PRAGUE UNIVERSITY OF ECONOMICS AND BUSINESS

Acta Informatica Pragensia
2022, Volume 11, Issue 3, pp. 396–422
Special Issue: Sustainable Solutions for Internet of Things Using Artificial Intelligence and Blockchain in Future Networks
https://doi.org/10.18267/j.aip.200

Review Open Access

Blockchain Design and Implementation Techniques, Considerations and Challenges in the Banking Sector: A Systematic Literature Review

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Abstract

Blockchain is transforming the banking sector and offering opportunities for significant cost reduction and efficient banking services. However, implementing blockchain is a challenge due to lack of adequate knowledge and skills on how to implement the technology. As a result, there are very few market-ready blockchain banking products and organisations are unable to realise the promised value. This paper presents an overview of the banking sector's blockchain use cases, design and implementation considerations and techniques. The aim is to offer an evidence-based primer to guide researchers and practitioners. The study relies on the systematic literature review method and reviews a total of 45 papers comprising 26 peer-reviewed scholarly articles and 19 technical reports from the banking industry. Leximancer software is used to support the thematic data analysis. The results show for the banking sector an increase in experimentation efforts geared towards the development of payment systems. The results also indicate key considerations from a technological, organisational and environmental perspective. The study highlights that platform selection, scalability and resilience are some of the critical technical considerations for implementing blockchain banking systems. Organisational considerations include collaboration and governance-related challenges. From an environmental perspective, the study notes several legal and regulatory considerations. This study contributes to the existing literature on blockchain adoption in banking, which is still in the nascent stage. The study also offers a research agenda for further understanding of blockchain implementation in the banking sector. Opportunities for further research are noted in the areas of interoperability, governance, security and privacy.

Keywords

Blockchain; Distributed ledger technology; Financial sector; Banking; FinTech.

Citation: Mafike, S., & Mawela, T. (2022). Blockchain Design and Implementation Techniques, Considerations and Challenges in the Banking Sector: A Systematic Literature Review. *Acta Informatica Pragensia*, 11(3), 396–422. https://doi.org/10.18267/j.aip.200

1 Introduction and Background

Technological innovations have unprecedented consequences on organisations and society. The emergence of the fourth industrial revolution (4IR) has disrupted traditional business models and altered how humans interact with technology (Schwab, 2018). These technologies provide opportunities for “innovation and competitiveness growth” (Bai et al., 2020, p. 1). The impact of the 4IR, and its associated technologies such as blockchain, span various countries and industries, including manufacturing (Daniyan et al., 2021), education (Penprase, 2018) and finance (Yu & Song, 2021). Blockchain is a technology enabling transparent and decentralised transactions famously associated with the cryptocurrency Bitcoin (De Filippi, 2016).

In the financial sector, blockchain is poised to have the most significant transformative effect on organisations (Tapscott & Tapscott, 2017). It is transforming business processes (Reijers et al., 2016) and has sparked “significant organisational changes by introducing new business models and organisational practices” (Beck & Müller-Bloch, 2017, p. 5392). Historically, banks, clearinghouses and brokers were the middlemen enforcing trust between transacting parties. However, through blockchain, transacting parties can now transfer funds directly to each other without employing an intermediary party. Blockchain-driven disintermediation threatens the fundamental role of the financial sector. However, it also brings about very attractive opportunities for the sector (Abbatemarco et al., 2020). It is these opportunities that are driving interest and investment in blockchain from the sector.

Blockchain presents opportunities for significant cost reduction, improved operational efficiency, security (Wu & Duan, 2019) and enhanced protection against illicit data manipulation (Kattwinkel & Rademacher, 2020). Furthermore, it has the potential to fast-track the development of new banking products and services, enhanced profitability and higher customer satisfaction (Mekinjić, 2019). Developing new products broadens product offerings, resulting in enhanced product differentiation, which in turn promotes a robust competitive market (Li et al., 2019). Thus, adopting blockchain in the sector has become a strategic imperative for maintaining a competitive market.

The banking sector is cognisant of the need to leverage blockchain in banking operations and processes and in developing new product offerings. This is evidenced by the increased investments and experimental projects geared towards blockchain, particularly around the area of payment settlements, cross-border payments and most recently on central bank digital coins (CBDC). However, despite this increase, there are very few blockchain-driven banking products on the market (Albrecht et al., 2018). This lack has been attributed to a number of challenges including: the immaturity of the technology, scalability and privacy issues, and the lack of adequate knowledge and skills for implementing blockchain systems. In addition, literature from an empirical academic perspective on blockchain implementation is limited. The existing literature on the topic of blockchain in banking focuses mainly on identifying potential use cases and areas in finance where blockchain can be applied (Guo & Liang, 2016; Osmani et al., 2020; Wang et al., 2020) and on the impact of blockchain on the sector (Casey et al., 2018; Collomb & Sok, 2016). Though these studies offer some interesting insights into the potential of blockchain in banking, they do not offer any practical insights into how the sector can implement blockchain to realise the expected benefits.

Although systematic literature reviews (SLR) have been published on blockchain in banking, the authors contend that the discussion on practical implementation considerations and techniques, along with associated challenges, has not received the necessary attention. The existing reviews predominantly focus on identifying the application, challenges and perceived benefits of blockchain. For instance, Ali et al. (2020) reviewed the state of play of blockchain in finance. Their review focused on blockchain-enabled benefits, challenges and functions. Similarly, other reviews (Dashkevich et al., 2020; Gan et al., 2021; Río & César, 2017) have identified areas and use cases of blockchain application in the central banks. Gan et al. (2021) offered insights into the application of blockchain in banking and highlighted the benefits and challenges of adopting the technology. Río and César (2017) found that several central banks were interested in adopting and implementing blockchain. However, none of the central banks had an operational blockchain-based system, thus pointing to challenges in implementing the technology. However, they do not offer any direction on how to address this challenge. Similarly, Dashkevich et al. (2020) examined blockchain applications in the context of global central banks. Their work identified types of use cases considered for blockchain adaptation. Contrary to the other reviews, their study also examined considerations for determining the suitability of blockchain for specific use cases. However, the study does not highlight any specific approaches or considerations for implementing the use cases.

Though these studies provide some insight into the benefits, challenges and applications of blockchain in the financial sector, and have highlighted implementation challenges, they do not speak to how effective implementation of the technology can be achieved. The studies do not offer any insights regarding implementation practices, techniques or considerations required to foster effective development of the technology in the banking sector. Furthermore, there is a gap in research efforts between industry and academia. The majority of the literature covering the practical implementation of blockchain in the banking sector originates from practitioners and industry. The authors argue that there is a need for a detailed examination of this topic from an empirical perspective to supplement the work done by practitioners and promote a better understanding of the nuances of blockchain implementation in the sector.

This SLR aims to address this gap by assessing the evidence from scholarly and practitioner literature on practical techniques, challenges and opportunities for implementing blockchain technology in the banking sector. The intention is to provide an evidence-based guide for the design and development of blockchain-based banking systems. To achieve this, the review is guided by the following research questions:

RQ1: For which banking operations have banks piloted or implemented a blockchain-based proof of concept?

RQ2: What are the challenges experienced with blockchain implementation in banking operations?

RQ3: What design and implementation considerations are reported in the literature on blockchain-based banking systems?

RQ4: What are the future research directions for blockchain implementation in the banking sector?

1.1 Research contribution

The contribution of this study is threefold.

- Firstly, this systematic literature review (SLR) supplements the existing literature on blockchain adoption by providing an in-depth review of the current literature on blockchain implementation in banking. Thus, it provides a thorough understanding of the nuances of blockchain implementation in the sector.
- Secondly, the SLR expands the existing literature on blockchain in banking by highlighting some key practical technological, organisational and environmental considerations for building blockchain-enabled banking systems. To our knowledge, no study to date has explored the practical considerations for designing and implementing blockchain banking systems.
- Thirdly, research into blockchain technology is still in the nascent stage in the main. This SLR contributes to the advancement of blockchain research by providing a roadmap for future research in the field of blockchain design, implementation and adoption in banking.

The rest of this paper is organised as follows. A brief overview of blockchain is provided in Section 2. Section 3 presents the research methodology for the study. The results are presented in Section 4 and the findings are discussed in Section 5. Finally, section 6 highlights the concluding remarks.

2 Blockchain Overview

Blockchain is the technology known for its application as the underlying technology for Bitcoin. It is a distributed and decentralised ledger consisting of a set of interlinked blocks of data (Hughes et al., 2019). It enables payment transactions to occur without the need for an intermediary party. This is in contrast to traditional payment systems, which rely heavily on central parties as intermediaries in transactions.

Blockchain comprises five main features: a shared transaction database, a consensus mechanism for updating the database, unique cryptographic signatures for time-stamping records, tamper-proof records and cryptographic hash, which links a block to its predecessor block. Each block contains a list of completed time-stamped transactions. Cryptographic algorithms are used to encrypt the blocks for anonymity and ensure immutability. However, portions of the transaction called the transaction headers are publicly available and, therefore, accessed by any node or computer in the blockchain network. A consensus mechanism is used for adding a new transaction record onto a block. This consensus mechanism enables all parties in the blockchain to reach an agreement regarding the contents and legitimacy of a transaction before the transaction is added to the block (Beck et al., 2018).

There are two types of blockchain platforms: permissionless and permissioned blockchain. In permissionless blockchain networks, any user in the network can access, read and write the ledger without a central authority granting permission. Since no central authority is required, the consensus mechanism is often used to prevent malicious users from publishing blocks (Yaga et al., 2019). Permissioned blockchain refers to blockchain systems that are privately owned by a single organisation or consortium. In permissioned blockchains, rights to write, validate and approve transactions are limited to the organisation or selected members in a consortium (Li et al., 2018).

3 Methods

This study is a systematic literature review (SLR). The study follows the steps defined by Kitchenham (2004) and aligns with the PRISMA 2015 guidelines. The main purpose of the review is to collect and summarise the literature on the implementation of blockchain in the banking sector to identify implementation techniques, best practices and considerations as reported in the literature. As per the guideline for conducting an SLR by Kitchenham (2004), a protocol was developed and peer-reviewed to mitigate the possibility of researcher bias. Once consensus was reached regarding the protocol by the researchers, the review was subsequently conducted as outlined below.

3.1 Search process

In this study, articles were sourced from two categories of resources. The first category includes electronic databases, and the second is credible company resources such as websites and publications. For the first category, a systematic search was carried out in the following electronic databases: Scopus, IEEE Xplore, ACM digital libraries and Science Direct. The search strings were formulated using “blockchain implementation” and “banking” as the primary keywords. To enhance our search efforts, alternative search keys were formulated using synonyms to the above such as: “distributed ledger”, “proof of concept” and “finance”, respectively.

For the second category, a general Google search was done to identify banking institutions involved in blockchain experimentation. The identified institutional websites were searched for relevant reports and working papers. Institutional websites and publications are regarded as credible resources from which grey literature for an SLR can be obtained because the knowledge and authority of the sources are well-established (Garousi et al., 2019). Literature on blockchain implementation is still scarce (Haddara et al., 2021); hence the choice to include grey literature. Using grey literature in an SLR reduces publication bias, leading to a more comprehensive and balanced view of the evidence. In addition, it can provide insights that may have been overlooked in the formal literature (Paez, 2017).

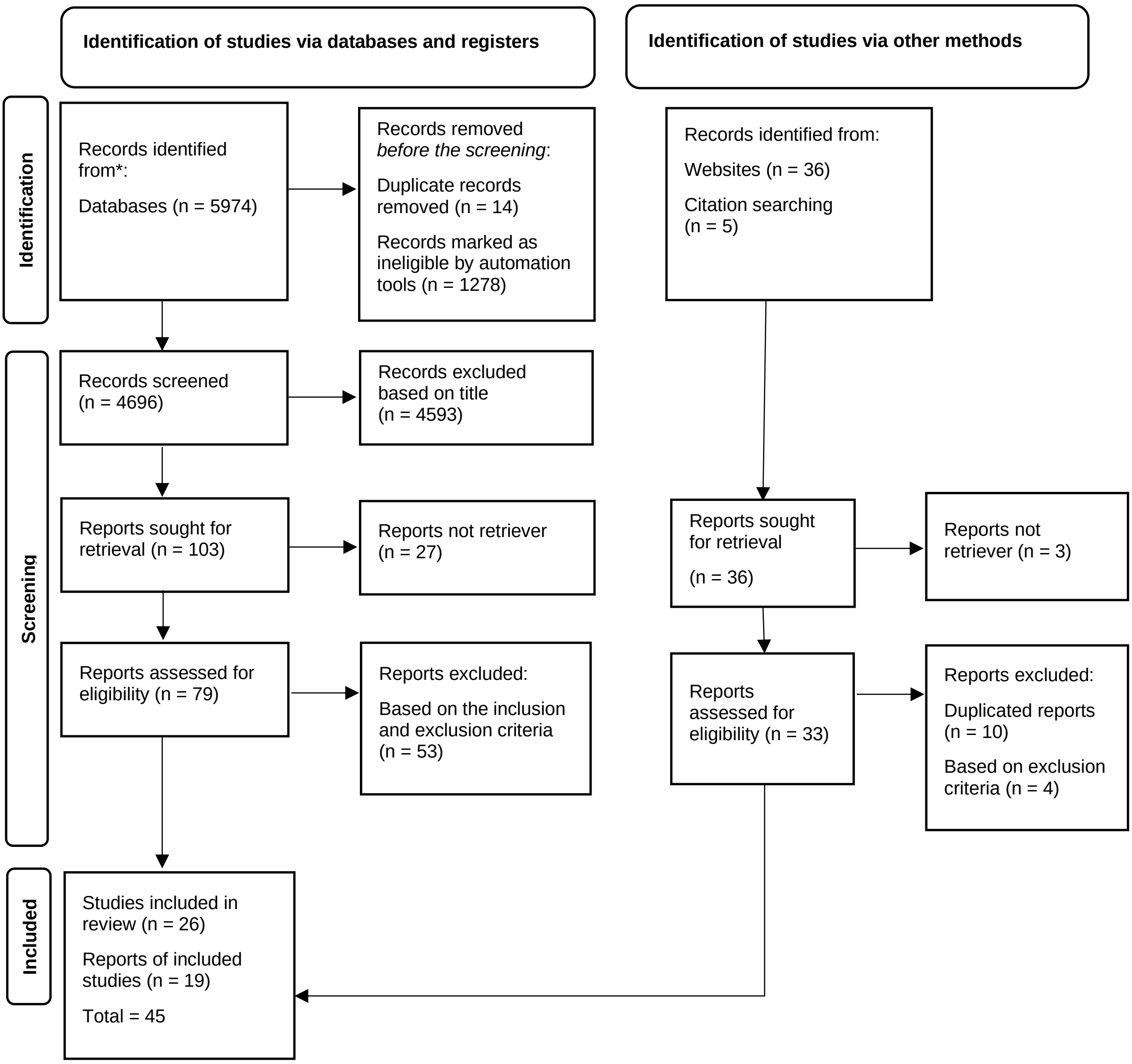

Figure 1. *PRISMA chart of the search strategy.*

3.2 Screening and selection methodology

The selected databases were searched to identify potential papers. Duplicated articles were removed. A title and abstract screening was performed on the remaining articles, and articles irrelevant to the research questions were excluded. In cases where the relevance of a paper could not be determined from its title and abstract, the researchers obtained and assessed a full copy. Full-text copies of the articles identified as relevant were downloaded and read. A decision to determine the final articles to review was made based on predefined inclusion and exclusion criteria. The criteria focused on including available peer-reviewed studies, published in English during the period 2008-2021, and studies discussing practical implementation of blockchain in the banking sector. In addition, forward and backward searches were carried out to identify articles that may have been missed during the initial searches. These were included in the final list of articles selected for review, as shown in Figure 1.

3.3 Quality assessment

As shown in Figure 1, 45 papers were included for review. We applied the quality assessment criteria proposed by Dybå and Dingsøyr (2008) and Garousi et al. (2019) respectively. Garousi et al. (2019) point that the quality assessment of grey literature warrants a different, more fine-grained approach as compared to formal empirical literature. They argue that this is because grey literature is more diverse, and the process of developing grey literature is less controlled. This study applied two separate assessment criteria (Dybå & Dingsøyr, 2008; Garousi et al., 2019) to evaluate the quality of the organisational reports and the academic articles respectively (see Appendix A).

3.4 Data analysis

A descriptive analysis of each paper was performed to gather general information such as the type of paper, year of publication, author's affiliation and geographical location of publication. Secondly, Leximancer software was employed to analyse the studies and reports separately. Leximancer is a data mining software used for automated content analysis (Angus et al., 2013). It identifies concepts and themes automatically from the text as well as co-occurrence relationships between the concepts. From the concepts and relationships, the tool generates a visual concept map. Using Leximancer to generate concepts reduces analytical bias (Lemon & Hayes, 2020) and provides statistically reliable and reproducible results (Angus et al., 2013). The results of the analysis are presented in the following section.

4 Results

This section first provides an overview of the final primary studies and the industry technical reports used in this review. This is followed by a content analysis of the results in line with each research question.

4.1 Overview of scholarly studies

Figure 2 depicts the number of the selected primary studies with their years of publication. It is evident from the final list of selected studies that the number of publications on blockchain implementation in the sector has increased considerably in the past two years. The year 2021 has the highest number of publications at 11, and 2017 has the least publications at only 1 study. This observation is expected because in the earlier years the technology was not well understood. However, interest in the technology has grown over the years; thus, the steady increase in research and experimentation efforts observed.

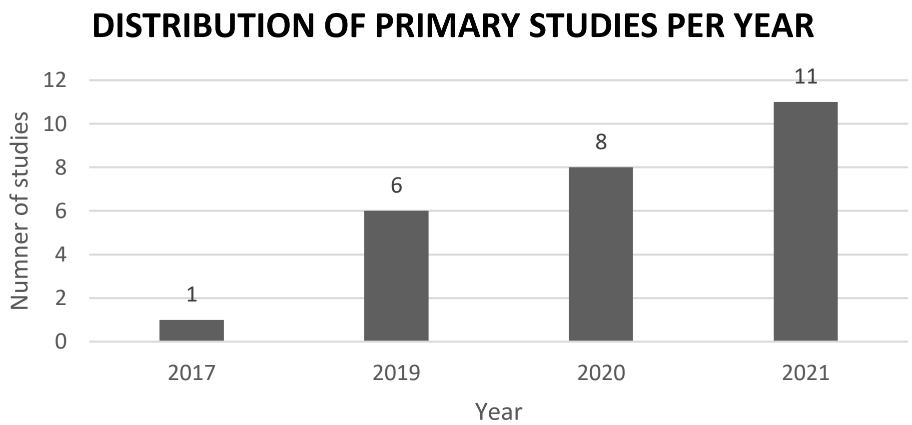

Figure 2. Distribution of primary studies by year of publication.

The studies were also classified according to their type, as shown in Figure 3. It is evident from the figure that most of the selected studies were conference papers at 58%, followed by journal papers at 38%, and the remaining 4% represents 1 paper from a seminar.

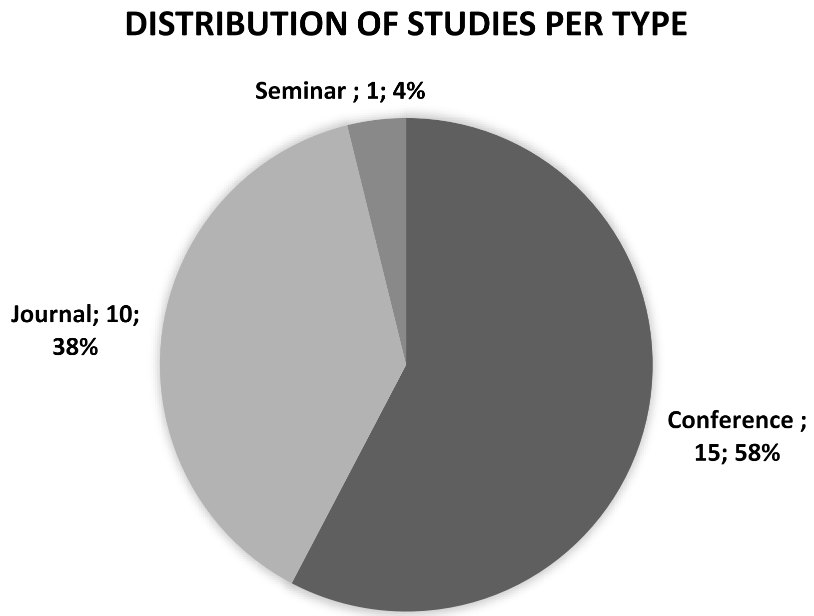

Figure 3. *Distribution of primary studies by type.*

4.2 Overview of technical reports

In addition to the primary scholarly studies, this review included 19 blockchain project technical reports obtained from various banking websites worldwide. It was found that central banks initiated all of the blockchain projects and commercial and retail banks were collaborators. Some of the banks embarked on multiple project phases. For instance, the Bank of Canada's (BoC) Project Jasper had different phases intended to achieve different objectives. Figure 4 illustrates the distribution of experimentation efforts by bank. The distribution shows the Monetary Authority of Singapore to be leading the pack in terms of the number of experimentation efforts.

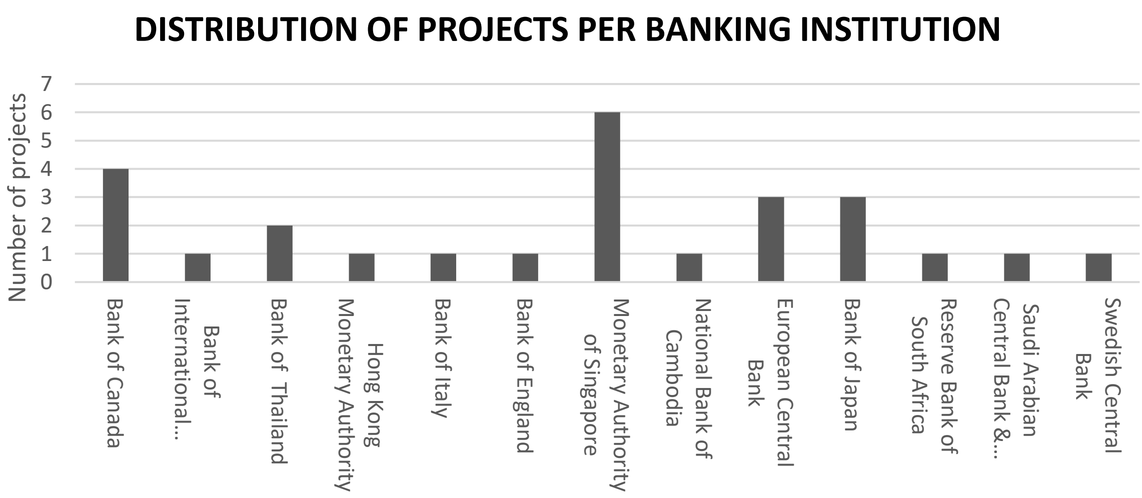

Figure 4. *Distribution of experimentation projects by banking institution.*

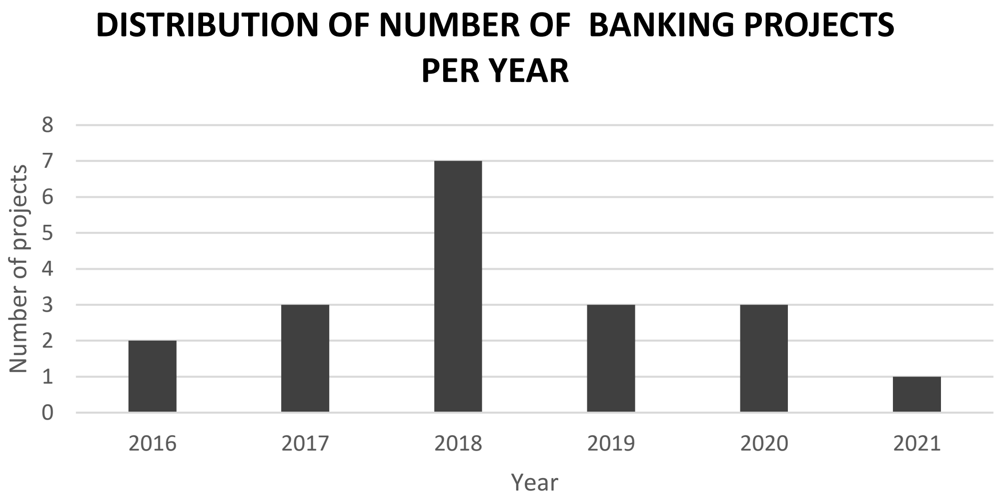

Figure 5. Distribution of the number of projects per year.

Figure 5 demonstrates the distribution of projects per year. It was observed that central banks started to experiment with blockchain in 2016, and the number of reports increased from then and peaked in 2018. The years 2019, 2020 and 2021 show a decline in experimentation efforts and published reports. This could be attributed to the COVID-19 pandemic lockdowns, which impacted on operations of organisations globally.

4.3 Content analysis results

The analysis of 26 scholarly articles revealed five main themes: *transaction*, *blockchain*, *implementation*, *banks* and *systems*. The concept map (see Figure 6) illustrates these themes and the associated concepts generated by Leximancer at a visibility concept setting of 100% and a theme size of 51%. The themes are the large coloured bubbles, and the concepts are the small grey dots. The frequency of occurrence of each of the five themes is presented in Figure 7. It shows that the concept *transaction* has the highest number of occurrences at 2832 hits, while *implementation* is the least occurring theme at 644 hits.

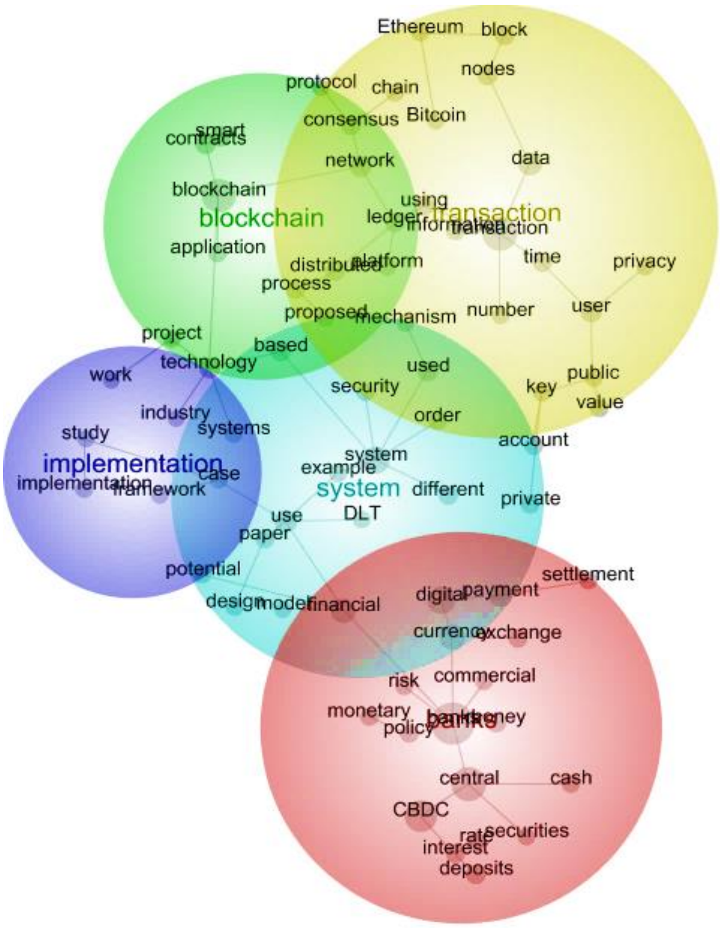

Figure 6. Leximancer concept map of themes and concepts from primary studies.

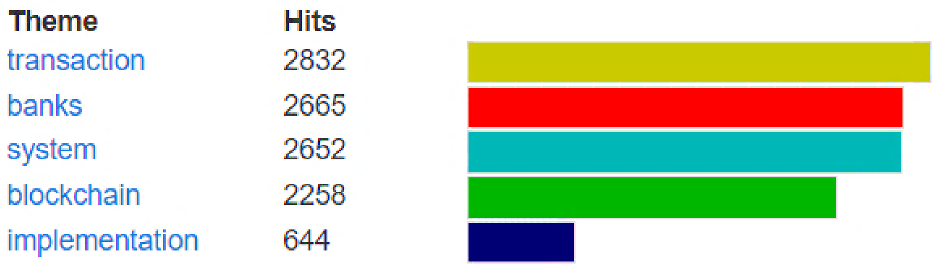

Figure 7. Frequency of occurrence of themes in primary studies.

The analysis of the 19 technical reports in Leximancer was carried out similarly to the above and resulted in 6 themes as shown in Figure 8. The themes are *node*, *transaction*, *banks*, *DLT*, *cash* and *amount*. The theme *banks* is the most frequently occurring theme in the text with a frequency of 11,114 hits, followed by *DLT* at 7729 hits. The rest of the themes and their corresponding occurrence frequencies are illustrated in Figure 9.

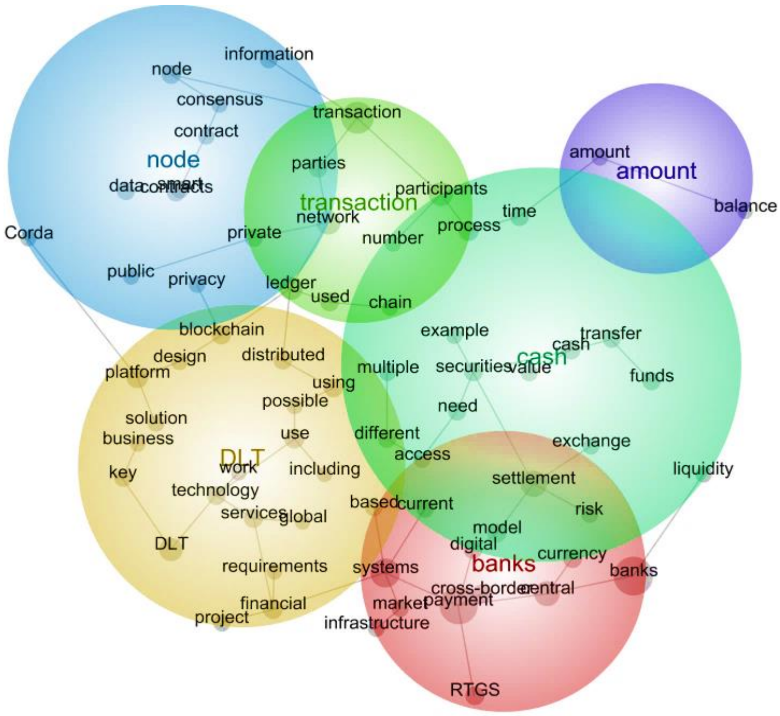

Figure 8. *Leximancer concept map of themes and associated concepts for technical reports.*

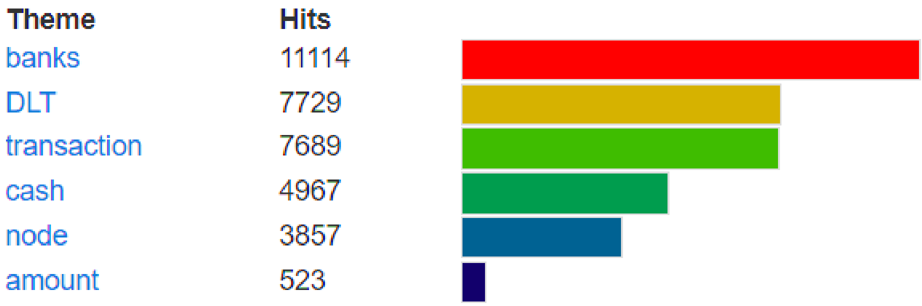

Figure 9. *Frequency of occurrence of themes from technical reports.*

5 Discussion

5.1 RQ1: For which banking operations have banks piloted or implemented a blockchain-based proof of concept?

5.1.1 Discussion of results from primary scholarly studies

The analysis of the primary studies to identify blockchain banking use cases reveals that the technology can be applied in various banking operations to serve different purposes. The main use case identified from the studies is CBDC, which constitutes 48% of use cases reported (see Figure 10). Know-your-customer and trade finance were also identified as other highly researched areas for blockchain implementation in banking at 12% each. Other use cases include interbank payments, cross-border payments and cheque clearance. With respect to CBDC, Pocher and Veneris (2021) explored the techno-legal approaches to designing CBDC for anti-money laundering compliance. Zhang et al. (2021) proposed a CBDC system that uses a hybrid consensus mechanism based on proof of stake and byzantine fault tolerance to improve transaction speed. The key role of CBDC is to enhance the efficiency and stability of payment systems.

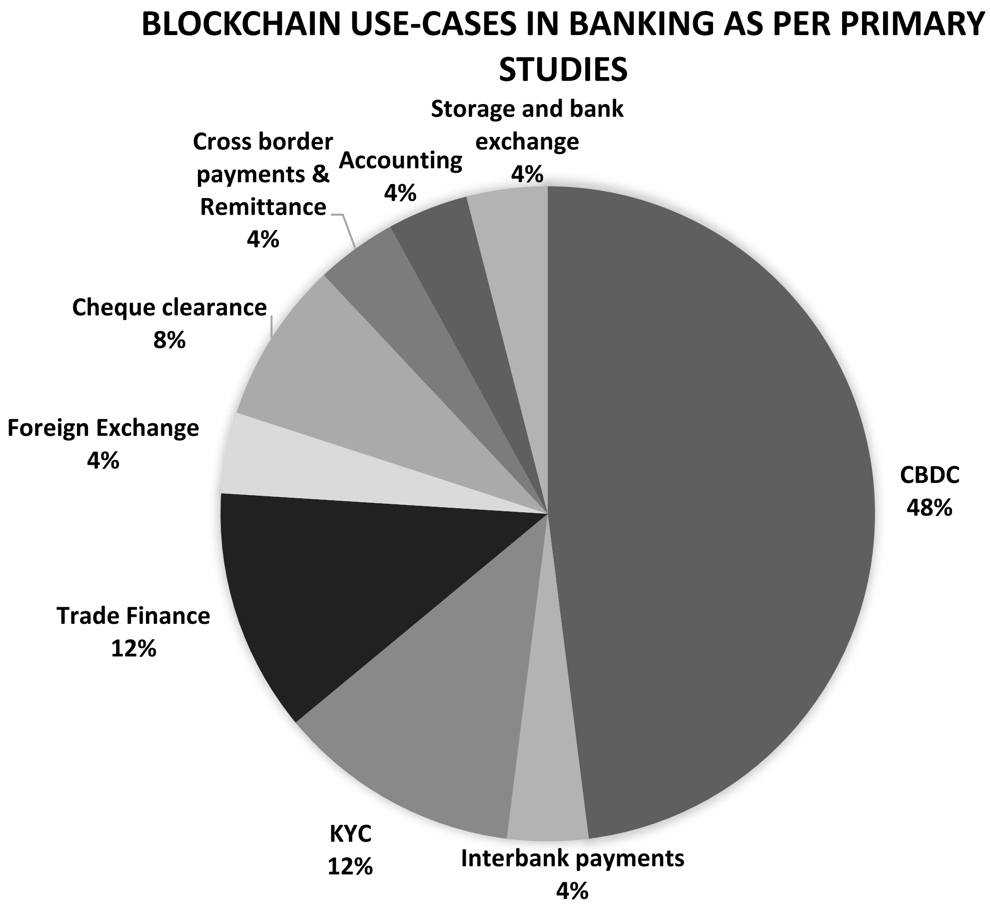

Figure 10. *Blockchain use cases in banking identified from primary studies.*

In addition, the primary studies suggest that banks are implementing blockchain to enhance the efficiency of cross-border payments and payment settlements and eradicate challenges associated with these types of payments. CBDC systems offer "real-time settlement and reduce costs" (Han et al., 2019, p. 268) associated with traditional payment systems. For example, Ariffin and Ismail (2019) proposed a blockchain-based system to enforce trust in traditional trade finance systems. On the other hand, in the case of Fu et al. (2021), blockchain was applied to simplify the complex process of traditional cross-border payment services. Blockchain is also used to address key limitations of current interbank payment settlements: the need for synchronisation and reconciliation of participating banks' databases and the need for central parties to facilitate payments between participating banks (Wu & Liang, 2017). Another use case is that blockchain can be applied to enforce transaction recording and accounting integrity in payment systems (Fan et al., 2020).

5.1.2 Discussion of results from technical reports

Findings from analysing the technical reports revealed growing interest in blockchain technology in the banking sphere, particularly within central banks. The majority of the proof of concept projects appear to be led by central banks, supported by commercial banks. From these projects, the following areas emerged as functional areas where banks are experimenting with blockchain: interbank payment settlements (Payments Canada et al., 2017), securities settlement (Monetary Authority of Singapore, 2017a), digital currencies (Monetary Authority of Singapore, 2017b) and cross-border payments (Bank of Canada & Monetary Authority of Singapore, 2019; Monetary Authority of Singapore, 2017a). The results of our analysis of functional areas are summarised in Figure 11 below.

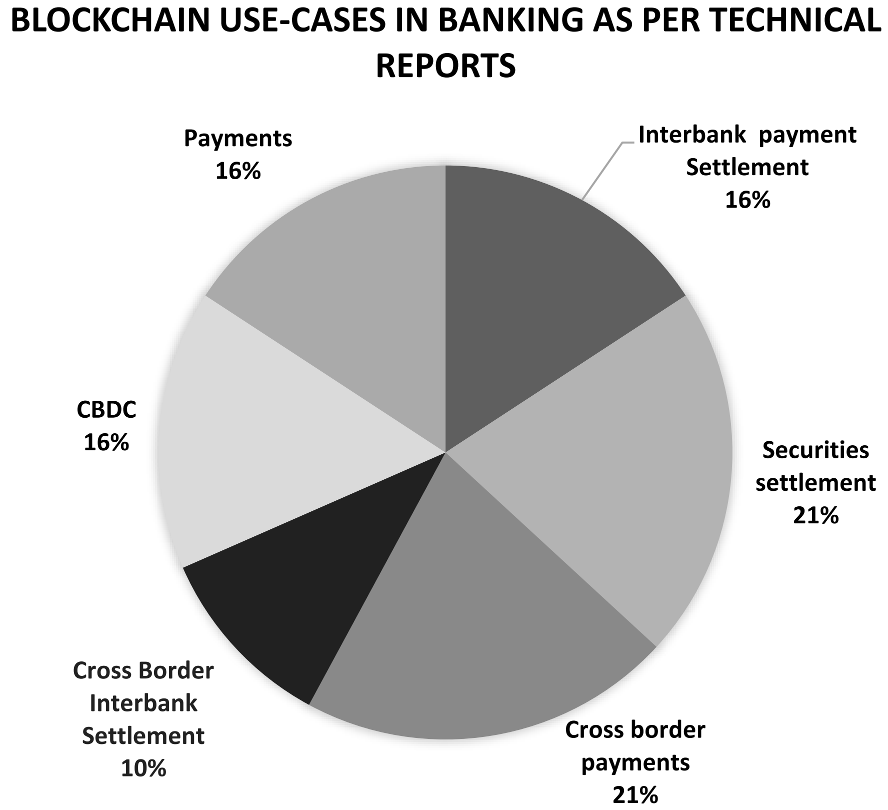

Figure 11. *Blockchain use cases identified from technical reports.*

Many central banks are experimenting with blockchain in cross-border settlements. The technology is regarded as highly relevant and suited to the area of cross-border payments, which are currently inefficient, slow, opaque and expensive (Auer et al., 2021). For instance, the Bank of International Settlements is exploring how multi-CBDC can be used to achieve interoperability in multi-currency cross-border payments to reduce the complexity, risk and high costs associated with these types of payments. Similarly, the technology is used to develop CBDC versions of the Hong Kong dollar and the Thai baht to facilitate efficient cross-border fund transfers between Hong Kong and Thailand banks (Hong Kong Monetary Authority & Bank of Thailand, 2018). The development of CBDC for use in cross-border payments seems to be a common application of the DLT among central banks. For instance, a CBDC was developed to settle cross-border payment obligations between Saudi Arabia and United Emirates banks (Saudi Central Bank, 2019).

In addition, the technology is applied in the securities settlements process. The BoC, in Jasper phase 3, developed a "blockchain integrated securities infrastructure to enhance the country's securities clearing and settlement process" (Bank of Canada, 2018, p. 9). They found that their system can functionally improve the securities settlement process and results in "better asset interactions during delivery vs payment (DvP) settlement relative to the currently siloed Canadian depository for securities (CDS) and Payments Canada's Large Value Transfer System (LVTS)" (Bank of Canada, 2018, p. 9). DvP refers to the securities method that guarantees that securities are transferred only if payment has been made. The MAS developed a blockchain-based DvP for settlement of tokenised assets and found that blockchain enhances the efficiency of the trade settlement and reconciliation process (Monetary Authority of Singapore, 2017b).

Some banks have also explored blockchain in interbank payment settlements. Project Jasper phase 1 investigated the use of blockchain for wholesale interbank payments using the Ethereum blockchain platform (Payments Canada et al., 2017). The South African Reserve Bank (SARB), through its project Khoka, also explored the role of blockchain in wholesale payment settlements between banks. They developed a real-time gross settlement system (RTGS) using tokens backed by central bank funds on the Quorum platform (South African Reserve Bank, 2018). Project Khoka involved the participation of several commercial banks linked to the blockchain. Each bank had its node to allow a realistic simulation and system testing. Similarly, the Central Bank of Brazil developed an interbank payment system intended for use as a backup system if the main current RTGS system fails (de Vilaca Burgos et al., 2017).

5.2 RQ2: What are the challenges experienced with blockchain implementation in banking operations?

Blockchain technology holds great potential for the banking sector; however, developing blockchain systems comes with a number of challenges. This section presents the findings in relation to the challenges as reported in the literature.

- *Platform interoperability*: Blockchain platform interoperability is one of leading pain points for blockchain implementation and adoption in the banking sector. The sector relies heavily on legacy technology for its operations. Thus, introducing blockchain solutions into the sector requires blockchain-enabled systems to be able to communicate with the existing legacy payment infrastructure. However, traditional banking systems were not designed to support blockchain; as a result, integrating the two leads to interoperability concerns. Furthermore, the financial market ecosystem traditionally involves many global participants using different technologies; as a result, introducing blockchain into the already complex system may lead to further interoperability challenges (South African Reserve Bank, 2018). Moreover, current global efforts in developing blockchain systems are carried out in silos and using different approaches and technologies. The absence of standardized ways of developing blockchain systems presents a challenge on how these systems can be integrated to communicate seamlessly and effectively. This is more so a challenge for cross-border and remittance payments, which require money to transcend across multiple jurisdictions. Moreover, legacy payment systems rely on a centralised mechanism. Incorporating blockchain, which is a decentralised technology, also introduces significant complexity, especially when decentralised systems are expected to rely on the existing central mechanism (Chapman et al., 2017).
- *Scalability and performance:* Some studies and reports cited scalability and performance as concerns, particularly for traditional blockchain platforms such as Ethereum, which rely on proof-of-work consensus mechanisms and store the entire ledger on every node (Monetary Authority of Singapore, 2017a). These platforms were found to have lower transaction speeds compared to their new counterparts such as Hyperledger, Quorum and Corda. However, in spite of the improved performance in recent platforms, there are still some performance challenges with these platforms. For instance, Corda's sequential processing of transactions introduces performance issues when the same bank node initiates two consecutive transactions because the second and subsequent transactions can only be processed when the previous one is completed (Bank of Thailand, 2018). Others (European Central Bank & Bank of Japan, 2020; South African Reserve Bank, 2018) alternatively found that even though blockchain payment systems meet the required transactions volume processing requirements, the performance degrades when the number of requests increases due to increasing network size.
- *Laws and regulations:* Provision of banking services is a highly regulated process globally. Banks adopting blockchain in their operations have to comply with local and global financial regulations. The challenge, however, is that current laws and regulations governing financial market systems are inappropriate for blockchain-based financial systems. By nature, transactions on the blockchain are immutable and transparent and this contradicts privacy laws (Zhang, 2020). Therefore, amendments to existing regulations are required to explore the benefits of blockchain

payment systems fully and to better suit the nature of transactions carried out through blockchain (Hong Kong Monetary Authority & Bank of Thailand, 2018).

5.3 RQ3: What design and implementation considerations are reported in the literature on blockchain-based banking systems?

This section discusses the practical techniques and considerations adopted by banks when implementing blockchain. The principles and techniques discussed are by no means exhaustive and cover mainly those principles that are common to all the use cases identified and addressed in RQ1 above. We share and discuss the results by focusing on the technical aspects (technology), organisational aspects (internal) and broader environmental aspects (external). This paper's focus on these aspects is guided by the TOE framework for technology adoption (Tornatzky et al., 1990).

5.3.1 Technical aspects and considerations

- *Blockchain platform*: One of the key considerations is identifying the “right” blockchain platform for the selected use case. Selecting the right platform that is fit for the purpose requires careful consideration and assessment of its functionalities, adaptability and compatibility to existing enterprise systems (Farshidi et al., 2020). There are a number of blockchain platforms available on the market. However, these platforms differ significantly in terms of their capabilities and features; as such, selection should be made with consideration to the type and performance requirements of the system being developed. In banking, the following emerge as the preferred platforms for developing blockchain-based systems: Corda, Hyperledger Fabric, Quoram and Ethereum. These platforms offer varying features and performance metrics. For instance, Ethereum has been found to be “more operationally efficient than Corda” (Payments Canada et al., 2017, p. 22). However, Corda has been found to outperform Ethereum concerning privacy requirements (Payments Canada et al., 2017). Ethereum has been found unsuitable for private enterprise blockchains where confidentiality is paramount, as in the case of wholesale settlements (South African Reserve Bank, 2018). Hyperledger Fabric and Quorum, however, provide strong data and identity protection (Bank of Thailand, 2018b) but have scalability issues (Monetary Authority of Singapore, 2017a; South African Reserve Bank, 2018).
- *Scalability*: Blockchain payment systems should be designed to accommodate current transaction volumes and future volume growth. They should also be designed to accommodate future additions of new participants with no or limited changes to the system design (Saudi Central Bank, 2019). One of the techniques used to achieve scalability is adopting platforms that do not use proof-of-work consensus mechanisms. For instance, in Jasper 2, Corda was adopted because its consensus method is not based on a fixed time but requires only nodes of the participating banks and a notary to verify transactions. Similarly, in project Ubin, Corda was employed because it allows addition of new nodes without the need for extensive changes to the existing nodes or network (Monetary Authority of Singapore, 2017a). Furthermore, Corda transactions are "sent on a need-to-know basis, and each peer only sees a subset of facts on the entire ledger" (Monetary Authority of Singapore, 2017a, p. 41). This addresses scalability concerns associated with updating the entire ledger (blockchain) on each node as is the case in Ethereum and other traditional blockchain platforms. In Hyperledger, bilateral channels are used. However, this method introduced management overheads when the number of nodes was increased (Monetary Authority of Singapore, 2017a). This approach would therefore be suitable for private and permissioned blockchains where the number of nodes is limited. The Quorum approach employs networks which enable dynamic addition of new nodes. However, this approach applies zero-knowledge proof (ZKP). A ZKP is a protocol through which one party can show another that they know a certain value without disclosing that value (South African Reserve Bank, 2018). ZKP is

used as a technique to enhance the privacy of data shared on the blockchain; however, it has been found to offer low transaction throughput (Monetary Authority of Singapore, 2017a; South African Reserve Bank, 2018).

- *Privacy*: The design of blockchain banking solutions should not compromise the privacy of participants and should offer privacy levels comparable to current systems. The Saudi Central Bank (2019) states that, as a design principle, the central bank should not have any visibility to the accounts of any bank not within its jurisdiction. Also, commercial banks should not have access or visibility to each other's balance sheets. To achieve this, they recommend solutions that take advantage of the inbuilt privacy features of the platform used. This approach was observed by the Monetary Authority of Singapore (2017a), which explored the use of Corda, Hyperledger and Quorum. The Corda approach uses the unspent transaction model output to ensure that the ledger is shared on a need-to-know basis. Confidential identities hide the identities of the transacting parties from all others not involved in the transaction. The Hyperledger approach leverages channels and the Quorum approaches uses constellations to send encrypted transactions which are visible to only the transacting parties, and ZKP was used to hide the balance of each bank from other banks. Other techniques applied Quorum Whisper messaging coupled with Pedersen commitments (South African Reserve Bank, 2018). Whisper is a secure peer-to-peer messaging system for sending private messages. Pedersen commitment is a cryptographic algorithm that requires the sender of the payment to commit to a value in a way that does not allow this value to be changed once the commitment has been effected (South African Reserve Bank, 2018).
- *Resilience*: Blockchain financial solutions should be developed to be resilient to failure. In other words, their design should incorporate disaster recovery mechanisms to handle different systems failures and reduce system downtime (Hong Kong Monetary Authority & Bank of Thailand, 2018). To ensure a resilient environment, all network participants should provide the necessary "operational capacity and sound risk and data management" (Morales-Resendiz et al., 2021, p. 7). De Vilaca Burgos et al. (2017) recommend using inbuilt platform resilience features such as those provided by Corda. Similarly, the Bank of Thailand (2018a) used enhanced Corda features and added control points containing saved transactions; these control points can be used for data recovery during a system failure. Furthermore, the study found that resilience was achieved when there were no single points of failure in the design. Alternatively, a multiple notary model is used to minimise the risk of a single point of failure (Bank of Thailand, 2018a). They further suggest that a timeout mechanism be used to enable active nodes to resume operation following system recovery.
- *Settlement finality*: This principle is considered the most important when implementing blockchain-based payment systems (Saudi Central Bank, 2019). It is defined by the Principles of Financial Market Infrastructures (PFMI). It states that financial market systems should provide clear and certain transaction settlements by the end of the value date at the least and the system should clearly define a point at which any unsettled transactions, transfer instructions and obligations cannot be revoked. In practice, settlement finality has been implemented in many ways. For instance, the Saudi Central Bank (2019) used bilateral channels managed using smart contracts to endorse transactions. However, the Bank of Canada (2018, p. 9), used the consensus mechanism of the Corda notary service to ensure settlement finality. Alternatively, the South African Reserve Bank (2018) applied the Istanbul Byzantine Fault Tolerance consensus mechanism.
- *Existing frameworks and systems*: According to the South African Reserve Bank (2018), existing systems and frameworks should be evaluated to ensure that they are suitable for integration with new blockchain-based systems. In support, the Saudi Central Bank (2019) states that risks to existing systems should be evaluated, and changes to these systems should be controlled to avoid unintended disruptions to existing business processes. They attribute this to the fact that

blockchain systems require multiple participants; as a result, any changes to existing systems may lead to a cascading effect on other systems in the network.

5.3.2 Organisational aspects and considerations

- *Scope*: The literature mentions the importance of defining a clear and confined scope when implementing the technology, regardless of the application. The definition of scope appears to vary within the examined literature, with some authors referring to scope in terms of the scope of application of blockchain technology, whether it is applied in CBDC development or other use cases. For example, in designing a CBDC, it is important to frame the scope of the CDBC to specify whether the CBDC will be used to replace cash or to complement cash (Kumhof & Noone, 2021) or for retail or wholesale purposes. Scope is also used to refer to the number of participants (banks or banking nodes) (Bank of Canada, 2018; Bank of Thailand, 2018a). The scope of application is an important consideration because it influences other considerations such as the nature of the blockchain, platform selection and the protocols to use.
- *Collaboration and definition of roles*: Traditional payment systems require the coordination of multiple participants, including the central bank, commercial banks and other financial service institutions. Similarly, blockchain payment systems also require a significant amount of coordination and operational effort to enable interoperability with the financial ecosystem. By design, blockchain technology uses a distributed ledger, and storing this ledger requires a concerted effort among the distributed nodes (or participants), as such roles must be clearly defined (Morales-Resendiz et al., 2021). Morales-Resendiz et al. (2021) recommend that the central bank's role as a regulator and operator of payments should be distinctly defined and different from the other participants. This is supported by two studies (Hong Kong Monetary Authority & Bank of Thailand, 2018a; Payments Canada et al., 2017) where the central bank was both the issuer of the digital currency and the regulator of payments and was granted access to all the records on the blockchain, whereas the other participating banks were allowed access to only their records.
- *Decentralisation and governance:* One of the main reasons why global banks are considering blockchain is the possibility of offering decentralised financial transactions (National Bank of Cambodia, 2020). To offer truly decentralised systems, new governance structures and frameworks need to be considered to ensure harmony and standardisation among participating banks (Monetary Authority of Singapore & Bank of Canada, 2019). Governance frameworks are necessary in blockchain systems to govern the consistency of the blockchain network and to ensure that no banking node is favoured over the others (Monetary Authority of Singapore, 2017a). A recommendation from the literature is that governance should be centralised even in a decentralised system (Monetary Authority of Singapore, 2017a), and be designated to the central bank (South African Reserve Bank, 2018).

5.3.3 Environmental aspects and considerations

- *Regulation and compliance*: The design of blockchain payment systems needs to consider local and global financial regulations. The type of regulatory framework to use should be guided by the nature of the desired blockchain solution (Sveriges Riksbank, 2017). However, the literature is unclear as to which framework is appropriate because the majority of studies and projects have left regulation as future work. However, there is consensus that for these systems to be fully operational and publicly available, they should be compliant with regulations. Also, research agrees that new, more suited regulations should be developed (Hong Kong Monetary Authority & Bank of Thailand, 2018) to accommodate the nature of transactions carried out on blockchain.

- *Legal compliance*: The literature has also highlighted legal compliance aspects that should be considered when designing blockchain payment systems. These include legal settlement finality, smart contracts and service level agreements. Concerning legal settlement finality, the South African Reserve Bank (2018) recommends that their current Payment Systems Act be revised to include settlements effected using digital currency in addition to fiat money. Additionally, they recommend that existing laws be used to cover the legality of blockchain systems concerning the finality of settlement. This is to ensure that digital currency payments are treated as equivalent to a complete and irreversible settlement against the central bank money similar to fiat settlements. Regarding smart contracts, a consideration is to ensure that the smart contract logic satisfies legal requirements and is legally binding to the participants (European Central Bank & Bank of Japan, 2018). Smart contracts are digital contracts defined as an automatically executed code used to define business logic (Monetary Authority of Singapore, 2017a) and are used in blockchain-based systems to enforce agreements and obligations in business transactions (National Bank of Cambodia, 2020). These contracts are used in some securities and interbank payment settlement systems to enforce trust among transacting parties.

5.4 RQ4: What are the future research directions for blockchain implementation in the banking sector?

Experimentation efforts concerning blockchain in banking are yielding value for the sector. The use of blockchain in securities settlement, cross-border and interbank wholesale payments enables transparent, faster and more cost-effective transactions (Bank of Canada, 2018). However, the sector still faces some challenges in implementing blockchain systems, and this hinders the sector from realising the full benefits of blockchain technology. As stated in the literature review results, the full-scale adoption of blockchain is limited due to technological, organisational and environmental challenges in interoperability, privacy and security, scalability, regulation and governance. Based on these results, some opportunities were identified for future research into this topic as follows.

5.4.1 Interoperability

It is evident from the literature that there is a genuine interest to adopt blockchain in the banking sector. This is evidenced by the number of experimental and proof-of-concept projects undertaken by the sector. However, the disjointed nature of these projects has led to a number of disparate heterogenous systems which cannot communicate (South African Reserve Bank, 2018). This is a challenge particularly for cross-border payments, in which a single transaction spans across a number of different networks. The absence of suitable standards and protocols is a challenge to achieving interoperability in blockchain banking systems (South African Reserve Bank, 2018). Interoperability solutions such as hash time locked contracts (HTLC) have been tested to facilitate communication across different chains in cross-border payments. However, due to the immaturity of the technology, the proposed solutions are conceptual and have not been tested in full-scale applications. As such, it is not clear at this stage which methods are effective in achieving interoperability among heterogenous blockchain banking systems. Another area that has been overlooked in the reviewed literature concerns blockchain-to-legacy interoperability. The literature focuses mainly on blockchain-to-blockchain interoperability and not how interoperability between blockchain and legacy systems can be achieved.

These limitations offer interesting opportunities for future research. For example, future research could focus on conceptualising and developing standards and frameworks for blockchain implementation in general. Future research could also investigate interoperability methods and protocols for achieving domestic and global financial market interoperability, including cross-border payments and CBDC. In addition, future studies can focus on privacy issues related to interoperability of blockchain systems in the financial and banking sector. Another important potential area for future exploration is that of blockchain-to-legacy enterprise system interoperability. Researchers and practitioners could explore approaches to enabling blockchain-to-legacy system interoperability. At the same time, a broader research area lies in understanding blockchain interoperability at all levels including sematic, syntactic, organisational and technical levels. To address these gaps, future research can ask the following questions:

- How can new standards be formulated for blockchain interoperability in the financial industry?
- What are the key requirements for enabling blockchain interoperability for the different levels of interoperability (semantic, technical and organisational levels)?
- What is the state of the art for blockchain interoperability and blockchain-to-legacy interoperability in banking systems?
- What are the methods, tools and approaches for achieving interoperability between blockchain and existing legacy banking systems?
- How can interoperability between private and public blockchains be enabled?
- What are the key design, regulatory and legal considerations for blockchain interoperability in banking systems?

5.4.2 Central bank digital currency

Research into blockchain-based CBDCs is still exploratory and in the early stages of experimentation. The existing literature focuses on the exploratory development of various types of CBDCs such as retail, wholesale and hybrid CBDCs. Most of the work in this area has focussed on the technical approaches to developing CBDCs (Kumhof & Noone, 2021; Morales-Resendiz et al., 2021; Auer et al., 2021). However, the majority of the research is carried out from the perspective of banking institutions and is mostly technical with very little attention given to understanding the social implications of CBDCs. It would benefit the literature to understand the antecedents and perceived benefits of adopting the technology from a consumer perspective. Therefore, future research is needed to explore the potential impact of CBDCs on consumers. Future studies could investigate consumer perceptions of CBDCs and explore methods and techniques that can be used to educate consumers about CBDCs. Other interesting areas worth exploring include socio-economic factors that may influence adoption of CBDCs in low-income communities. In addition, there are still open issues on technical challenges relating to the user privacy and integrity of CBDC payment systems. Studies have shown that achieving user privacy in CBDC payments comes at a trade-off on integrity (Moubarak et al., 2020). Total anonymity and privacy of users can compromise the integrity of the payment systems by allowing illicit transactions, cybercrime and money laundering. On the other hand, taking a relaxed approach to the user privacy requirements would compromise the security of the payment system. Future research should therefore explore design approaches which promote a balance between user privacy and integrity while at the same time satisfying regulatory requirements. Other interesting avenues for future research can focus on legal, ethical and regulatory perspectives on CBDCs. Several questions related to CBDCs that scholars and practitioners may consider are:

- What strategies can be employed to educate consumers about CBDCs?
- What are the implications of adopting CBDCs for consumers?
- What socioeconomic factors may affect the adoption of CBDCs in low-income communities?
- How can CBDCs promote financial inclusion?

5.4.3 Blockchain governance

Stakeholder participation and governance in blockchain systems is decentralised and achieved through consensus mechanisms and autonomous smart contracts. This is in contrast to the highly centralised governance models used in banking where supervision and monitoring are the responsibilities of central banks and boards of directors. Introducing blockchain into the banking ecosystem, particularly in payment systems, requires the collaborative participation of multiple stakeholders with different interests. The governance of these collaborative networks is critical for the success of these networks. However, the disparities between the traditional centralised governance models used in the sector and the decentralised consensus-based models present a challenge for banks which are looking to adopt blockchain. Existing research in this area focuses mainly on blockchain consensus mechanisms used to govern blockchain platforms. However, governance issues relating to forming new blockchain networks, particularly consortium networks in the industry, have been overlooked. Therefore, there is a need for empirical research to explore the considerations and conditions for establishing consortium networks in the industry. The following research questions could be addressed:

- How does blockchain impact on traditional governance models in the banking sector?
- What are the considerations for the establishment of a new governance model for blockchain-based banking consortium networks?
- What power dynamics come into play in the establishment of blockchain consortium networks?
- What incentive mechanisms can be used to encourage participation in consortium blockchain networks?
- What new governance models will emerge as a result of blockchain technology?

5.4.4 Security and privacy

Although blockchain technology is designed to be highly secure and to protect the integrity of digital information, it is not entirely immune to cyber security attacks. Blockchains consist of a number of layers which contribute to their desirable properties, but may also lead to security concerns. Risks to the security of blockchain-based systems relate to weakness in some consensus mechanisms, smart contracts, protocols, and network vulnerabilities of the blockchain network (Hasanova et al., 2019). It is critical for organisations adopting the technology to understand the security risks posed by the technology at different levels. To address these concerns, researchers have evaluated potential attacks and vulnerabilities of blockchain systems. However, most of the work has focused on public blockchains and on technical nuances of security in blockchains. As more and more organisations, particularly banks, implement permissioned networks, it is important to understand the security issues that may arise from adopting the technology. Future research is required to understand the security and privacy implications of integrating blockchain with legacy enterprise systems. Issues of access control management and smart contracts should be investigated. It is also important for researchers to understand the risks associated with human users of blockchain systems. The following questions would help address these concerns:

- How can robust, privacy-preserving and efficient access control mechanisms for enterprise blockchain systems be designed?
- How can vulnerabilities in smart contracts be evaluated?
- What security vulnerabilities and attack vectors arise as a result of the participation of human users in blockchain systems?
- What techniques can be used to mitigate against security attacks which exploit user vulnerabilities in blockchain systems?
- How can user training and awareness be conducted to enhance the protection of users of blockchain systems?

6 Conclusion

6.1 Limitations and future research

Blockchain technology is still in its infancy. As a result, there is a significant lack of literature on blockchain in general, especially in the banking sector. Therefore, the study was limited to 45 papers. Furthermore, the study follows a systematic literature review methodology which has its own limitations. Systematic literature review studies typically suffer from selection bias, publication bias and data extraction (Nightingale, 2009). Similar to other systematic literature review studies, this study is limited in how sample articles were selected. The study excluded studies that were not in English even though they may have been relevant. Additionally, papers were sourced from four scholarly databases. This implies that publications from other databases, which could have been relevant to the study, may have been missed, thus leading to publication bias.

Future studies may seek to expand the search to include additional databases to broaden the scope of the search and articles that may be included. The study only focused on identifying key considerations and techniques. Additional studies may extend the review to include architectural considerations. Other studies can explore institutional readiness for adopting blockchain, while others can evaluate the suitability of blockchain for various banking and financial operations and functions. Furthermore, as the technology matures, newer, more efficient approaches may emerge, and additional studies may focus on these aspects.

6.2 Contribution

6.2.1 Theoretical implications

In the main, research into blockchain is limited and still in the nascent stage. This is more so the case for blockchain adoption and implementation in the financial sector. Despite the transformative potential of the technology for the sector, research into blockchain implementation in the sector is still limited. Current research mainly focuses on elucidating the potential benefits of adopting the technology, identifying possible use cases and exposing challenges of adopting blockchain in the sector. However, none highlight key considerations and techniques for implementing blockchain. This study extends the literature on blockchain adoption in general by identifying key challenges hindering blockchain implementation in banking. Furthermore, the study proposes a research agenda to address some of the identified challenges. In addition, the study contributes to the understanding of blockchain implementation in banking. It highlights key implementation considerations and techniques used in developing blockchain-based banking systems. The identified considerations and techniques can serve as a reference point for researchers who are interested in implementing blockchain for banking applications and for further research. Moreover, the study applied the Technology, Organisation and Environment framework as a theoretical lens to classify the implementation considerations and techniques. The study builds on the TOE framework by demonstrating its utility in addressing blockchain-related research questions.

6.2.2 Practical implications

The study may have the following implications for practitioners and institutions looking to adopt and implement blockchain. Firstly, the study is based on a review of current peer-reviewed literature and industry literature. Thus, the findings presented are drawn from real and practical banking blockchain initiatives. As a result, they can be adopted by other banking institutions. Secondly, the study identified existing use cases on blockchain in banking and challenges that hinder the implementation and adoption of blockchain in the sector. Other banking and financial institutions considering blockchain implementation may consider these as a starting point for adopting the technology. Furthermore, institutions can use the identified challenges to guide their decisions to adopt or not to adopt the technology. Lastly, the study also presents a number of key practical considerations and techniques for implementing blockchain banking systems. These will act as a starting point and guide for other financial organisations, helping them determine appropriate techniques for their selected blockchain use case implementation.

6.3 Concluding remarks

Blockchain technology and its benefits have piqued interest of the banking sector. In recent years, there has been a significant increase in blockchain-driven projects and research undertaken by the sector to leverage the benefits offered by the technology. However, to date, there are no market-ready blockchain systems deployed by the sector, and the majority of the projects are still in the experimental stage. On this basis, the authors found it essential to review the existing literature to improve the understanding of the technology and to obtain a broader picture of the current considerations, practices and challenges in implementing blockchain in the sector. This study contributes to the limited blockchain literature.

In summary, a systematic literature review was carried out on 45 papers selected using pre-defined inclusion and exclusion criteria. The reviewed papers comprised 19 technical project reports and 26 peer-reviewed scholarly articles. The selected papers were analysed, and an overview of key design and implementation considerations and techniques was presented. The paper also presented several blockchain banking use cases identified in the literature. In addition, the key challenges encountered when implementing the technology were also identified.

The analysis showed that most of the experimental work done in the banking sector concerns the application of blockchain in CBDC development and various payment systems. It also highlighted that there are varying approaches to developing blockchain in banking systems. However, there are common key considerations such as privacy, scalability and resilience that should be taken into account regardless of the use case. Furthermore, the analysis revealed regulatory and interoperability issues as some of the challenges that need to be addressed for blockchain banking systems to reach the production stage. The paper further proposes a research agenda for blockchain in the banking sector based on the lessons from the SLR.

Additional Information and Declarations

Funding: This work is based on research supported in part by the National Research Foundation of South Africa; Grant Number 127495.

Conflict of Interests: The authors declare no conflict of interest.

Author Contributions: S.S.M.: Conceptualization, Methodology, Writing – Original Draft Preparation. T.M.: Supervision, Writing – Reviewing and Editing.

Appendix A

Table A1. *Quality assessment checklist for the academic articles*.

Quality criteria	Yes	No
QC1. Are the aim and objectives stipulated clearly?		
QC2. Is there a rationale explaining clearly why the study was undertaken?		
QC3. Is the idea presented clearly?		
QC4. Are there clearly stated findings with credible results and justified conclusions?		
QC5. Is the context of the study articulated clearly?		
QC6. Do the findings provide value for research or practice? (Does it enrich or add something unique to the research?)		
QC7. Does the paper specify the research design for the study?		
QC8.Does the paper justify the appropriateness of the research design?		
QC9. Does the paper specify the limitations of the study?		

Table A2. *Quality assessment criteria for technical reports*.

Quality criteria	Yes	No
QC1. Is the source published by a reputable organisation?		
QC2. Is the author associated with a reputable institution?		
QC3. Does the author have expertise in the area?		
QC4: Are the aims and objectives clear?		
QC5: is the methodology clearly stated		
QC6: is the source presented in an objective manner?		
QC7. Are there clearly stated findings with credible results and justified conclusions		
QC8. Is the context of the study articulated clearly?		
QC9. Do the findings provide value for research or practice? (Does it enrich or add something unique to the research?)		

Table A3. *Primary studies included for review.*

Primary Study	Title	Authors	Year
S1	A Hybrid Model for Central Bank Digital Currency Based on Blockchain	Jinnan Zhang, Rui Tian, Yanghua Cao, Xueguang Yuanzefeng Yu, Xin Yan, & Xia Zhang	2021
S2	A Compendium of Practices For Central Bank Digital Currencies For Multinational Financial Infrastructures	Edwin Ayisi Opare & Kwangjo Kim	2020
S3	An Intelligent Cross-Border Transaction System Based on Consortium Blockchain: A Case Study in Shenzhen, China	Zhengtang Fu1, Peiwu Dongid, Siyao Li, &Yanbing Ju	2021
S4	Blockchain-Based Distributed Banking for Permissioned and Accountable Financial Transaction Processing	Wenjun Fan, Sang-Yoon Chang, Shawn Emery& Xiaobo Zhou	2020
S5	Impact Of Bitcoin's Distributed Structure on The Construction of The Central Bank's Digital Currency System	Jun Yang, Zhiguang Li	2020

Primary Study	Title	Authors	Year
S6	Implementation Of Blockchain in Financial Sector to Improve Scalability	Sheetal Sinha,Kumkum,Ruchika Bathla	2019
S7	Implementing A Retail CBDC: Lessons Learned and Key Insights	Raúl Morales-Resendiz A , Jorge Ponce B , Pablo Picardo B , Andrés Velasco C , Bobby Chen D , León Sanz E , & Gabriela Guiborg F , Björn Segendorfff , Joséluis Vasquez G , John Arroyo H , Illich Aguirre H , Natalie Haynes I , Novelette Panton I , Mario Griffiths I , Cedric Pieterz J , & Allister Hodge K	2021
S8	Improving Banking Transactions Using Blockchain Technology	Seybou Sakho, Zhang Jianbiao, &Firdaous Essaf,	2019
S9	Online Digital Cheque Clearance and Verification System Using Block Chain	Bogahawatte W.W.M.K. A; Isuri Samanmali A.H. L; Perera K.D. M; Kavindi M.A. T; Senaratne A. N; Rupasinghe L. P	2021
S10	Opportunities, Challenges and Promotion Countermeasures Of Central Bank Digital Currency	Xidi Zhang	2020
S11	Privacy And Transparency In CBDCs: A Regulation-By-Design AML/CFT Scheme	Nadia Pocher & Andreas Venerisy	2021
S12	Rembit: A Blockchain Based Solution for Remittances to Ethiopia	Piergiorgio Ricci& Valentina Mammanco	2019
S13	The Design and Empirical Research of One Main Stem With Others Branchesmonetary System Based On Blockchain Technology	Qi Jiayin & Li Zhibing	2020
S14	He Design and Implementation of Trade Finance Application Based on Hyperledger Fabricpermissioned Blockchain Platform	Nizamuddin Ariffin & Ahmad Zuhairi Ismail	2019
S15	The Impact of Blockchain in Banking Processes: The Interbank Spunta Case Study	Nicola Cucari, Valentina Lagasio, Giuseppe Lia & Chiara Torriero	2021
S16	A Blockchain-Based Framework for Central Bank Digital Currency	Xuan Han, Yong Yuan, Fei-Yue Wang	2019
S17	Design Principles and Best Practices of Central Bank Digital Currency	Dongcheng Lia, W. Eric Wonga, Sean Panb, Liang Seng Kohb, & Matthew Chaua	2021
S18	Exploration And Practice of Interbank Application Based on Blockchain	Tong Wu & Xiubo Liang	2017
S19	Central Bank Digital Currencies— Design Principles For Financial Stability	Michael Kumhof & Clare Noone	2021
S20	Blockchain Implementation Method for Interoperability Between CBDCs	Hyunjun Jung and Dongwon Jeong	2021
S21	Integrated DLT And Non-DLT System Design for Central Bank Digital Currency	Danarto Tri Sasongko & Setiadi Yazid	2021
S22	A Blockchain Technology Approach for The Security And Trust In Trade Finance	N. Jain & R. R. Sedamka	2020
S23	Blockchain Systems for Trade Clearing	Tsai, Wei-Tek, Luo, Yong, Deng, Enyan, Zhao, Jing, Ding, Xiaoqiang, Li, Jie, &Yuan, Bo	2020
S24	Blockchain-Based Solution for Detecting And Preventing Fake Check Scams	B. Hammi,S. Zeadally, & Y. C. E. Adja M. D. Giudice & J. Nebhen	2021
S25	Transforming The Know Your Customer (KYC) Process Using Blockchain	P. Yadav & R. Chandak	2019
S26	Blockchain Enabled KYC Solutions Using Hyperledge Fabric	R. R. Biradar & M. Dakshayini	2020

Table A4. *Technical project reports included for review.*

Report	Title	Organisation	Year
R1	Project Jasper: A Canadian Experiment with Distributed Ledger Technology For Domestic Interbank Payments Settlement	Bank Of Canada	2016
R2	Jasper Phase 3: Securities Settlement Using Distributed Ledger Technology	Bank Of Canada	2018
R3	Multi-CBDC Arrangements and The Future of Cross-border Payments	Bank Of International Settlements	2021
R4	Project Scriptless Bond: Investing in Thailand's Future Transforming The Securities Markets Infrastructure With Blockchain	Bank Of Thailand	2018
R5	Inthanon-Lionrock: Leveraging Distributed Ledger Technology to Increase Efficiency In Cross-Border Payments	Bank Of Thailand & Hong Kong Monetary Authority	2018
R6	Spunta Case: Fast and Transparent Interbank Reconciliation Powered By Distributed Ledger Technology	Bank Of Italy& R3	2020
R7	Cross-Border Interbank Payments and Settlements: Emerging Opportunities for Digital Transformation	Bank Of Canada, Bank of England & Monetary Authority of Singapore	2018
R8	Jasper – Ubin Design Paper: Enabling Cross-Border High Value Transfer Using Distributed Ledger Technologies	Bank Of Canada & Monetary Authority of Singapore	2019
R9	Project Ubin Phase 5: Enabling Broad Ecosystem Opportunities	Monetary Authority of Singapore	2020
R10	The Future Is Here Project Ubin: SGD On Distributed Ledger	Monetary Authority of Singapore	2016
R11	Project Ubin: Delivery Versus Payment on Distributed Ledger Technologies	Monetary Authority of Singapore and Singapore Security Exchange	2018
R12	Project Ubin Phase 2: Re-Imagining Interbank Real-Time Gross Settlement System Using Distributed Ledger Technologies	Monetary Authority of Singapore	2017
R13	Project Bakong: Next Generation Payment System	National Bank of Cambodia	2020
R14	Payment Systems: Liquidity Saving Mechanisms in A Distributed Ledger Environment	European Central Bank & Bank of Japan	2017
R15	Project Khokha: Exploring the Use Of Distributed Ledger Technology For Interbank Payments Settlement In South Africa	Reserve Bank of South Africa	2018
R16	Project Aber: Saudi Central Bank and Central Bank of The U.A.E. Joint Digital Currency and Distributed Ledger Project	Saudi Arabian Central Bank & Central Bank of United Emirates	2019
R17	Stella 2: Securities Settlement Systems: Delivery vs. Payments in a Distributed Ledger Environment	European Central Bank & Bank of Japan	2018
R18	Stella 3: Synchronised Cross-border Payments	European Central Bank & Bank of Japan	2019
R19	The Riksbank's E-Krona Project	Swedish Central Bank	2017

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Editorial record: The article has been peer-reviewed. First submission received on 13 October 2022. Revision received on 16 November 2022. Accepted for publication on 28 November 2022. The editors coordinating the peer-review of this manuscript were Venkatachalam Kandasamy, Mohamed Abouhawwash, Nebojsa Bacanin. The editor in charge of approving this manuscript for publication was Zdenek Smutny.

Special Issue: Sustainable Solutions for Internet of Things Using Artificial Intelligence and Blockchain in Future Networks.

Acta Informatica Pragensia is published by Prague University of Economics and Business, Czech Republic.

ISSN: 1805-4951