it more accessible.

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Appendices

Appendix A: Declarations of Co-Authorship and Individual Contributions

In the following, I describe the co-authors' contributions to the essays.

Essay 1: An In-Depth Investigation of the Performance Characteristics of Hyperledger Fabric

This research paper was co-authored by Tobias Guggenberger, Johannes Sedlmeir, Gilbert Fridgen, and André Luckow. The co-authors contributed as follows:

Tobias Guggenberger (co-author)
Tobias Guggenberger co-developed the research project. He contributed by developing the paper's technical foundations and the Hyperledger Fabric chaincode. Further, he engaged in textual elaboration, especially in the introduction, technical background, related work, discussion, and conclusion sections. He also participated in research discussions and provided feedback on the paper's content and structure. Thus, Tobias Guggenberger's co-authorship is reflected in the entire research project.

Johannes Sedlmeir (co-author)
Johannes Sedlmeir co-developed the research project. He contributed by developing the paper's technical foundations, implementing the DLPS artifacts, and performing the experiments. Further, he engaged in textual elaboration, especially in the methodology, results, discussion, and conclusion sections. He also participated in research discussions and provided feedback on the paper's content and structure. Thus, Johannes Sedlmeir's co-authorship is reflected in the entire research project.

Gilbert Fridgen (subordinate co-author)
Gilbert Fridgen provided mentorship, participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Gilbert Fridgen's co-authorship is reflected in the entire research project.

André Luckow (subordinate co-author)
André Luckow provided mentorship, participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, André Luckow's co-authorship is reflected in the entire research project.

Essay 2: Attacking the Trust Machine: Developing an Information Systems Research Agenda for Blockchain Cybersecurity

This research paper was co-authored by Vincent Schlatt, Tobias Guggenberger, Jonathan Schmid, and Nils Urbach. The co-authors contributed as follows:

Vincent Schlatt (co-author)

After a prior version of the manuscript with reduced content was published jointly by the authors in 2021, Vincent Schlatt took over the lead role in developing the research project further. He initiated and developed the project into a journal publication. Vincent Schlatt was strongly involved in analyzing and structuring the results of the literature review and developed the research framework and agenda. Furthermore, he engaged in textual elaboration throughout the essay and performed the revisions. Thus, Vincent Schlatt's co-authorship is reflected in the entire essay

Tobias Guggenberger (subordinate co-author)

Tobias Guggenberger co-developed the research project, developed the paper's theoretical foundation, participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. He also supervised the development of the research framework. Thus, Tobias Guggenberger's co-authorship is reflected in the entire research project.

Jonathan Schmid (subordinate co-author)

Jonathan Schmid co-developed the research project, performed the data collection, participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Jonathan Schmid's co-authorship is reflected in the entire research project.

Nils Urbach (subordinate co-author)

Nils Urbach supervised the research project and provided mentorship. Further, he participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Nils Urbach's co-authorship is reflected in the entire research project.

Essay 3: Kickstarting Blockchain: Designing Blockchain-Based Tokens for Equity Crowdfunding

This research paper was co-authored by Tobias Guggenberger, Benjamin Schellinger, Victor von Wachter, and Nils Urbach. The co-authors contributed as follows:

Tobias Guggenberger (co-author)

Tobias Guggenberger co-developed the research project. He contributed by developing the paper's theoretical foundation, conducting and analyzing the expert interviews, developing the theoretical contribution, and engaging in textual elaboration. Additionally, he participated in research discussions and provided feedback on the paper's content and structure. Thus, Tobias Guggenberger's co-authorship is reflected in the entire research project.

Benjamin Schellinger (co-author)

Benjamin Schellinger co-developed the research project. He contributed by developing the paper's theoretical foundation, conducting and analyzing the expert interviews, developing the theoretical contribution, and engaging in textual elaboration. Additionally, he participated in research discussions and provided feedback on the paper's content and structure. Thus, Benjamin Schellinger's co-authorship is reflected in the entire research project.

Victor von Wachter (co-author)

Victor von Wachter initiated and co-developed the research project. He contributed by developing the paper's theoretical foundation, designing, developing, and testing of the IT-artifact, conducting and analyzing the expert interviews, developing the theoretical contribution, and engaging in textual elaboration. Additionally, he participated in research discussions and provided feedback on the paper's content and structure. Thus, Victor von Wachter's co-authorship is reflected in the entire research project.

Nils Urbach (subordinate co-author)

Nils Urbach supervised the research project and provided mentorship. Further, he participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Nils Urbach's co-authorship is reflected in the entire research project.

Essay 4: Improving Inter-Organizational Information Sharing for Vendor Managed Inventory: Towards a Decentralized Information Hub Using Blockchain Technology

This research paper was co-authored by Tobias Guggenberger, André Schweizer, and Nils Urbach. The co-authors contributed as follows:

Tobias Guggenberger (co-author)

Tobias Guggenberger initiated and co-developed the research project. He contributed by developing the paper's theoretical foundation, designing, developing, and testing of the IT-artifact, conducting and analyzing the expert interviews, developing the theoretical contribution, and engaging in textual elaboration. Additionally, he participated in research discussions and provided feedback on the paper's content and structure. Thus, Tobias Guggenberger's co-authorship is reflected in the entire research project.

André Schweizer (co-author)

André Schweizer co-developed the research project. He contributed by developing the theoretical contribution and engaging in textual elaboration. Additionally, he participated in research discussions and provided feedback on the paper's content and structure. Thus, André Schweizer's co-authorship is reflected in the entire research project.

Nils Urbach (co-author)

Nils Urbach supervised the research project and provided mentorship. Further, he participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Nils Urbach's co-authorship is reflected in the entire research project.

Essay 5: Designing a Cross-Organizational Identity Management System: Utilizing SSI for the Certification of Retailer Attributes

This research paper was co-authored by Tobias Guggenberger, Daniela Kühne, Vincent Schlatt, and Nils Urbach. The co-authors contributed as follows:

Tobias Guggenberger (co-author)

Tobias Guggenberger initiated and developed the research project. He contributed by developing the paper's theoretical foundation, designing, developing, and testing the IT artifact, conducting and analyzing the expert interviews, developing the theoretical contribution, and engaging in most of the textual elaboration. Additionally, he participated in research discussions and provided feedback on the paper's content and structure. Thus, Tobias Guggenberger's co-authorship is reflected in the entire research project.

Daniela Kühne (subordinate co-author)

Daniela Kühne supervised the research project and provided mentorship. Further, she participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Daniela Kühne's co-authorship is reflected in the entire research project.

Vincent Schlatt (subordinate co-author)

Vincent Schlatt co-developed the research project by conducting expert interviews, participating in research discussions, providing feedback on the paper's content and structure, and engaging in textual elaboration. He also supported the development of the artifact design. Thus, Vincent Schlatt's co-authorship is reflected in the entire research project.

Nils Urbach (subordinate co-author)

Nils Urbach supervised the research project and provided mentorship. Further, he participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Nils Urbach's co-authorship is reflected in the entire research project.

Essay 6: You Can't Manage What You Can't Define: The Success of Blockchain Projects Beyond the Iron Triangle

This research paper was co-authored by Tobias Guggenberger, Jens-Christian Stoetzer, Lukas Theisinger, Julia Amend, and Nils Urbach. The co-authors contributed as follows:

Tobias Guggenberger (co-author)

Tobias Guggenberger initiated and co-developed the research project. He contributed by developing the paper's research design and the theoretical foundations. Further, he engaged in textual elaboration, especially in the introduction, theoretical background, methodology, discussion, and conclusion sections. He also participated in research discussions and provided feedback on the paper's content and structure. Thus, Tobias Guggenberger's co-authorship is reflected in the entire research project.

Jens-Christian Stoetzer (co-author)

Jens-Christian Stoetzer co-developed the research project. He contributed by conducting and analyzing the expert interviews. Further, he engaged in textual elaboration, particularly in the introduction, theoretical background, methodology, results, discussion, and conclusion sections. He also participated in research discussions and provided feedback on the paper's content and structure. Thus, Jens-Christian Stoetzer's co-authorship is reflected in the entire research project.

Lukas Theisinger (co-author)

Lukas Theisinger initiated and co-developed the research project. He contributed by conducting and analyzing the expert interviews. Further, he engaged in textual elaboration, particularly in the introduction, theoretical background, methodology, results, discussion, and conclusion sections. He also participated in research discussions and provided feedback on the paper's content and structure. Thus, Lukas Theisinger's co-authorship is reflected in the entire research project.

Julia Amend (subordinate co-author)

Julia Amend supervised the research project and provided mentorship. Further, she participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Julia Amend's co-authorship is reflected in the entire research project.

Nils Urbach (subordinate co-author)

Nils Urbach supervised the research project and provided mentorship. Further, he participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Nils Urbach's co-authorship is reflected in the entire research project.

Essay 7: Governing Digital Identity Ecosystems: Towards an Information Ecology Theory of Digital Innovation Ecosystems

This research paper was co-authored by Martin Brennecke, Tobias Guggenberger, Nils Urbach, and Fabiane Völter:

Martin Brennecke (co-author)

Martin Brennecke initiated and co-developed the research project. He contributed by conducting and analyzing the expert interviews and developing the theoretical foundations. Further, he engaged in textual elaboration, particularly in the introduction, theoretical background, methodology, results, discussion, and conclusion sections. He also participated in research discussions and provided feedback on the paper's content and structure. Thus, Martin Brennecke's co-authorship is reflected in the entire research project.

Tobias Guggenberger (co-author)

Tobias Guggenberger initiated and co-developed the research project. He contributed by developing the paper's research design and the theoretical foundations. Further, he engaged in textual elaboration, especially in the introduction, theoretical background, methodology, results, discussion, and conclusion sections. He also participated in research discussions and provided feedback on the paper's content and structure. Thus, Tobias Guggenberger's co-authorship is reflected in the entire research project.

Nils Urbach (co-author)

Nils Urbach supervised the research project and provided mentorship. Further, he participated in research discussions, provided feedback on the paper's content and structure, and engaged in textual elaboration. Thus, Nils Urbach's co-authorship is reflected in the entire research project.

Fabiane Völter (co-author)

Fabiane Völter co-developed the research project. She contributed by developing the paper's research design and the theoretical foundations, as well as by recruiting experts. Further, she engaged in textual elaboration, especially in the introduction, theoretical background, methodology, results, discussion, and conclusion sections. She also participated in research discussions and provided feedback on the paper's content and structure. Thus, Fabiane Völter's co-authorship is reflected in the entire research project.

Appendix B: Other Publications

Table 2: Overview of Other Publications

Reference	**VHB JQ3 ranking**	**Publication state**
Guggenberger, T., Neubauer, L., Stramm, J., Völter, F., & Zwede, T. (2023). Accept Me as I Am or See Me Go: A Qualitative Analysis of User Acceptance of Self-Sovereign Identity Applications. In *Proceedings of the 56th Hawaii International Conference on System Sciences (HICSS).* https://eref.uni-bayreuth.de/71942/	C	Published
Brennecke, M., Guggenberger, T., Sachs, A., & Schellinger, B. (2022). *The Human Factor in Blockchain Ecosystems: A Sociotechnical Framework. 17th International Conference on Wirtschaftsinformatik (WI).* https://eref.uni-bayreuth.de/68928/	C	Published
Brennecke, M., Guggenberger, T., Schellinger, B., & Urbach, N. (2022). The De-Central Bank in Decentralized Finance: A Case Study of MakerDAO. In *Proceedings of the 55th Hawaii International Conference on System Sciences (HICSS).* https://eref.uni-bayreuth.de/67152/	C	Published
Duda, S., Geyer, D., Guggenberger, T., Principato, M., & Protschky, D. (2022). A Systematic Literature Review on How to Improve the Privacy of Artificial Intelligence Using Blockchain. In *Proceedings of the Pacific Asia Conference on Information Systems (PACIS).* https://eref.uni-bayreuth.de/70371/	C	Published
Feulner, S., Guggenberger, T., Stoetzer, J.-C., & Urbach, N. (2022). Shedding Light on the Blockchain Disintermediation Mystery: A Review and Future Research Agenda. In *Proceedings of the 30th European Conference on Information Systems (ECIS).* https://eref.uni-bayreuth.de/69277/	B	Published
Hoffmann, M., Völter, F., & Guggenberger, T. (2022). *Self-Sovereign Identity: Herzlich willkommen im Zeitalter der Datensouveränität. Kompetenzzentrum Öffentliche IT (ÖFIT) Blog.* https://eref.uni-bayreuth.de/68551/	n/a	Published
Guggenberger, T., Lockl, J., Röglinger, M., Schlatt, V., Sedlmeir, J., Stoetzer, J.-C., Urbach, N., & Völter, F. (2021). Emerging Digital Technologies to Combat Future Crises : Learnings From COVID-19 to be Prepared for the Future. *International Journal of Innovation and Technology Management*, *18*(4). https://eref.uni-bayreuth.de/65810/	C	Published
Guggenberger, T., Michael Kuhn, & Benjamin Schellinger. (2021). Insured? Good!: Designing a Blockchain-based Credit Default Insurance System for DeFi Lending Protocols. In *Proceedings of the 4th Middle East & North Africa Conference for Information System (MENACIS).* https://eref.uni-bayreuth.de/68522/	n/a	Published

Reference	**VHB JQ3 ranking**	**Publication state**
Jöhnk, J., Albrecht, T., Arnold, L., Guggenberger, T., Lämmermann, L., Schweizer, A., & Urbach, N. (2021). *The Rise of the Machines: Conceptualizing the Machine Economy*. *Proceedings of the 25th Pacific Asia Conference on Information Systems (PACIS)*. https://eref.uni-bayreuth.de/66555/	C	Published
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An In-Depth Investigation of the Performance Characteristics of Hyperledger Fabric[2]

Authors

Tobias Guggenberger, Johannes Sedlmeir, Gilbert Fridgen, André Luckow.

Abstract

Private permissioned blockchains are deployed in ever greater numbers to facilitate cross-organizational processes in various industries, particularly in supply chain management. One popular example of this trend is Hyperledger Fabric. Compared to public permissionless blockchains, it promises improved performance and provides certain features that address key requirements of enterprises. However, also permissioned blockchains are still not as scalable as centralized systems, and due to the scarcity of theoretical results and empirical data, their real-world performance cannot be predicted with the necessary precision. We intend to address this issue by conducting an in-depth performance analysis of Hyperledger Fabric. The paper presents a detailed compilation of various performance characteristics using an enhanced version of the Distributed Ledger Performance Scan (DLPS). Researchers and practitioners alike can use the various performance properties identified and discussed as guidelines to better configure and implement their Hyperledger Fabric network. Likewise, they are encouraged to use the DLPS framework to conduct their measurements.

Keywords: Benchmarking, Blockchain, Distributed ledger, Scalability, Supply chain, Throughput.

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Attacking the Trust Machine: Developing an Information Systems Research Agenda for Blockchain Cybersecurity[3]

Authors

Vincent Schlatt, Tobias Guggenberger, Jonathan Schmid, Nils Urbach.

Abstract

Blockchain-based systems have become increasingly attractive targets for cybercrime due to the rising amount of value transacted in respective systems. However, a comprehensive overview of existing attack vectors and a directive discussion of resulting research opportunities are missing. Employing a structured literature review, we extract and analyze 87 relevant attacks on blockchain-based systems and assign them to common attack vectors. We subsequently derive a research framework and agenda for information systems research on the cybersecurity of blockchain-based systems. We structure our framework along the users, developers, and attackers of both blockchain applications and blockchain infrastructure, highlighting the reciprocal relationships between these entities. Our results show that especially socio-technical aspects of blockchain cybersecurity are underrepresented in research and require further attention.

Keywords: Blockchain, IT Security, Structured Literature Review, Research Agenda.

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Kickstarting Blockchain: Designing Blockchain-Based Tokens for Equity Crowdfunding[4]

Authors

Tobias Guggenberger, Benjamin Schellinger, Victor von Wachter, Nils Urbach.

Abstract

Blockchain-based tokens seek to overcome the friction and opaqueness of the legacy financial infrastructure in the company funding process, particularly in the early-stage and equity crowdfunding domain. While Initial Coin Offerings and Security Token Offerings proposed a solution for crowdfunding, early-stage companies still face challenges in using blockchain as an alternative equity funding infrastructure. In this context, the idea of blockchain-based equity tokens remains hypothetical. In addition, the literature lacks design theory for the development and implementation of blockchain-based equity tokens. This research bridges this gap by designing, developing, and evaluating an equity token prototype for crowdfunding, following the design science research (DSR) approach. We propose a refined crowdfunding model and derive seven design principles that contribute to the design theory of equity tokens. The research results show that blockchain-based equity tokens improve efficiency, transparency, and interoperability while meeting regulatory requirements and facilitating secondary market trading.

Keywords: Blockchain, Design Science, Equity Crowdfunding, Initial Coin Offering, Security Token Offering, Tokens.

[4] This essay has been published in:
Guggenberger, T., Schellinger, B., Wachter, V. von, & Urbach, N. (2023). Kickstarting blockchain: Designing blockchain-based tokens for equity crowdfunding. Electronic Commerce Research. https://doi.org/10.1007/s10660-022-09634-9

Improving Inter-Organizational Information Sharing for Vendor Managed Inventory: Towards a Decentralized Information Hub Using Blockchain Technology[5]

Authors

Tobias Guggenberger, André Schweizer, Nils Urbach.

Abstract

Supply chain literature has long recognized the benefits of information sharing. Researchers and practitioners see high potential for improving processes, enabling new replenishment policies, and enhancing supply chain integration. Even though information technology represents a vital role as a driver and a success factor for implementing information sharing, established technologies still do not reflect the highly decentralized and fragmented characteristics of complex and often global supply chains. Early research shows that blockchain might be an enabler for the supply chain management. However, little is known about how blockchain might improve information sharing for complex, multi-tier supply chains. Therefore, this paper aims at analyzing how and to what extent blockchain can facilitate information sharing for vendor managed inventory by designing a software prototype based on Hyperledger Fabric using the design science research approach. This research took place in close cooperation with a leading German healthcare technology manufacturer, which allowed us to ground our study both on literature and practical insights. With our research results, we contribute to the supply chain knowledge base by introducing the decentralized information hub model, describing how companies utilize decentralized technologies, such as blockchain, to facilitate information sharing.

Keywords: Blockchain, design methodology, DLT, inventory management, software design, supply chain management.

[5] This essay has been published in:
Guggenberger, T., Schweizer, A., & Urbach, N. (2020). Improving Inter-Organizational Information Sharing for Vendor Managed Inventory: Towards a Decentralized Information Hub Using Blockchain Technology. IEEE Transactions on Engineering Management, 67 (2020). https://eref.uni-bayreuth.de/56055/

Designing a Cross-Organizational Identity Management System: Utilizing SSI for the Certification of Retailer Attributes[6]

Authors

Tobias Guggenberger, Daniela Kühne, Vincent Schlatt, Nils Urbach

Abstract

The introduction of blockchain offers new opportunities to rethink enterprise identity management. Recently, a new concept has emerged in the blockchain community called self-sovereign identity. Self-sovereign identity combines several existing decentralized identity management approaches, promising new ways to promote more convenient, connected and secure identity services for the private and public sector. Nevertheless, research in this area is still in its infancy. Most of the very few articles focus either on the opportunities self-sovereign identity might offer or on very specific technical features. Studies on real-world applications of organizations using modern self-sovereign identity implementations and design theory are very rare. To fill this gap, we follow the design science research approach to design, implement and evaluate a self-sovereign identity system to present tax attributes of online retailers. We present four design principles and conclude that the use of self-sovereign identity and blockchain offers opportunities to improve verification processes.

Keywords: Blockchain; Identity Management; Self-Sovereign Identity; Public Sector; Design Science.

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You Can't Manage What You Can't Define: The Success of Blockchain Projects Beyond the Iron Triangle[7]

Authors

Tobias Guggenberger, Jens-Christian Stoetzer, Lukas Theisinger, Julia Amend, Nils Urbach

Abstract

Companies across industries aim to disseminate blockchain through respective projects that evaluate, design, or implement use cases. However, due to its novelty and complexity, blockchain poses novel challenges in carrying out such projects. Companies use success criteria to constantly evaluate projects. Even though literature provides frameworks for the general evaluation of projects, no research yet investigated if success criteria fundamentally differ for blockchain projects due to the characteristics of the technology. Therefore, we assess success dimensions and criteria, deduced and evaluated from an in-depth interview study with blockchain experts from 12 different projects. We contribute to the theory on blockchain project management by introducing a new success dimension and specific success criteria for blockchain projects. Our findings help to elaborate the value of blockchain in companies and novel possibilities to evaluate respective projects. We provide additional insights by assessing their relative importance and discussing implications for theory and practice.

Keywords: Blockchain, Project Management, Project Success, Success Criteria.

[7] This essay has been published in:
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Governing Digital Identity Ecosystems: Towards an Information Ecology Theory of Digital Innovation Ecosystems[8]

Authors

Martin Brennecke, Tobias Guggenberger, Nils Urbach, Fabiane Völter.

Extended Abstract

As a result of the ever-increasing interconnection brought about by the internet, we observe the prevalence of modular designs. This modularity allows different actors to provide single components of a product (Clark, 2014). Combining these components allows almost unlimited possibilities to create new composite products and bring innovations to the market (West & Wood, 2014). Over the past few years, this has increasingly led to the development of *digital business ecosystems* in which organizations maintain independent relationships with each other (Wang, 2021).

Recently, we have observed the development of new ecosystems that aim to create digital identity solutions. These digital identity ecosystems are characterized by multiple stakeholders, who, on the one hand, provide technical artifacts, such as network infrastructures, wallets, and connection modules, which form a platform for the ecosystem (Soltani et al., 2021). On the other hand, we find services such as providing digital trust and issuing certificates that evolve around these artifacts, forming a digital business ecosystem for identities (O'Halloran et al., 2021). While these digital identity ecosystems offer transformative potential for the digital identity arena, they are relatively new, with research still in its early stages.

To this end, we propose that Wang's (2021) information ecology theory of digital innovation ecosystems provides a useful theoretical framework for capturing the underlying interactions and value-creation functions of digital identity ecosystems. This theory is based on research in digital innovation and ecosystems. It recognizes that previous literature in IS and organizational research tends to favor analyzing parts of ecosystems rather than looking at them in their entirety. In particular, this novel theory promises to provide a whole-of-entity view of digital identity ecosystems, thus, offering

[8] At the time of publication of this thesis, this essay is in preparation for submission to a scientific journal. Thus, I provide an extended abstract that covers the essay's content.

new insights into the interaction of ecosystems. On this basis, we ask:

RQ1: H*ow can a digital identity ecosystem be structured, understanding them as a holarchy?*

RQ2: How do organizations in digital identity ecosystems interact with each other within and across ecosystem levels/their holarchy? (Essay 7)

To answer these questions, we present an embedded single-case study of the showcase program *Secure Digital Identities*, a collection of projects aiming to advance the development of digital identities in Germany. First, we applied the concept of understanding ecosystems as a holarchy (Wang, 2021) to the showcase program. In this way, we structure the digital identity ecosystem at hand and present various products, services, and industry ecosystems currently being developed within and by the showcase projects. Second, we analyzed the nature and intensity of interactions within and between ecosystems. Overall, the goal of interoperability of identity solutions is reflected in the collaboration between stakeholders, which in turn influences the shape of the observed interactions. In particular, the innovation task of *integration* is particularly pronounced in the showcase projects. For example, knowledge and expertise are shared intensively. As such, ecosystem actors measure the value of their solutions by their usefulness to the ecosystems.

This essay aims to contribute to our understanding of digital identity ecosystems and furthers the ecology theory of digital innovation ecosystems initially proposed by Wang (2021). Notably, we examine how digital identity ecosystems are structured and what interactions exist within and between respective ecosystems. Furthermore, by applying the ecology theory of digital innovation ecosystems, we extensively evaluate and validate this only recently proposed theory. Finally, we present a new part-whole interaction in our empirical data, i.e., *compiling*. Compiling has been proposed in the literature in the past (Negoita et al., 2018) but lacked empirical evidence (Wang, 2021), which we provide with our study.

Keywords: Digital identity ecosystems, case study research, information ecology, digital innovation ecosystems.

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