Distributed Ledger Technology (DLT) Applications in Payment, Clearing, and Settlement Systems:
A Study of Blockchain-Based Payment Barriers and Potential Solutions, and DLT Application in Central Bank Payment System Functions

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ABSTRACT

Payment, clearing, and settlement systems are essential components of the financial markets and exert considerable influence on the overall economy. While there have been considerable technological advancements in payment systems, the conventional systems still depend on centralized architecture, with inherent limitations and risks. The emergence of Distributed ledger technology (DLT) is being regarded as a potential solution to transform payment and settlement processes and address certain challenges posed by the centralized architecture of traditional payment systems (Bank for International Settlements, 2017). While proof-of-concept projects have demonstrated the technical feasibility of DLT, significant barriers still hinder its adoption and implementation.

The overarching objective of this thesis is to contribute to the developing area of DLT application in payment, clearing and settlement systems, which is still in its initial stages of applications development and lacks a substantial body of scholarly literature and empirical research. This is achieved by identifying the socio-technical barriers to adoption and diffusion of blockchain-based payment systems and the solutions proposed to address them. Furthermore, the thesis examines and classifies various applications of DLT in central bank payment system functions, offering valuable insights into the motivations, DLT platforms used, and consensus algorithms for applicable use cases. To achieve these objectives, the methodology employed involved a systematic literature review (SLR) of academic literature on blockchain-based payment systems. Furthermore, we utilized a thematic analysis approach to examine data collected from various sources regarding the use of DLT applications in central bank payment system functions, such as central bank white papers, industry reports, and policy documents.

The study's findings on blockchain-based payment systems barriers and proposed solutions; challenge the prevailing emphasis on technological and regulatory barriers in the literature and industry discourse regarding the adoption and implementation of blockchain-based payment systems. It highlights the importance of considering the broader socio-technical context and identifying barriers across all five dimensions of the social technical framework, including technological, infrastructural, user practices/market, regulatory, and cultural dimensions.

Furthermore, the research identified seven DLT applications in central bank payment system functions. These are grouped into three overarching themes: central banks' operational responsibilities in payment and settlement systems, issuance of central bank digital money, and regulatory oversight/supervisory functions, along with other ancillary functions. Each of these applications has unique motivations or value proposition, which is the underlying reason for utilizing DLT in that particular use case.

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LIST OF ABBREVIATIONS

FMI – Financial Market Infrastructure

DLT – Distributed Ledger Technology

UK – United Kingdom

FPS – Faster Payment System

BT Group – British Telecommunications Group

CPMI – Committee on Payments and Market Infrastructures

PSP – Payment Service Provider

RTGS – Real Time Gross Settlement

DNS – Deferred Net Settlement

BACS – Bankers' Automated Clearing System

NIE – New Institutional Economics

ACH – Automated Clearing House

CHAPS – Clearing House Automated Payment System

APACS – Association of Payments and Clearing Services

POC – Proof of Concept

ICS – Image Clearing System

ISA – Individual Savings Account

DCSP – Directly Connected Settling Participants

DCNSP – Directly Connected Non-Settling Participants

C&CCC – Cheque and Credit Clearing Company

BoE – Bank of England

IPSL – Intelligent Processing Solutions Ltd

ATM – Automated Teller Machine

PSP – Payment Service Provider

GBP – British Pound Sterling

MLR – Multivocal Literature Review

SLR – Systematic literature review

KYC – Know Your Customer

AML – Anti-Money Laundering

CBDC – Central Bank Digital Currency

BIS – Bank for International Settlements

PoW – Proof of Work

PoS – Proof of Stake

DPoS – Delegated Proof of Stake

PBFT – Practical Byzantine Fault Tolerance

FBA – Federated Byzantine Agreement

RPCA – Ripple Protocol Consensus Algorithm

PoAu – Proof of Authority

DPoS – Delegated Proof of Stake

PoET – Proof of Elapsed Time

PoAc – Proof of Activity

PoB – Proof of Burn

PoC – Proof of Capacity

RQ – Research Question

STS – Social Technical Systems

TIS – Technological Innovation System

STT – Social Technical Transition

R&D – Research and Design

TIS – Technological Innovation System)

PICO – Population Intervention Comparison Outcome

IEEE – Institute of Electrical and Electronics Engineers

TPS – Transactions Per Second

SEGWIT – Segregated Witness

PCN – Payment Channel Networks

DoS – Denial of Service

DDoS – Distributed Denial of Service

DCAP – Decentralized Anonymous Conditional Payment

RAM – Random Access Memory

NCDS – Network Coded Distributed Storage

RtbF – Right to be Forgotten.

GDPR – General Data Protection Regulation

DAP – Decentralized Anonymous Payment

CC – Comparison Criteria

ACM – Association for Computing Machinery

LVPS – Large-Value Payment System

PFMI – Principles of Financial Market Infrastructure

LSM – Liquidity Savings Mechanism

SGD – Singapore Dollar

SWIFT – Society for Worldwide Interbank Financial Telecommunication

HTCL – Hashed Timelock Contract

HKMA – Hong Kong Monetary Authority

BOT – Bank of Thailand

SEPA – Single Euro Payments Area

SDD – SEPA Direct Debit

DDBMS – Distributed Database Management Systems

FCA – Financial Conduct Authority

GDP – Gross Domestic Product

WBG – World Bank Group

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CHAPTER ONE: INTRODUCTION

1.1 Background

1.1.1 Payment and settlement systems

Payment, clearing, and settlement systems are essential components of the financial markets and exert considerable influence on the overall economy (Ali & A. Salameh, 2023). These systems provide the necessary infrastructure and channels for the secure and efficient transfer of funds, allowing payment obligations arising from financial and economic transactions throughout the entire economy to be fulfilled (Umali et al., 2019). This in turn promotes the smooth flow of funds and reduces transaction costs in payment transactions. Businesses and individuals can therefore transact more readily and efficiently, resulting in increased economic activity and growth.

In addition to facilitating transactions, payment and settlement systems are critical to monetary policy (Papadia, 2018). For example, in the United Kingdom, The Bank of England's RTGS system serves as a channel for implementing monetary policy decisions by providing liquidity to the country's financial system to ensure banks and other financial institutions have funds to meet their obligations as they arise, and settling interbank obligations (Bank of England, 2022). Any financial, legal, or operational defect in a clearing and settlement institution could pose a systemic risk to the whole financial system. This is the risk that the failure of an infrastructure in a payment, clearing, and settlement arrangement, has the potential to lead to a chain reaction of defaults of other entities, destabilizing the entire financial system (The Banque de France, 2021).

Prior research has documented the significance of payment and settlement systems for the economy, particularly in the context of emerging economies. For example, Afaha's (2019) research reveals a significant positive correlation between electronic payment systems and real Gross Domestic Product (GDP) growth in Nigeria. Similarly, Rooj and Sengupta's (2020) research demonstrates the positive impact of real-time gross settlement (RTGS), a payment system that facilitates real-time fund transfer between financial institutions, on India's economic development. The study also reveals a two-way causal relationship between RTGS and economic development, in which economic growth causes an increase in both the value and number of RTGS transactions.

Given their significant role in economies, various global and national institutions lead initiatives to support the development of efficient and accessible payment systems. For instance, the World Bank Group (WBG) integrates the promotion of safe, reliable, and efficient domestic and cross-border payment systems into their work to reduce poverty and promote shared prosperity. It has consequently implemented a range of initiatives such as developing payment system strategies, establishing institutional arrangements, and providing technical and financial support for payment system components to countries. Moreover, the WBG has contributed to the development of international payment system standards and shared knowledge related to global payment systems. The importance of resilient and efficient payment systems is also emphasized by the Committee on Payments and Market Infrastructures (CPMI) in promoting financial stability, further emphasizing their significance (Bank for International Settlements, 2023; World Bank, 2023).

1.1.2 DLT Innovation in Payment, Clearing and Settlement Systems

The origin of payment systems can be traced back to the earliest human civilizations, in which bilateral barter trade was the primary mode of exchange of goods and services between parties. As commerce became increasingly complex, barter trade was rendered impractical, leading to the gradual adoption of symbolic representation of value such as shells, pearls, and metal coins. Over time, currencies evolved and became more standardized and regulated, giving rise to various forms of electronic payment systems.

In the last few decades, payment and settlement systems have undergone significant technological advancements and innovation. According to Bech and Hancock (2020), innovation in wholesale payment systems has occurred in cyclical patterns over the past few decades. The first wave of innovations during the 1990s was characterized by the implementation of (RTGS) systems, which effectively reduced credit risk but led to increased liquidity requirements for participants in payment, clearing and settlement arrangements. The subsequent wave of innovation during the 2000s aimed to address this challenge by introducing liquidity-saving mechanisms and multicurrency functionality. Current trends have focused on "broadening access of the payment systems to non-bank payment service providers (PSPs), extending operational hours, and enhancing the interoperability between systems" (Bech & Hancock, 2020). The retail payment landscape has also undergone significant changes, which are attributed to technological advancements, evolving consumer preferences, and demands for faster and more convenient payment methods (Bech & Hancock, 2020). At first, the emphasis was on improving the front-end to offer more convenience for consumers, such as by implementing mobile and contactless payment methods.

More recent advancements have expanded the focus on enhancing back-end arrangements as well. An example of this is the introduction of closed-loop systems like WeChat Pay, launched in 2011, which offer services directly to both payers and payers.

Despite the significant advancements in payment system technology that have enhanced reliability, availability, and security, centralized payment systems' fundamental framework has remained unchanged. In general, financial market infrastructures (FMIs) are commonly responsible for maintaining the accuracy and security of a central ledger, as well as managing certain risks on behalf of participants in several markets (Bank for International Settlement, 2017). In most countries for instance, the central bank acts as the settlement agent, while each participant, typically a bank or non-bank payment service provider with direct access to the payment system, "maintains a recorded balance in the ledger at the central bank, which is also reflected in the participant bank's internal ledger (Six, 2023)". Transactions between participants are ultimately settled by adjusting their balances at the central bank.

While centralized payment, clearing, and settlement systems have been the backbone of financial transactions for many years, there are areas where they could be improved to meet the evolving needs of the financial ecosystem and enhance their efficiency and reliability. For example, the Bank of England is exploring the RTGS renewal initiative to strengthen payment system resilience, promote interoperability between payment systems, facilitate broader access, and improve user functionality (Bank of England, 2023). Distributed ledger technology (DLT) has garnered recognition as a potential catalyst to drive transformation and tackle various challenges in the financial services industry including payment, clearing and settlement processes (Fong et al., 2021). Its potential has been highlighted in recent literature by Xu et al. (2019), Ali et al. (2020), Dicuonzo et al. (2021), Javaid et al. (2022), and Banerjee & Chandani (2022). According to Rauchs et al. (2018), DLT refers to an "electronic record-keeping system that allows multiple independent parties to establish consensus on the authoritative ordering of cryptographically validated ('signed') transactions." This technology integrates several pre-existing technologies, including distributed databases, cryptography, and peer-to-peer networking, to revolutionize how information is recorded, stored, and distributed.

The key characteristics of DLT which collectively enable a secure and decentralized approach to record-keeping and data management include distributed databases, consensus mechanisms, and cryptographic hashes (Rauchs et al., 2018). The distributed nature of DLT systems enables participants to collaboratively maintain and verify data in a peer-to-peer network, without relying on a central trusted authority (Nguyen et al., 2022). Unlike conventional centralized and other distributed database systems, which have a single entity controlling and storing data in one location, DLT systems distribute the database or ledger across multiple nodes in the network, increasing its security and resilience (Rauchs et al., 2018). On the other hand, the consensus mechanism is fundamental in facilitating consensus among participants on a network on the validity of transactions and the status of the ledger. In public blockchains, all participants can propose new transactions, which others validate through consensus protocols and cryptographic methods to prevent fraudulent activities like double spending (Nguyen et al., 2019). In contrast, permissioned DLT systems prioritize speed and efficiency over security, owing to their distinct attributes, such as restricted accessibility and participation. This enables the use of consensus algorithms that align with these requirements. Lastly, cryptographic hashes are an essential component of DLT systems as they are applied to ensure the integrity and immutability of the data stored on the ledger. This is achieved through employing mathematical algorithms that transform data into a distinctive code of a fixed size, which acts as a digital fingerprint. If any modifications are made to the original data, the hash value will be different, notifying network participants of the presence of tampering or fraudulent activity.

The operational principle of DLT systems can be exemplified through a transaction on the bitcoin blockchain, which is a prominent type of DLT system that has attracted considerable attention since its introduction in 2008.

"The following sequence is followed in a transaction involving Alice and Bob, where Alice intends to transfer 1 bitcoin to Bob: Alice uses her private key to generate a transaction that includes details specific to the transaction, such as the sum of money she wants to transfer and Bob's address. The information is hashed and subsequently broadcast to the bitcoin network. A miner then bundles up this transaction with others and validates them by executing the Signature Script along with the PubKey Script. If the outcome is a "true" result, indicating validity, the transaction is added to the block, and the block is subsequently broadcast to the network for validation by other nodes. Once verified, the block is incorporated into the chain and identified as the most recent block. As additional blocks are appended to the chain, the count of confirmations for Alice's transactions increases" (Nguyen et al., 2019).

Some key areas of interest of DLT application in the financial services industry include payment and settlement systems (Mills et al., 2016; Karaindrou, 2017), know your customer (KYC) procedures and identity management (Parra-Moyano & Ross, 2017), securities trading, issuance & post-trade settlement (Priem, 2018), digital currencies (Hashimy & Sandner, 2020), asset tokenization (Trivedi et al., 2021), cross-border remittances (Rella, 2019), trade finance (Kowalski et al., 2021), fraud detection (Ashfaq et al., 2022), and capital markets (Wu & Duan, 2019). The scope of this research is limited to the application of DLT in payment, clearing, and settlement processes.

The potential benefits of DLT in this domain include "streamlining operations, enhancing regulatory efficiency, mitigating counterparty risk, decreasing clearing and settlement times, improving liquidity and capital, and minimizing instances of fraud" (Mills et al., 2016; World Economic Forum, 2015). Various industry proof of concepts and pilots have been conducted to evaluate the feasibility and effectiveness of DLT in payment, clearing, and settlement processes. For instance, the Bank of Canada conducted an experiment in wholesale payment systems using DLT-based RTGS and found that it could reduce settlement risks, costs, and counterparty risks while increasing speed and efficiency (Chapman et al., 2017). Another area where DLT shows potential is cross-border payment systems, as demonstrated by Project Inthanon LionRock between HKMA (Hong Kong Monetary Authority) and Bank of Thailand (BOT), which led to the enhancement of cross-border payment efficiency and improvement in transparency and traceability of transactions (Hong Kong Monetary Authority, 2019). Furthermore, DLT can provide a secure platform for reducing counterparty risk, enhancing transparency and auditability of clearing and settlement systems (Mills et al., 2016). Lastly, DLT can streamline the KYC and AML (Anti Money Laundering) processes, reducing compliance costs and providing greater security and privacy protection (Parra-Moyano & Ross, 2017).

1.2 Statement of the Problem

Despite several proof-of-concept projects and pilots demonstrating the technical feasibility of DLT in payment, clearing, and settlement processes, the technology is still in its early developmental stage, with various challenges hindering its adoption and implementation. Researchers have identified these challenges across various dimensions, including technical, social, and regulatory challenges (Holotiuk et al., 2018; Kawasmi et al., 2020; Saheb & Mamaghani, 2021; Gan et al., 2021; Weerawarna et al., 2023).

Technical challenges include issues related to scalability (Zhang & Yang, 2021), security threats and vulnerabilities (Rahouti et al., 2018), and challenges in maintaining both transparency and privacy in blockchain-based payment systems (Uddin et al., 2021; Jia et al., 2022). Social challenges include the rigidity of user preferences and routines on dominant modes of payments (Nadeem et al., 2020) and lack of knowledge and awareness of blockchain-based payment systems (Presthus & O'Malley, 2017). Regulatory challenges include lack of adequate regulatory frameworks (Politou et al., 2021), requirement for regulatory compliance (Politou et al., 2021) and lack of clear governing structure (Ziolkowski et al., 2020).

Several of these challenges have also been reflected on white papers of pilots and proof of concept projects. One such project was conducted by Payments Canada, Bank of Canada, R3, and Canadian commercial banks, which aimed to explore the feasibility of using DLT for domestic RTGS systems (Garratt et al., 2017). This project, named Project Jasper, assessed whether a DLT system could fulfill the requirements of a financial market infrastructure, as outlined in the Principles of Financial Market Infrastructure (PFMI). The platform was built on the Ethereum protocol, and the central bank's role was to issue digital depository receipts for exchange and settlement between participating financial institutions. While Phase 1 of the project successfully demonstrated value transfer between participants, it did not provide the required settlement finality for a core settlement system. Furthermore, according to the report, earlier versions of public permissionless DLT systems did not offer an overall net advantage over existing centralized systems. Similarly, the Australian Securities Exchange (ASX) attempted to replace its legacy clearing and settlement system with a DLT project called CHESS but faced several technical and operational challenges that led to the project's abandonment in 2021 (ASX, 2021). Addressing these challenges is crucial for the successful adoption and implementation of DLT-based systems in payment, clearing, and settlement processes.

There has been a noticeable increase in research and industry interest regarding the potential implementation of DLT in the financial services sector. This trend is reflected in review papers authored by Ali et al. (2020), Trivedi et al. (2021), Pal et al. (2021), and Gan et al. (2021). Certain studies have focused on identifying the particular use cases of DLT within the broader context of the financial services industry. Zhang et al. (2020) identified three primary use cases for DLT in finance, namely cryptocurrency and trading platforms, cross-border payments, and digital asset register and management. Guo and Liang (2016) identified several areas where DLT can be applied including payment clearing systems, development of credit information systems for banks, establishment of data ownership, and promotion of data sharing. Jaroodi & Mohamed, (2019) identified "digital currencies, stock trading, insurance marketplace, financial settlements, and peer- to- peer global financial transactions as the key applications of blockchain in the financial services industry". These studies provide valuable insights into the potential of DLT in financial services.

There are also several published reviews that have synthesized the literature on DLT application in the financial services industry. For instance, Trivedi et al. (2021) conducted an SLR to investigate the development, challenges, and applications of blockchain in the financial sector and identified various barriers to adoption, including technical challenges like scalability, interoperability, and security issues and regulatory challenges including lack of legal framework, standardization, and governance. Ali et al. (2020) also conducted an SLR on blockchain in financial services, focusing on the benefits, challenges, and functionality.

Despite the valuable insights provided by studies on DLT, several gaps and limitations persist and require attention to enhance comprehension of its potential and impact on the financial services industry, particularly in payment, clearing and settlement processes. Holotiuk et al. (2018) posit that the utilization of DLT applications in the payment industry is currently restricted to pilot studies, as the technology remains in the developmental stage. Similarly, Ali et al. (2020) highlights a lack of scholarly and empirical research on the present state-of-the-art of blockchain-enabled benefits, challenges, and functions, despite the abundance of grey literature on the subject (Brandão et al., 2018). Another gap in the literature pertains to the absence of theory driven research with comprehensive theoretical evaluation and review frameworks, that assess the barriers impeding the adoption and diffusion of blockchain-based payment systems. While there have been several Systematic Literature Reviews (SLRs) and surveys on the barriers to the adoption of blockchain technology in the financial services industry, such as those conducted by Ali et al. (2020), Trivedi et al. (2021), Pal et al. (2021), and Gan et al. (2021), none of these studies provide a comprehensive analysis that aggregates all major barriers of blockchain-based payment systems, ranks them according to their significance, establishes their inter-relatedness, and identifies their corresponding proposed solutions.

Given the existing gaps and limitations in the literature, there is a need for a more in-depth investigation focusing on applications of DLT in payment, clearing and settlement systems, and barriers to adopting blockchain-based payment systems. Such a study should broaden the scope to include proposed solutions and countermeasures. Bridging these research gaps is crucial and timely as academic research provides a theoretical foundation for practical implementation in any field. In the case of DLT implementation in central bank payment system functions, academic research can provide insights into the underlying social, technical, and economic principles and implications of DLT applications. The insights gained from research can play a crucial role in guiding practical implementation and facilitating the resolution of potential challenges that may arise in the process. Bridging the research gap between industry practitioners and academics can effectively ensure that practical implementation is grounded in sound theoretical foundations and can thus more effectively accomplish its intended objectives.

1.3 Research Questions and Objectives

This thesis aims to assess the barriers to adoption and implementation of blockchain-based payment systems and to conduct a systematic analysis of DLT applications in central bank payment systems functions. The purpose is to contribute to the developing area of DLT application in payment, clearing and settlement systems, which is still in its initial stages of applications development and lacks a substantial body of scholarly literature and empirical research.

To accomplish this, the researcher formulated two sets of Research Questions and their subsequent Objectives.

The first set of research questions are:

(RQ1): What is the current state of research on the barriers to adoption and diffusion of blockchain-based payment systems?

(RQ2): What are the barriers to adoption and diffusion of blockchain-based payment systems?

(RQ3): What solutions have been proposed in the literature to address the identified barriers to adoption and diffusion of blockchain-based payment systems?

These research questions will be explored through the following two objectives. Research Objective 1 (RO1) is to identify the socio-technical barriers that hinder the adoption and diffusion of blockchain-based payment systems. The second Research Objective 2 (RO2) is to examine the proposed solutions in the literature to overcome these barriers.

The second set of Research Questions are:

(RQ4): What is the current state of the art of research and development of DLT applications in central bank payment system functions?

(RQ5): What are the specific applications of DLT in central bank payment system functions? Subset research questions for each application are:

(RQ5.1): What is the motivation behind adopting DLT in the specific use case?

(RQ5.2): What DLT platforms are used, and what algorithm consensus are implemented in the proof of concepts, pilots, and projects considered in the literature pool?

These research questions will be addressed by the third and fourth Research Objectives. Research Objective 3 (RO3) is to identify current DLT applications in central bank payment system functions using central banks' white papers, industry reports, policy documents, and other relevant sources. The fourth Research Objective 4 (RO4) is to systematically classify and synthesize the state-of-the-art and practice in DLT applications in central bank payment system functions. This objective aims to focus on identifying the motivation behind adopting DLT in each applicable use case and the specific DLT platforms and consensus algorithms used.

1.4 Research Contributions

The presented PhD thesis contains several chapters, each making a distinct contribution to the literature on DLT application in payment, clearing and settlement processes. The subsequent paragraphs elaborate on these contributions.

The thesis contributes to the literature by providing an overview of the current payment and settlement systems. The literature on DLT frequently concentrates on the potential of DLT to revolutionize present payment and settlement systems; however, there is limited discussion about the current systems. Therefore, this chapter fills a gap in the literature by providing an understanding of the context in which DLT innovation is taking place and identifying potential areas where DLT can address existing challenges. Additionally, the chapter reviews relevant literature to identify some institutional and economic factors that influence innovation in payment and settlement systems using the UK as an illustrative case. Future research can build on these preliminary insights.

The thesis contribution to the literature also lies in its provision of foundational knowledge and a structured approach to comprehending and assessing the potential implementation of DLT in payment, clearing, and settlement systems. It reviews relevant literature and reports to offer an overview of DLT applications, discusses the technological components of DLT systems, and the potential configurations of

DLT systems. This information can be beneficial to researchers and industry practitioners seeking to gain knowledge in DLT applications.

A significant theoretical contribution to academic literature is on the application of socio-technical systems theory to the blockchain context, specifically in assessing the barriers of blockchain-based payment systems. To the best of our knowledge, the social-technical systems perspective has not been applied in any previous studies to evaluate the barriers of blockchain-based payment systems.

The study's findings indicate that the application of the social-technical systems perspective is applicable to the blockchain context, and it offers a valuable approach for considering and identifying barriers that may not be apparent on a surface level. The social-technical systems theory recognizes the interdependence of social and technical factors in influencing the adoption and diffusion of innovations, thus offering a more intricate comprehension of the barriers to adoption in the context of blockchain-based payment systems.

In the context of blockchain-based payment systems, industry stakeholders have placed significant emphasis to the development of diverse types of blockchain systems, applications, and solutions to address the limitations of existing blockchain-based payment systems. For instance, alternative consensus protocols to the initial proof of work have been explored to address scalability and energy efficiency challenge. However, by employing the social- technical systems perspective the study's findings suggest there are other significant and latent barriers that require attention beyond the technical aspect. The socio-technical perspective also underscores the importance of recognizing the interrelatedness of barriers across multiple dimensions. The research findings reveal instances where the factors within the technical and social dimensions of blockchain-based payment systems do not function optimally together, creating barriers to adoption of blockchain-based payment systems. For instance, a key property of public blockchain systems is the immutability of data. This could conflict with requirements for regulatory compliance, for example the GDPR’s “Right to be Forgotten (RtbF)” provision that gives individuals the right to erasure of their personal data. This highlights the need for an integrated approach to identifying and addressing barriers in blockchain-based payment systems that recognizes the interplay between technical and social factors, in line with sociotechnical system theory's principle.

Conversely, the study also contributes to social-technical systems research by demonstrating its applicability in the context of blockchain-based payment systems. It provides evidence of how this perspective can be applied to assess the barriers to adoption and implementation of blockchain-based payment systems. This approach could serve as a model for future research that examines the barriers to adoption and implementation of blockchain applications in various contexts beyond payment systems.

Another contribution of this study to the literature is through the identification of unique barriers to adoption and implementation of blockchain-based payment systems. By specifically analyzing blockchain-based payment systems, this study draws targeted insights that are specific to this context. To the best of the researcher's knowledge, this is the first SLR to adopt a narrow focus on blockchain- based payment systems. Other SLRs take a broad approach to blockchain adoption in the financial services industry or cryptocurrency. This has led to the identification of barriers that are unique to this context. One such barrier is the inefficiency of public blockchain in processing micropayments, which has not been previously highlighted in SLRs focusing on the adoption of blockchain in the broader financial services industry.

The identification of barriers to blockchain adoption across multiple dimensions including (technological, infrastructure, institutional, cultural, and market/user preferences) is also a contribution to literature as, no other study has considered these exact dimensions in-depth for this context. While previous studies have identified barriers in some of these dimensions, the present study provides a more comprehensive description of the barriers in a payment systems context and aggregates them in a matrix hence provides a more nuanced understanding of the challenges faced by the industry in adopting blockchain-based payment systems. This has led to the identification and discussion of existence of other barriers that have either not been thoroughly discussed in earlier research or have been underestimated in their impact on blockchain adoption. For instance, within the technology dimension, while previous studies have identified the immaturity of technological designs as a barrier, the present study has recognized the importance of the supporting infrastructure required for implementation. The absence of a robust physical infrastructure can cause network latency, system downtime, and slow processing times, which can make it less attractive to potential users. Similarly, the lack of supportive financial infrastructure can make it difficult to transfer funds seamlessly, limiting adoption and implementation. Moreover, the availability of a comprehensive knowledge infrastructure is crucial in ensuring that users have the skills to operate and maintain the system effectively, yet this aspect has received less coverage compared to the technological immaturity. In the infrastructure dimension, the study has identified network connectivity requirements as a barrier, particularly in areas with unreliable and intermittent network connectivity. In the institution dimension, the study has identified the lack of clear governing structure as a barrier to the widespread adoption and utilization of blockchain-based payment systems. The identification of these unique barriers by considering these dimensions further reinforces the novelty of this study, as it provides new insights into latent barriers that need to be considered and must be addressed to achieve widespread adoption and implementation of blockchain-based payment systems.

In addition to identifying barriers, the research also presents a significant contribution to literature by considering proposed solutions for each barrier. The study explores the solutions proposed in existing literature as countermeasures for the barriers to blockchain-based payment systems. This approach sets the study apart as the first SLR on blockchain-based payment systems that considers corresponding solutions proposed for each barrier. This contribution is important because the identification of barriers to the adoption and implementation of blockchain-based payment systems is only one part of the equation. It is equally important to explore potential solutions to overcome these barriers. By considering proposed solutions for applicable barriers, the study provides a more comprehensive understanding of the extent of the barriers and potential solutions and their effectiveness. This is particularly valuable to practitioners seeking to implement blockchain-based payment systems while encountering various obstacles, as well as policymakers interested in understanding how these concerns can be addressed. Additionally, this contribution is crucial for researchers who seek to further advance the knowledge base on blockchain-based payment systems. By exploring proposed solutions for each barrier, the study can help researchers identify gaps in the literature and develop new and innovative solutions to overcome these barriers. Furthermore, the study's approach of considering proposed solutions can serve as a basis for future research on the effectiveness and feasibility of these solutions in practice.

Regarding methodological contribution, the thesis applies a unique systematic approach to selecting central bank white papers, policy documents and industry reports on DLT applications in central bank payment systems functions. The multivocal literature review (MLR) approach employed to identify and select the sources highlights its potential application in emerging research areas, such as DLT in central bank payment systems, where diverse opinions and viewpoints exist, and academic literature lags industry development. The absence of prior research on DLT application in central bank payment systems function adopting this specific approach of document selection, as revealed by the researcher's thorough review of the existing literature, serves to underscore the novelty of the study. The use of official publications, such as white papers, enhanced the reliability and credibility of the research, as these publications undergo review and approval by the central bank's management before publication. Furthermore, the use of thematic analysis with software support in NVivo is a notable methodological contribution to academic literature on DLT.

This approach provides a more systematic and rigorous way to analyze the vast amounts of data available on DLT applications in central bank payment system functions. It allows for a more in-depth and comprehensive analysis of the data, leading to a better understanding of the topic. While thematic analysis has been used in other research contexts, its application to DLT applications in central bank payment system functions is relatively new. As such, this chapter makes a notable contribution to the existing literature by presenting a fresh perspective on this topic and offering practical guidelines on how thematic analysis can be effectively applied in this area of study.

The thesis also makes several empirical contributions to the literature on DLT applications in central bank payment systems functions by conducting a comprehensive analysis and synthesis of a wide range of sources, including official publications from central banks, and proof of concept and pilot projects white papers. First, the research identifies and classifies the various applications of DLT in central bank payment systems functions, presenting a consolidated view of the field. This approach provides a more comprehensive and nuanced understanding of how DLT is being used in this context, which can be valuable for policymakers and practitioners who are interested in implementing DLT-based solutions in central bank payment systems. By understanding the different ways in which DLT can be used, they can make more informed decisions about which applications to prioritize and how to address the potential benefits and challenges associated with each one.

The classification of DLT applications in central bank payment system functions into operational responsibilities, issuance of central bank digital money, regulatory oversight/supervisory functions, and other ancillary operational management functions is also a novel way of categorizing the use cases. This approach enhances the existing knowledge on DLT in central bank payment systems by providing a comprehensive way to understand the various ways in which DLT can be utilized within the context of central banks' overarching responsibilities. It also provides a basis for classification, which can serve as a guide for policymakers and practitioners who are interested in implementing DLT-based solutions in central bank payment systems. By using this classification matrix, they can better understand the potential benefits associated with each type of application and make informed decisions about which ones to prioritize.

Another notable empirical contribution of the research is its analysis of the motivations, DLT platforms, and consensus algorithms for applicable use cases in central bank payment systems. As one of the few studies in this area, the research provides valuable insights into the current state of practice by collating evidence from various sources and presenting a ranking of the most used DLT platforms and consensus algorithms. This information is crucial for policymakers and practitioners who are interested in implementing DLT-based solutions in central bank payment systems, as it enables them to make informed decisions about which platforms and consensus algorithms to prioritize. By providing a comprehensive understanding of the different DLT applications and their corresponding motivations, this study advances the body of knowledge on DLT in central bank payment systems. Its empirical findings offer new insights into how DLT is used in this context, allowing for a more nuanced understanding of the potential benefits associated with its implementation. This contributes to the broader academic literature on the use of emerging technologies in central bank payment systems and helps to inform future research in this area.

The study's unique consideration of DLT-based interbank payment rails operated by central banks is another contribution to the literature. By differentiating between DLT-based domestic RTGS (Real Time Gross Settlement) systems and DLT-based cross-border interbank payment and settlement arrangements, the research offers a more nuanced understanding of the potential benefits associated with each type of system. This approach is a novel way of considering DLT-based interbank payment rails, as most studies tend to aggregate DLT- based payment systems without distinguishing between domestic and cross-border systems. Furthermore, the study's findings on the primary drivers for DLT-based domestic RTGS systems and DLT-based cross-border interbank payment and settlement arrangements are also noteworthy contributions to the literature. By highlighting resilience as a primary driver for DLT-based domestic RTGS systems, the study offers a preliminary guide for evaluating the potential benefits of these systems and for developing strategies for their successful implementation. This finding suggests that there may be benefits to implementing DLT-based systems in addition to, or instead of, traditional domestic RTGS systems which are in most countries already considered efficient. Further research would be necessary to fully assess the benefits of implementing DLT-based systems for domestic RTGS. Similarly, the finding that efficiency is the primary driver for DLT-based cross-border interbank payment and settlement arrangements is also an important contribution to the literature. This insight highlights the importance of inefficiency in cross-border payment and settlement systems and suggests that DLT-based cross border arrangements may offer unique advantages in this context. This finding provides a valuable starting point for further research into the potential benefits and challenges of DLT-based cross-border interbank payment and settlement arrangements.

Lastly, by identifying gaps in the existing literature and outlining potential areas for future research, the chapter could help drive further innovation and development in DLT and central bank payment systems.

1.5 Research Methodology

Chapters 2 and 3 are integral to the thesis, as they provide the necessary background for the subsequent empirical analysis. These chapters follow a literature review approach incorporating industry reports with aim to identify, analyze, and synthesize available information on conventional payment, clearing, and settlement systems, as well as DLT in payment, clearing, and settlement systems. The methodology employed in these chapters is designed to provide a foundational understanding of the context in which DLT innovation is taking place.

To achieve this, relevant literature and sources were identified and critically analyzed. This review process provided insights into the existing payment, clearing, and settlement systems, as well as the potential advantages and disadvantages of using DLT in these systems. The review process was conducted rigorously, ensuring all relevant information was captured. The resulting insights offer a comprehensive understanding of the background and context in which DLT innovation is taking place in payment, clearing, and settlement systems. This understanding is essential for the subsequent empirical analysis presented in the thesis, which builds upon the foundational knowledge presented in Chapters 2 and 3.

We employed a systematic literature review (SLR) methodology that utilizes 55 academics studies published between 2017 and 2022 to identify barriers to adoption and implementation of blockchain-based payment systems, along with proposed solutions in the existing literature. The rationale for employing the SLR lies in its capacity to gather and synthesize a diverse array of studies, which provides insights into existing research gaps and areas that require further investigation. Moreover, the interdisciplinary nature of blockchain technology, which intersects with multiple domains such as computer science, social sciences, economics, and law, underscores the need for an approach that enables a range of literature across disciplines to be analyzed and synthesized enabling a more holistic perspective on the barriers and proposed solutions of blockchain based payment systems.

The first step involved constructing the search string, which was then applied to the selected databases to identify the relevant studies. The Population Intervention Comparison Outcome (PICO) approach proposed by Kitchenham et al., (2009) was adopted to guide the identification of the key words that were used in the search string construction resulting in the use of the search string [Blockchain AND Payment]. The selected databases include IEEE Xplore, Emerald Insight, Elsevier/Science Direct, Sage Journals, Oxford University Press, Wiley, and Taylor & Francis. Following the initial retrieval of potential sources for the study, a two-phase screening process was undertaken. The first phase involved screening the titles and abstracts of the sources, while the second phase involved a thorough reading of the journals that remained after the first phase. This screening process was conducted using predetermined inclusion and exclusion criteria to ensure the sources were relevant to the study, leaving a final set of 55 papers for analysis in the study. To extract the relevant data from the literature, a data extraction form was created. The form included the overarching social technical dimension, which served as a reference guide for identifying and systematically categorizing the barriers and corresponding proposed solutions. Each identified barrier and corresponding proposed solution were classified in the corresponding column within the social technical dimension. Once the data was extracted, data synthesis was conducted using a framework synthesis approach. In Chapter 4, the findings are presented descriptively, and tables are used to summarize the data and highlight some key findings.

In the second phase of the research, we employed a thematic analysis methodology to conduct a qualitative analysis on a range of documents that encompassed grey literature, such as central bank white papers on DLT applications in central bank payment system functions, industry reports, policy document manuals, and relevant academic literature on the topic, as the primary data source. The first step in this process involved employing a multivocal literature review approach (MLR) to select and screen the relevant documents for analysis. This approach ensured that the analysis considered a broad range of perspectives and viewpoints on the subject matter and allowed for a comprehensive and thorough understanding of the research topic. It is particularly well-suited for emerging topics where academic literature may not yet fully capture industry trends and insights as it ensures that research is not limited to one viewpoint, and that all relevant perspectives are considered. The approach adopted for the data extraction was a multi-stage approach. In the first stage, a data extraction form, in the form of a spreadsheet hosted on Google sheet, was created to extract bibliometric data, deduce specific DLT applications in central bank payment system functions. Subsequently, we utilized Braun and Clarke (2006), guidelines for conducting thematic analysis to conduct a qualitative analysis on the collected data. Thematic analysis is a qualitative research method that aims to identify, analyze, and report recurring patterns within a dataset. It can provide a detailed examination of a specific theme or group of themes within the data in relation to a particular question or area of interest, known as a semantic approach. In this study, thematic analysis was used to achieve the objective of providing a more in-depth exploration of specific themes within the dataset, which was guided by the was guided by the research question focusing on the motivation/value proposition (i.e., the driving force of implementing DLT in that specific use case). The initial step of thematic analysis involved the researcher becoming acquainted with the data. During this stage, we commenced the process of populating data related to the DLT platforms employed and the consensus algorithms utilized in the proof of concepts, pilots, and projects considered in the dataset in the google form. The second step of the thematic analysis involved generating initial codes. The coding process was carried out using NVivo software, where relevant text excerpts were tagged to their corresponding codes. In the third step, the researcher searched for themes by grouping the codes into meaningful clusters after completing the coding process. In the fourth step, we read the tagged extracts on NVivo corresponding to each theme which resulted in the collapse of some themes into others. In the last step of the analysis, we reviewed and renamed some themes to better reflect the research questions. We then developed synthesis of the research topic. The findings are presented in a descriptive manner, and NVivo code extracts and tables are used to summarize the data and highlight some key findings.

1.6 Summary of Key Findings

The chapter on barriers and proposed solutions for blockchain-based payment systems underscores the importance of considering the complex interplay of social and technical factors when evaluating the barriers to the adoption and implementation of blockchain systems, particularly in the context of payment systems. The research identified significant barriers within each dimension including technology, infrastructure, institutional, culture and markets and user preferences dimensions, underlining the multifaceted nature of the barriers hindering the widespread adoption and implementation of blockchain-based payment systems.

The findings of the research reflect that the current body of academic literature on blockchain-based payment systems has concentrated on technical factors that already have well-established proposed solutions, while overlooking other essential barriers within different dimensions. The study's narrow focus on payment systems also reveals latent barriers that are specific to this segment of the financial services and should be considered. For example, previous research and industry discourse has emphasized the immaturity of technological designs as a barrier within the technology dimension, but the current study recognizes the significance of the supporting infrastructure required for successful implementation. A lack of robust physical infrastructure can lead to network latency, system downtime, and slow processing times, discouraging potential users. Similarly, a lack of supportive financial infrastructure can hinder seamless fund transfers, limiting adoption and implementation. Additionally, the availability of a comprehensive knowledge infrastructure is critical to ensure users have the necessary skills to operate and maintain the system effectively. However, these aspects have received less, or no attention compared to technological immaturity in previous SLRs or in the reviewed literature.

The chapter on Distributed Ledger Technology (DLT) Niches and Experimentation in Central Banks Payment Systems Functions identifies the various use cases related to DLT-based applications in central bank payment system functions including DLT-Based Domestic RTGS Systems, DLT-based cross-border settlement arrangements, DLT as infrastructure for CBDCs, Information registry and data sharing, and DLT-based digital KYC/AML applications. These use cases are broadly categorized into three themes: operational responsibilities, issuance of central bank digital money, and regulatory oversight/supervisory functions, and other ancillary operational management functions. This novel classification approach enhances the existing knowledge on DLT in central bank payment systems by providing a comprehensive way to understand the various ways in which DLT can be utilized within the context of central banks' overarching responsibilities.

The classification generated from the comprehensive review of DLT applications in central bank payment systems can serve as a guide that can be used as a reference point by policymakers and practitioners looking to implement DLT-based solutions. The primary motivation across the different use cases is to improve efficiency compared to conventional payment systems or ways of performing payment system functions. However, for some use cases, such as DLT-based domestic RTGS systems, the pilot results have shown limited efficiency gains. The variety of DLT platforms and consensus algorithms identified suggests that there is no one-size-fits-all solution for implementing DLT-based applications in central bank payment systems. Additionally, the study highlights the varying roles of central banks in implementing DLT-based applications, with some use cases requiring a more active role from the central banks, such as DLT-based interbank payment rails and DLT as infrastructure for CBDCs. Policymakers and practitioners should consider these factors when evaluating the potential benefits and challenges of implementing DLT-based applications in central bank payment systems.

1.7 Thesis Structure

This section outlines the structure of the remaining sections of the thesis.

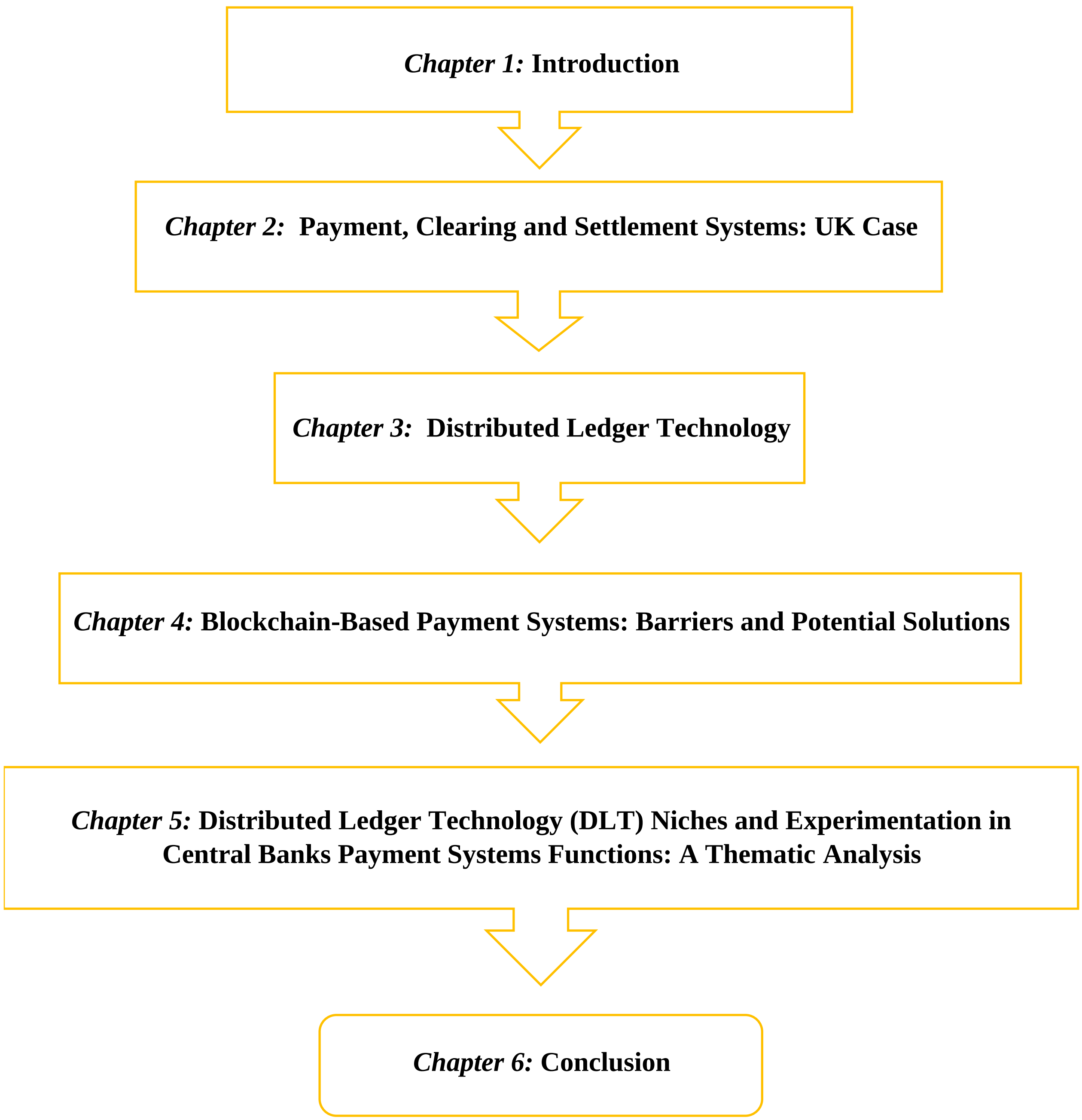


Figure 1. 1 Thesis Structure

Chapter 2: Payment, Clearing and Settlement Systems: UK Case

This chapter's main objective is to furnish a comprehensive understanding of payment, clearing and settlement systems, as well as some key institutional and economic factors influencing innovation in these systems. The UK is used as an illustrative case study to enhance the reader's comprehension. Consequently, the chapter provides the background context that serves as foundation for the subsequent chapters, that explore DLT applications in payment, clearing and settlement.

Chapter 3: Distributed Ledger Technology

This chapter aims to offer a comprehensive understanding of the basic principles of DLT application of in payment, clearing and settlement processes. It first elaborates on the fundamental concepts of DLT systems and discusses their technological components and the potential configuration of DLT payment systems. By providing this foundational information, the chapter sets stage for subsequent chapters that provide in-depth analysis and evaluation of specific DLT applications in payment, clearing and settlement arrangements.

Chapter 4: Blockchain-Based Payment Systems: Barriers and Potential Solutions

This empirical chapter focuses on the barriers that impede the widespread adoption and implementation of blockchain-based payment systems, and the corresponding solutions proposed in literature to mitigate them. To provide a comprehensive analysis of these barriers, the chapter contextualizes blockchain-based payment systems as social technical systems and introduces the social technical system perspective as a framework for understanding the barriers to adoption. By utilizing this structured analysis, the chapter aims to offer a deeper understanding of the social and technical factors that contribute to the barriers faced by blockchain-based payment systems. Ultimately, this chapter aims to contribute to the literature on blockchain-based payment systems by providing a nuanced perspective on the barriers to adoption and implementation of blockchain-based payment systems, and the strategies that can be employed to overcome them.

Chapter 5: Distributed Ledger Technology (DLT) Niches and Experimentation in Central Banks Payment Systems Functions: A Thematic Analysis

This chapter's objective is to analyze the various DLT applications in central bank payment system functions. The chapter aims to offer a systematic approach for comprehending the outlook and applications of DLT in central bank payment systems functions, by examining the underlying motivations and identifying DLT platforms and consensus algorithms being adopted where applicable. By providing a comprehensive examination of the various niches and experimentation in central bank payment system functions, this chapter aims to contribute to the literature on DLT and central bank payments, and to inform future research and practice in the field.

Chapter 6: Conclusion

The conclusion will summarize the key findings of the thesis and their implications for future research, practice, and policy. It will also highlight the limitations of the study and suggest potential avenues for further research in this field.

CHAPTER TWO: PAYMENT, CLEARING AND SETTLEMENT SYSTEMS: UK CASE

2.1 Introduction

Payment, clearing, and settlement systems encompass payment instruments, processes, supporting technical services for clearing, fund transfer, final settlement, and related regulations and rules that facilitate the exchange of funds and assets to fulfil financial obligations (Ali & A. Salameh, 2023). These systems are critical for the smooth operation of financial markets because they enable efficient and secure settlement of transactions between financial institutions (The Banque de France, 2021). They provide the basis for facilitating financial market transactions, promoting economic growth, facilitating the digital economy, and ensuring financial stability (World Bank, 2023). As a result, ongoing development and innovation of these systems is critical for global economic growth. Furthermore, the rapid evolution of technology, as well as the increasing scale and complexity of digital payments, necessitate the continuous improvement of these systems to meet the needs of a rapidly changing digital landscape.

The typical sequence of steps followed in a funds-only transfer involving monetary financial instruments include submission, validation, conditionality, and settlement as described in (Mills et al., 2016). To initiate a transfer, a payer submits a payment request to the payment system using their preferred payment instrument such as online banking, credit/debit card, or digital wallets. Once the payment message is submitted, the next stage involves clearing procedures within the payment system, which involves validating and reconciling the payment instructions between banks or other financial institutions. During this process, financial institutions, including the payer's bank and the payee's bank, depend on the payment system to act as an intermediary. The clearing processes can also incorporate security measures aimed at confirming the legitimacy of both the sender and the message. The third step involves processes that ensure required conditions for settlement, such as the availability of sufficient funds, are met. If the payment meets the conditions, it proceeds to the settlement phase, which involves the actual funds transfer between parties. Settlement can either be final or provisional. The transfer processes typically involve the use of a financial market infrastructure (FMI), which serves as a central hub and provides a framework for settling transactions.

This chapter aims to enhance the understanding of payment, clearing, and settlement systems by providing a comprehensive overview. It establishes the foundation for the empirical chapters by providing crucial background and context of the conventional centralized architecture and the processes within, that are likely to be impacted either in part, or completely by DLT-based payment systems which informs the analysis of potential barriers and proposed solutions for blockchain-based payment systems and DLT applications in central bank payment system functions. The literature on DLT frequently concentrates on the potential of DLT to revolutionize present payment and settlement systems; however, there is limited discussion about the current systems. Therefore, this chapter fills a gap in the literature by providing an understanding of the context in which DLT innovation is taking place and identifying potential areas where DLT can address existing challenges.

Additionally, the chapter introduces the key institutions and economic factors that influence innovation of payment, clearing, and settlement systems, including network effects, economies of scale and scope, natural and quasi-monopolies, as discussed in previous works by Chiu (2017) and Gogoski (2012). Although the coverage of these concepts is not exhaustive, the chapter provides valuable insights into the relevant factors in the UK context. These insights are particularly relevant to the broader literature on DLT application in payment systems. Researchers and practitioners can use these insights as starting points to understand and explore how these factors influence the adoption of DLT-based payment systems.

The structure of the remaining part of this chapter is as follows: Section 2.2 provides an overview and typology of Payment, Clearing, and Settlement Systems. Section 2.3 discusses the relevant literature on institutional and economic factors that influence innovation in payment systems. Section 2.4 presents the UK's payment systems industry as an illustrative case. Finally, Section 2.5 provides a summary of the chapter.

2.2 Payment, Clearing, and Settlement Systems: Overview and Typology

2.2.1 Overview of Payment, clearing and settlement systems

"According to the Bank of England (2023), a payment system refers to a standardized set of rules and procedures that enable the transfer of funds between financial institutions, individuals, and businesses." A payment system is usually overseen by an operator and depends on infrastructure providers for the provision of necessary hardware, software, and communication networks (Bank of England, 2023).

The focus of this thesis is on interbank fund transfer payment systems, a form of payment systems that enables funds to be transferred between different banks. Such systems typically involve credit institutions as participants and are subject to banking supervision. An example of a payment system in the UK is the Faster Payment System (FPS) operated by Faster Payments Scheme Ltd. The infrastructure provider for the system is Vocalink while the communication network provider which facilitates transmission of payment messages is BT Group. A well – designed payment system can support economic development and growth because efficient payment flow reduces transaction costs in the exchange of goods, services, and assets in national and international markets, which stimulates consumption, consequently spurring economic growth. Also, systematically important payment systems can play a crucial role in maintaining a country's financial stability. Any financial, legal, or operational defect in a clearing and settlement institution could pose a systemic risk to the whole financial system. This is the risk that the failure of an infrastructure in a payment, clearing, and settlement arrangement, has the potential to lead to a chain reaction of defaults of other entities, destabilizing the entire financial system (The Banque de France, 2021).

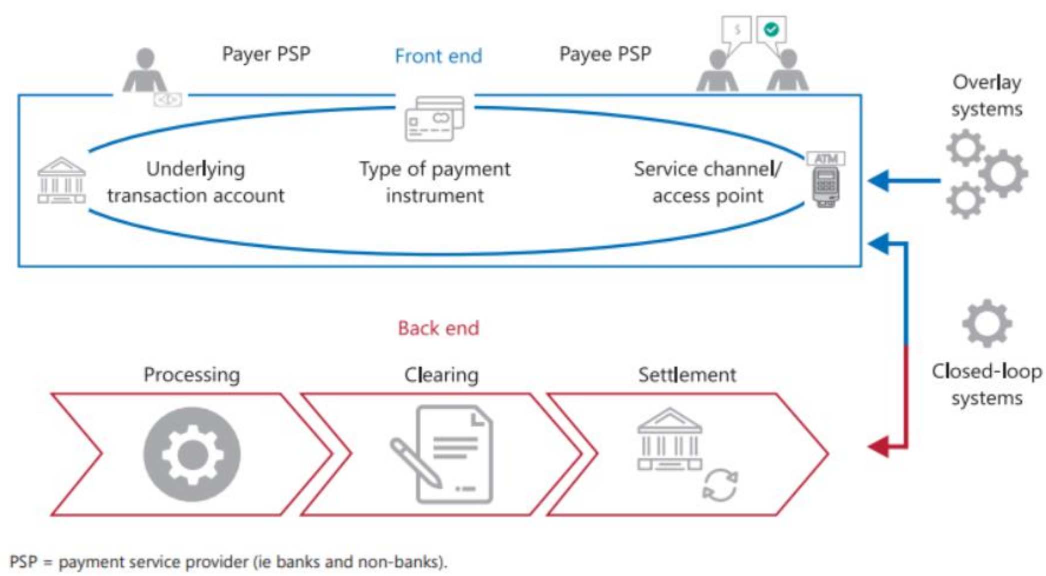


Figure 2. 2 A Core Payment System Adopted from BIS (2020), as adapted from CPMI (2018).

Rambure (2008) categorises payment systems into three modules including payment instruments, payment processing (including clearing), and settlement. Payment instruments encompass the various tools and procedures used to initiate funds transfer, through the authorization and submission of payment orders and requests by the payer or payee. These instruments can be cash-based or non-cash. Non-cash payments such as e-wallets, m-wallets, debit cards, credit cards and bitcoin can be subdivided further into paper-based or electronic money depending on their physical form characteristics. Payment processing (including clearing) on the other hand involves the exchange of data relating to funds transfer across financial institutions. This component may also include reconciling the net positions of the involved parties, which aids in determining the final positions for settlement (Rambure., 2008). Lastly, payment settlement refers to the completion of a transaction, which represents the overarching objective of a payment system. The settlement process can be final or provisional depending on the systems design or the payment instrument used as a mode of payment.

The transaction flow in a payment system consists of seven stylised steps (European Central Bank, 2010). The first step involves the selection of a payment instrument and the initiation of the transaction. In this step the payer selects a payment instrument and submits a payment instruction to the payment service provider (PSP). The way transactions are initiated can vary based on whether the payer uses a credit or debit-based payment instrument. Payment transactions using credit-based payment instruments involve a "credit-push" method where the payer initiates the transaction by requesting their payment service provider to send the funds. In contrast, debit-based instruments utilize a “debit-pull” method which involves the payer supplying their account information to the payee, who then requests their payment service provider to pull funds from their payers 'account. The second step involves the validation procedures, where the payer’s bank verifies and authenticates the legal and technical validity of the payment instrument and checks the availability of funds or overdraft facilities. The third step is clearing, where the payment service provider reconciles their internal accounting system ledgers either through either debits or credits. The fourth step involves payment clearing and settlement, which involves the transmission, reconciliation, and sorting of data relating to funds transfer across financial institutions using either clearing houses or bilateral/multilateral arrangements (*Payment and settleme*nt). The fifth step is payment settlement, where the payment obligations between or among counterparties is discharged. The settlement can occur on a gross basis individually referred to as Realtime gross settlement (RTGS), or on deferred net settlement (DNS) refers to a batch settlement system where transactions are netted and settled on a regular basis, which can either be final or provisional. The sixth step is internal processing, where the acquiring bank or non-bank payment service provider credits the payee's account. Lastly, the ultimate step involves communication, where the payer and the payee are notified that the payment transaction has been affected in the form of either a message or an account statement.

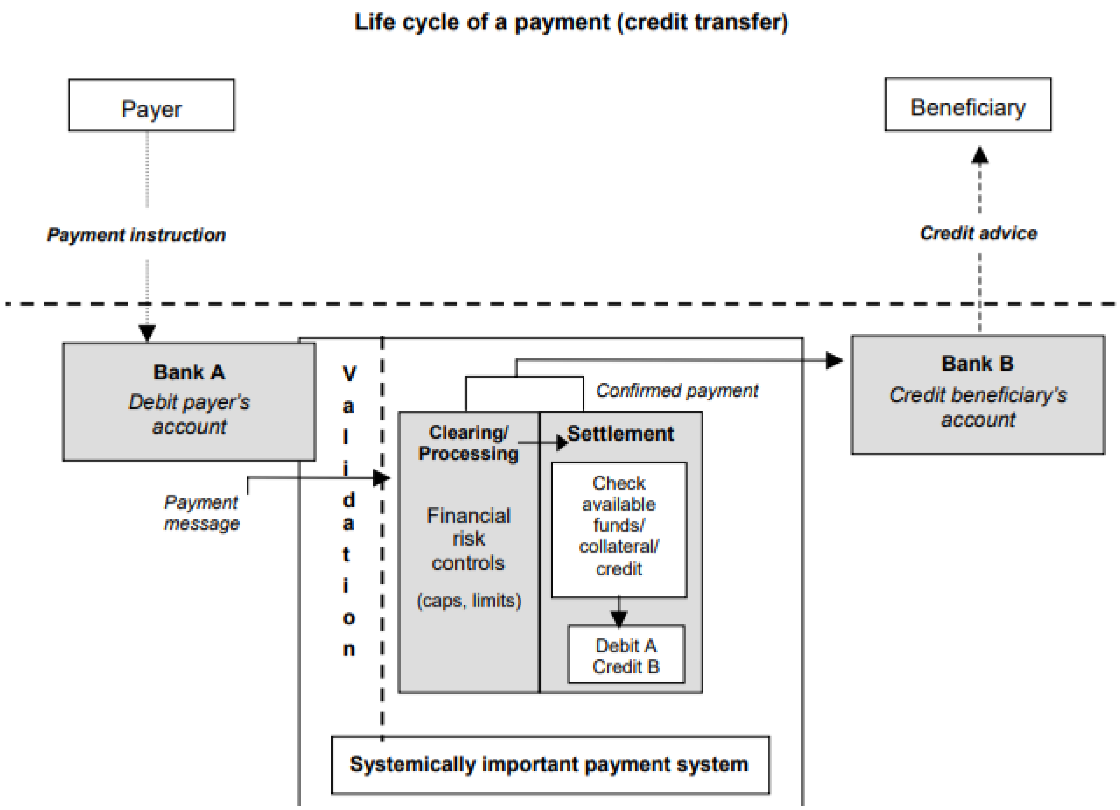


Figure 2.1 illustrates a stylized payment transaction flow in a payment system. Source: (Committee on Payment and Settlement Systems 2001)

2.2.2 Types of payment systems

Payment systems can be categorized according to three main dimensions: centralized/ decentralized/ distributed, open loop/closed loop/hybrid models, and retail/ wholesale-oriented payment systems (European Central Bank, 2010).

The centralized, decentralized, or distributed dimension pertains to the distribution of control and authority over the payment system. In a centralized payment system, a central authority such as the system operator is endowed with authority to control data, and operation of the payment system. Most conventional interbank fund transfer systems are centralized. In a decentralized payment system, control or authority over the payment systems is distributed across a network of stakeholders/nodes, while in distributed payment systems, control is further distributed among all participating nodes (Fanti & Viswanath, 2019).

The open loop, closed loop, or hybrid models pertains to the level of interaction between the payer, payee, and the payment system. In an open loop model, there is no direct connection between the payee, payer, and the payment system. The payment flow is instead through intermediaries including issuing and acquiring payment service providers. In a closed loop model in contrast, there is direct connection between the payee, payer, and the payment system. Conventional issuing and acquiring payment service providers do not act as intermediating agents, rather the payment system connects the payers and the payees to one another. A hybrid model on the other hand combines the elements of both open and closed loop models.

The third dimension, retail/wholesale-oriented payment systems, is based on the types of payment processed through the payment system. Retail payment systems typically process low-value, high- volume payments that are not urgent for businesses and households while wholesale-oriented payment systems, typically process high-priority, high-value payments such as transactions between financial institutions.

2.2.3 Key participating entities in a payment system

There are multiple stakeholders involved in a payment system, including payment system operators, payment system participants, settlement agent, and infrastructure providers (Payment Systems Regulator, 2014). The payment system operators oversee the operation of the payment systems. An example of a payment system operator is Pay.UK, that owns and operates the Bacs payment system in the UK (Bacs, 2023). Systematically important payments systems are typically owned, governed, and controlled by either central banks or private sector institutions, such as a cooperative of banks (European Central Bank, 2010). In some cases, both public and private agencies may jointly operate the payment systems. Payment system participants include financial institutions such as the acquiring bank, issuing bank and authorized electronic money institutions which act as intermediaries between payers/payees and the payment system. These participants may be direct or indirect participants. The settlement agents in a payment system are typically central banks in many jurisdictions. They have an oversight role over payment clearing and settlement systems, to ensure secure and efficient payment systems. Lastly, infrastructure providers such as VocaLink provide the necessary hardware, software, secure telecommunications, and network for the payment clearing and settlement schemes.

2.3 Discussion of the relevant literature on key concepts on institutional and economic factors that influence innovation in payment systems.

The payment systems, including financial market infrastructure for payments, are a fundamental component of the financial system, and their innovation is fundamental to the efficiency and competitiveness of the sector. Innovation in payment systems is influenced by a range of institutional and economic factors. This section reviews select literature to identify key institutional and economic factors that influence innovation in payment systems before applying them to the UK case.

2.3.1 Overview of literature on key institutional factors that facilitate or impede innovation in payment systems.

2.3.1.1. Emergence of institutions in payment systems

Schout and North (1991) defined institutions as "the humanly devised constraints that structure political, economic, and social interaction." They also noted that these constraints can take both formal and informal forms, with formal rules including “constitutional law, common law, and regulations, and informal rules including conventions, norms of behaviour, taboos, customs, traditions, and self-imposed codes of conduct.” North and Coase suggest that institutions emerge as a response to minimize transaction costs that arise from uncertainties in exchange. These costs include the cost of obtaining information and making exchanges. For example, formal regulations can reduce transaction costs by providing a framework for interaction that reduces uncertainty and increases trust between individuals and groups involved in an economic exchange. The new institutional economics (NIE) asserts that institutions are key for successful collaborations in imperfect markets that are characterized by high information cost, opportunistic behavior of organizations and bounded rationality (Briggs & Brooks, 2011).

In the context of payment systems, Chiu, (2017) and Briggs & Brooks, (2011) apply this approach to explain how institutions underpinning payment systems emerge, and impact innovation of payment systems. Specifically, Chiu’s (2017) paper on “the institutionalization of fundamental tenets in payment systems’ adopts North (1992) and Coase (1937) perspective to explain the emergence of institutions in payment systems. The paper posits that payment systems have intermediaries between the payers and payees who perform functions such as validation, clearing and settlement to facilitate transactions and mitigate risk such as agency costs, default costs and legal costs. The need to minimise these transaction costs and mitigate risks has therefore led to the establishment of institutions, both formal and informal. Formal institutions are established by organizations such a country's central bank. These rules and regulations govern the participants in a payment system in that country. Informal institutions, on the other hand include the norms and expected behaviours which have evolved overtime within the payment system ecosystem and guide the use of a certain means of payment. Briggs & Brooks (2011) also contend that payment systems are entrenched in broader institutional frameworks, that incentives and guides participants, such as central banks, regulatory agencies, payment card networks, payment system operators, and industry associations, to establish and enforce standards and rules, provide oversight and supervision, and promote collaboration and information-sharing among stakeholders, driving efficiency and innovation.

2.3.1.2 Institutions that facilitate innovation of payment system

Well-designed institutional frameworks are key for promoting innovation in payment systems (Chiu, 2017) and (Briggs & Brooks, 2011). Effective institutional frameworks can provide a suitable environment for innovation by promoting collaborative arrangements and efficient procedures in a payment system, while also mitigating risks (Briggs & Brooks, 2011). Collaboration among stakeholders, including financial institutions, technology providers, merchants, and consumers, is essential for the development of electronic payment systems. Institutions can facilitate this collaboration by providing a neutral platform for dialogue, coordination, and adoption of common standards and protocols. Furthermore, Chiu (2017) highlights the essential function of institutions in promoting commercial competition and facilitating the emergence of radical innovations in payment systems that yield social advantages while safeguarding consumer protection and security.

2.3.1.3 Institutions that impede innovation of payment system.

According to (Chiu, 2017) and (Briggs & Brooks, 2011), institutions can also impede innovation in payment systems by reinforcing the incumbent's dominance and resisting innovation that may challenge existing payment systems. One such institution is regulatory requirements that are too rigid and susceptible to anti-competitive practices resulting in prohibitive costs, poor service standards and irresponsiveness to user needs (Chiu, 2017). Additionally, inadequate regulations which may not be equipped to handle complex legal issues arising with new payment systems can also impede the innovation of payment systems. Finally, fragmentation caused by the presence of multiple non-interoperable standards and protocols, as well as a lack of collaboration among stakeholders in the payment system industry, can stifle innovation (Briggs & Brooks, 2011).

2.3.2 Overview of literature on key economic factors that facilitate or impede innovation in payment systems.

This section elucidates the select economic concepts within the context of payment systems and discusses how these factors influence innovation of payment systems.

2.3.2.1 Network effects in payment systems industry

Network effects refer to the phenomenon in which the benefits or value that a user derives from using a particular good or service increases as more users join and use the same product or service (Beck et al., 2006). This effect is frequently observed in industries with a large user base, because as more users join and use the platform, the value increases for all users, such as a reduction in cost. For instance, in the case of social media platforms, as more users join and use a platform, there is greater potential for connections, content and engagement opportunities increases. Similarly, in telecom industries, as more users join a network, there is potential for wider network of people to communicate within the network, hence making the network more valuable to existing and potential users.

The network effects can occur either directly or indirectly (Veljanovski, 2007). Direct network effects occur when the value of a product, service, or platform increases with an increase in the number of users consuming the good or service or connecting to the platform. On the other hand, indirect network effects arise when a platform or service relies on the participation of multiple user groups. In this case, the value of the platform or service increases for one user group when a new user from a different user group joins the network. The payments and settlement system sectors are acknowledged to be network industries that display network effects. This means that the value or usefulness of the system, such as an interbank fund transfer system, increases as more participants connect to it. (Gowrisankaran & Stavins, 2004) and (Krivosheya, 2021). In this study's context, the network is the group of participants comprising businesses, consumers, financial institutions, payment systems operators and settlement agents, among others, that make up the participants in the payment systems industry.

The network effects in the payment and settlement system industry occur in different forms. For instance, Veljanovski (2007) discusses two forms of network externalities within an automated electronic house (ACH) payment system. The first form occurs when the value of an ACH payment system to participating banks and other payment service providers increases when a bank or payment service provider adopts that ACH payment system. Incumbent participants are therefore able to exchange payments within the same platform with an additional counterparty. The second form of network effect is observed in electronic payment products that are technology driven. Such products are typically associated with informational networks where the value of the product increases with an increase in users due to lower costs resulting from user familiarity (Veljanovski., 2007). Additionally, payment and settlement systems exhibit network effects in the form of incremental growth in the number of banks and payment service providers connecting to the system, prompting system operators to add complementary services and enhance existing services such as speed and security of processing transactions. This, in turn, attracts more participants to connect to the platform, eventually benefiting existing participants (Rosenbaum et al., 2017). Moreover, the incentive for banks and payment service providers to join a network depends on how many other institutions are "connected" through the system, creating a direct network effect (Veljanovski, 2007).

The influence of network effects on innovation in payment systems can be dual. On one hand, strong network effects can have a negative impact on innovation in payment systems by creating substantial obstacles to entry and competition, thereby restricting the capacity of new payment systems to gain traction in the industry (Carletti et al., 2020). For example, large entrenched systems with established network participants may have a cost and quality advantage over smaller payment systems. This can lead to disproportionate selection of the larger system over smaller rivals by banks and other payment service providers, further entrenching the larger system and limiting competition. As a result, smaller systems may eventually disappear while the larger system continues to grow. This natural limit on competition by network effects can stifle innovation and impede the development of new payment systems.

On the other hand, network effects can also drive innovation in payment systems. As more participants join and use a payment system, the value of that system increases for all participants. This can incentivize the payment systems operators to continue investing in the system and enhance its features and capabilities to maintain a competitive position. Additionally, the existence of several payment systems with strong network effects may encourage greater competition and innovation in the industry as each system seeks to differentiate itself from its rivals.

2.3.2.2 Economies of Scale and Scope

Economies of scale and scope is another concept in business economics that can influence innovation and competitiveness in payment systems (Gogoski, 2012). Economies of scale refer to the cost reductions realized by an organization as output increases. This is often realized as increased output, spreads fixed costs such as infrastructure development and maintenance costs are spread over a more units. The payment system industry is recognized to exhibit economies of scale as the value of using a payment system increases as more participants use the payment system (Gogoski, 2012). Furthermore, the high sunk costs of establishing and operating a payment system can be spread out over a larger volume of transactions with increased payment system usage.

Economies of scope, on the other hand, refer to the cost reductions that can be realized when a single firm produces two or more distinct products compared to separate firms producing those products independently. In the payment industry, payment systems may demonstrate economies of scope when they combine various functions in the transaction process by packaging similar or interconnected payment services or activities (Gogoski, 2012). This can result in cost savings and improved efficiency for the payment system. Both economies of scale and scope can have a significant impact on payment system innovation and competitiveness (Bolt & Humphrey, 2015). Larger payment systems with strong network effects, for example, may be able to achieve economies of scale, allowing them to provide lower-cost and higher-quality services to participants. Smaller payment systems may find it difficult to compete and innovate as a result. However, economies of scope can also foster innovation by encouraging payment system operators to combine a variety of services in novel ways to create differentiated products and services. This can open opportunities for new market entrants, fueling competition and innovation.

2.3.2.3 Natural and quasi-monopolies

In markets with significant network effects and economies of scale, there is a possibility for the emergence of natural monopolies or quasi-monopolies, whereby one or a few large players dominate the market. A natural monopoly is characterized by a sub additive cost function, meaning that it is less expensive to produce two or more outputs together than to produce each output separately Bolt & Humphrey (2015). Payment systems, with their strong network effects and economies of scale, are therefore prone to becoming natural monopolies, as noted by (Bolt & Humphrey, 2015) (Gogoski, 2012). Moreover, natural monopolies can form in the payment system industry due to the high fixed costs associated with establishing such systems relative to the marginal cost of processing transactions for an additional member. Monopolistic payment system operators may abuse their dominant positions by engaging in anticompetitive practices including raising prices, delivering subpar service, and may hinder innovation and competition in the industry.

2.4 UK's payment systems case

This following section will provide an overview of the UK payment systems market, highlighting some key institutions and economic factors underpinning the UK payments system sector and how they influence innovation in the sector.

2.4.1 Introduction to the UK payment system sector

The UK payment sector has historically been dominated by cash payments up until the last quarter of 2017 when card usage surpassed the volume of cash transactions (Caswell et al., 2020). However, changing consumers preferences, rapid technological advancements and advent of online banking, mobile banking, and contactless payments have triggered a shift from the use of cash to other forms of digital payments. Additionally, the COVID-19 pandemic in 2019 accelerated this trend further. According to UK Finance, the volume of cash payments is forecast to only constitute 16% of all payments made in UK by 2027, relative to 61% in 2017 (UK Finance, 2018, pp. 4-11). In addition to the growth in card payments, there has also been a notable growth in the usage of digital wallets in e-commerce transactions, which are growing at twice the rate for card payments further exacerbating the decline in cash usage (Caswell et al., 2020). This transition from cash to digital payments has led to a corresponding increased demand for digital payment solutions, which are faster, secure, and more convenient, highlight the need for innovation in the payment, clearing and settlement systems infrastructure that underpins digital payment transactions.

The UK has two primary forms of payment systems: high-value payment systems and retail payment systems. The high-value payment system typically facilitates high-value, time-critical transactions while the retail payment system typically facilitates smaller- value transactions for consumers and businesses. In addition to technological advances and changing consumer preferences, innovation in the UK payment systems sector is also shaped by institutional arrangements and economic factors. The following section describes the UK high value and retail payment systems, and highlights select institutions and economic factors that are shaping innovation in the sector.

2.4.2 The UK high value payment system

The Clearing House Automated Payment System (CHAPS) is the high-value payment system in the United Kingdom, established in 1984 by a consortium of banks that were part of the Association of Payments and Clearing Services (APACS) (Chiu, 2017). This system is a critical component of the UK financial infrastructure. It supports high value, same day payments through its network of 35 direct participants constituted of banks, non-bank financial institutions, financial market infrastructures, and over 5000 indirect participants who access the system through correspondent arrangements with direct participants (Bank of England, 2021, pp. 1-2). The CHAPS payment system operates on the Bank of England's Real Time Gross Settlement (RTGS) infrastructure which provides the ultimate settlement (Bank of England, 2021, pp. 1-2).

Chiu (2017) notes that a key institution supporting the UK's high-value payment system is a network of peer clearing, which comprises "major global payment and custody banks, financial market infrastructures, traditional high-street banks in the UK, and more recently, non-bank payment service providers and challenger banks (Bank of England, 2021)". These entities collaborate to facilitate efficient multilateral clearing and settlement. The coordination between the peer clearing entities is aimed at minimizing transaction costs due to uncertainties in exchange, which is consistent with the arguments put forward by North (1992) and Coase (1937) on the emergence of institutions in response to the need to minimize transaction costs that arise because of uncertainties in exchange.

The second key institution underpinning the UK high value payment system is the central bank (Chiu, 2017). The Bank of England was admitted as the infrastructure provider and operator of the payment system in 2017 (Bank of England, 2017). Although CHAPS is composed of private bank and non-bank clearing financial institutions and other financial market infrastructure, it is considered a public infrastructure due to its systemic nature. A potential participant failure or operational defects of the system could lead to a system-wide contagion endangering the stability of the entire financial system. The central bank operational and oversight function over the CHAPS system is therefore crucial in enabling the UK high value payment system to achieve its commercial objectives such as efficiency in clearing and settlement as well as to promote the public good Chiu (2017). It achieves this through various operational and oversight functions aimed at ensuring monetary and financial stability. One of its core responsibilities is to maintain the RTGS, which is the underlying infrastructure supporting CHAPS payment system (Bank of England, 2021) Additionally, the central bank provides intraday liquidity to CHAPS participants through repo agreements and maintains an active policy interest in payment systems. These functions are key to maintaining confidence and trust amongst the scheme's participants that payment obligations will be honored (Chiu., 2017).

According to Chiu (2017), the competitiveness of the UK high value payment system is limited by its institutional features, which are settled and uncompetitive. Competition by infrastructure in CHAPS is less contestable since the RTGS system is maintained by the Bank of England. Moreover, although competition at the operator level of the payment system is feasible, the possibility of substitution among competitors is limited since new entrants "need to satisfy the commercial as well as public policy objectives that the high value payment system serves" (Chiu, 2017). The Bank of England support has major influence on driving innovation within the CHAPS system. For instance, The Bank of England initiated a Proof of Concept (POC) in 2018 with the aim of exploring the potential for a new RTGS system to facilitate settlement in systems using Distributed Ledger Technology (DLT) (Bank of England, n.d.).

2.4.3 The UK retail payment system

There are several interbank retail payment systems in the UK, each designated for a specific purpose. These include Bacs, the Faster Payments Scheme (FPS), the Image Clearing System (ICS), and Link.

Bacs is the oldest UK payment system, and it offers an Automated Clearing House (ACH) service that facilitates high-volume, regular payments, including direct debits and direct credits (*Payment systems - pay.uk* 2023). Direct debits are a preferred alternative for companies to 'pull' recurring payments, such as bills from their customers, whereas direct credits are used by companies to settle payments such as salaries, benefits, standing orders and business – to business invoices. It is owned and operated by Pay.UK limited and it outsources its infrastructure to VocaLink.

The Faster Payment System scheme (FPS) is a real-time payment system that operates 24/7 and was launched in 2008 (Pay.UK., n.d.). It processes immediate, 24/7, interbank electronic fund transfers between bank accounts of individuals and businesses within the UK. FPS has over 30 directly connected settling participants (DCSPs), including bank and non-bank financial institutions. Additionally, there are also indirectly connected non-settling participants who access the FPS through a sponsoring participant and indirect agencies (Pay.UK., n.d.). The participants' settlement positions are sent to the Bank of England for settlement in three cycles each day on weekdays. (Payment Systems Regulator., n.d.). It also outsources its infrastructure to VocaLink.

The Image Clearing System (ICS) is responsible for processing digital images of cheques. It was launched in 2019 and is owned and operated by the Cheque and Credit Clearing Company (C&CCC) (Pay.UK Limited, n.d.). The scheme has 20 bank and non-bank financial institutions and 20 switch participants. The clearing of cheques under the scheme is outsourced by its participants to IPSL and Hewlett Packard Enterprise Services (KPMG, 2014).

Link is the cash machine (ATMs) network responsible for setting rules for ATM operators (Link Scheme, 2023). The operation of the scheme is overseen by Link Scheme Holdings Ltd. Its main purpose is to enable partnerships among banks, building societies, and other organizations that provide cash machines and/or cards that are compatible with these ATMs (KPMG, 2014). The scheme has 38 bank and non-bank institutions participants. Its ultimate settlement is via the Bank of England and its switch proprietary software is managed by VocaLink.

The UK retail payment system sector, like the wholesale payment system, is influenced by underlying institutions and economic factors, which shape the innovation within these systems. Chiu (2017) has pointed out that although the coordination of the high value and retail payment systems in the UK is done by a network of peer clearing, there are significant institutional differences between the two. These differences include the distinct roles played by the central bank and the regulatory and oversight bodies supporting each system. The Bank of England plays a pivotal role in governing the UK high value payment system, and operating the core RTGS infrastructure that provides ultimate settlement in the system. In contrast, the Bank of England role is less prominent in the UK retail payment system. Although the central bank still provides ultimate settlement for the retail payment systems, it does not operate the core clearing infrastructure using its RTGS processor (Chiu., 2017). Instead, the clearing processes are facilitated by networks of clearing institutions such as the BACS. Chiu (2017) notes that due to the Bank of England's limited involvement in retail payment systems, commercial policy tends to dominate, resulting in the interests of clearing banks being prioritized. The payment services offered to users might therefore not be competitive in terms of cost and speed, hence indicating an opportunity for innovation.

The peer clearing network is also an essential component for the transfer of funds across payment institutions in the UK's retail payment systems, similar to the country's high-value payment systems (Chiu., 2017). This reflects the need for economic coordination among economic agents to minimize transaction costs and exchange uncertainty, as North (1992) and Coase argued (1937). By ensuring that funds can be transferred seamlessly across different payment systems, it allows consumers and businesses to make payments using their preferred method of payment.

In addition to the central bank and a network of peer clearing firms, market-based governance and consumer protection regulations are also key institutions that underpin the UK retail payment systems and influence their innovation (Chiu, 2017). For example, the Payment Systems Regulator, established in 2014, has statutory objectives aimed at "promoting the development and innovation of payment systems, particularly the infrastructure used to operate them" (Payment Systems Regulator., 2021). It drives innovation in the UK retail payment system sector through its role as a concurrent competition regulator. In this capacity, it collaborates with the Competition and Markets Authority to investigate and prohibit anti-competitive agreements and abuses of dominant positions, thereby fostering competition (Payment Systems Regulator.,2023). This framework promotes innovation and improvement in the architecture of payment systems, hence allowing for increased diversity and efficiency in payment services (Payment Systems Regulator.,2023).

In terms of economic factors influencing innovation in UK retail payment systems, established retail payment systems economies of scale and brand recognition, may impede the development and adoption of innovative payment systems. Moreover, a potential challenge for new entrants to the payment systems market is the prevalence of existing systems like BACS and Faster Payments, which can create powerful network effects. This can hinder the ability of new players to acquire market share, ultimately limiting competition and innovation in the market (Chiu., 2017).

System	Products Supported	Participants (Network of Peer Clearing entities)	Operators	Limitations	Founded Year
Clearing House Automated Payment System (CHAPS)	High-value transfers for both wholesale financial and retail payments GBP payments	- 30 direct participants. - Over five thousand indirect financial institutions	CHAPS Clearing Company Ltd. (UK)	High cost – Direct participants are charged an annual charge, amounting to £30,000 for CHAPS tariff and £15,000 for DvP RTGS tariff (£15,000). Furthermore, they are also charged a per-item charge amounting to 31.9p for CHAPS tariff and £1.60 for DvP RTGS tariff. These costs are relatively high compared to other payment systems such as Bacs. Limited operating hours - The CHAPS system operates from 6 am to 6 pm on weekdays, excluding weekends, which poses a barrier for users with time-	1984

				sensitive transactional needs. Resilience challenge – The Bank of England response to the consultation on the roadmap for the 'RTGS service beyond 2024' highlighted the need to adapt the RTGS system to enhance its resilience.	
Faster Payments Service (FPS)	"Credit transfers, Standing Orders, corporate bulk payments in sterling (Retail-Value)" (KPMG, 2014)	- "Over 30 Directly Connected Settling Participants (DCSPs) including bank and non-bank financial institutions. - Directly Connected Non-Settling Participants (DCNSPs) and Indirect Agency." (Pay.UK., n.d.)	Pay.UK	Transaction Limits - The FPS payment system imposes a £ 1 million cap on the amount that can be transferred in a single transaction.	2008
Image Clearing System (ICS)	GBP/Euro cheque clearing/USD cheque clearing (Retail-value)	Settlement participants including 20 bank and non-bank financial institutions and 20 bank and non-bank	Cheque and Credit Clearing Company. (UK)	Extended processing time-ICS processing time aligns with traditional cheque clearing timelines (end of the next weekday (bank	1985

		financial institutions switch participants		holidays excluded) hence not suitable for time sensitive transactions.	
Bankers' Automated Clearing System (BACS)	Bulk credit transfer, Direct Debit (Retail value)	27 direct participants in Bacs payment services and 50 Current Account Switch Service participants.	Pay.UK	Extended processing time- Payments typically require 3 to 5 working days to clear hence it's comparatively slower than FPS and CHAPS. Limited operating hours - Payment requests must be submitted before 5.00pm, otherwise they will carry over to the subsequent day of the processing cycle.	1968
LINK	Cash machine (ATM) network (Retail Value)	38 bank and non-bank institutions	Link Scheme Holdings Ltd.	Reduced cash acceptance- The payment system encounters a barrier with the diminishing acceptance of cash as a payment method.	1985

Table 2. 1 The various payment systems arrangements in the UK Interbank Payment Schemes

2.5 Summary

In conclusion, this chapter contributes to the understanding of payment, clearing and settlement systems by providing a comprehensive overview of payment, clearing and settlement systems. It highlighted the stylized typical sequence followed in a payment system, which includes selection of a payment instrument, validation procedures, clearing, payment clearing and settlement, settlement, internal processing, and communication. The use of payment systems financial market infrastructure (FMI) was also discussed, which serves as a central hub and provides a framework for settling transactions between financial institutions.

The chapter also contributes to the understanding of select institutional and economic factors that influence innovation and competitiveness of payment, clearing and settlement arrangements. Formal and informal institutions emerge in payment systems to minimise transaction costs and mitigate risks. Well-designed institutional frameworks promote collaboration among stakeholders and provide a suitable environment for innovation while mitigating risks. However, institutions that reinforce incumbent dominance, have rigid regulatory requirements, inadequate legal frameworks, or fragmentation can impede innovation. The chapter also discusses some economic factors that influence innovation and competitiveness, such as network effects, economies of scale and scope, natural and quasi-monopolies, and their relevance in the payment, clearing and settlement context.

The chapter also presents the UK case, providing practical insights into the types and role of the payment system and the institutional and economic factors that influence innovation and competitiveness in the UK context. The UK has two primary forms of payment systems: high-value payment systems and retail payment systems. The Clearing House Automated Payment System (CHAPS) is the high-value payment system in the United Kingdom

The Clearing House Automated Payment System (CHAPS) is the UK's high-value payment system, which facilitates high-value, time-critical transactions (Chiu., 2017). Two key institutions underpinning the UK high-value payment system are the network of peer clearing entities and the central bank (Chiu., 2017). The competitiveness of the UK high-value payment system is limited by its institutional features, since although competition at the operator level of the payment system is feasible, the possibility of substitution among competitors is limited since new entrants "need to satisfy the commercial as well as public policy objectives that the high value payment system serves" (Chiu, 2017). The Bank of England's support has a considerable influence on driving innovation within the CHAPS system, with the bank actively exploring the renewal of the Real-Time Gross Settlement to support distributed ledger technologies (DLT) settlement models.

The UK has several interbank retail payment systems, including Bacs, the Faster Payments Scheme (FPS), the Image Clearing System (ICS), and Link. The Bank of England plays a lesser role in governing the UK retail payment system compared to its role in the high-value payment system. The Payment Systems Regulator, established in 2014, promotes innovation and improvement in the architecture of payment systems, other market-based governance and consumer protection regulations are also key institutions that underpin the UK retail payment systems and influence their innovation. Established retail payment systems economies of scale and brand recognition may impede the development and adoption of innovative payment systems.

This chapter sets the stage for the empirical chapters on “Blockchain-based payment systems: barriers and potential solutions” and “DLT niches and experimentations in central banks payment functions” by providing a foundational understanding of payment, clearing, and settlement systems and the institutional and economic factors that influence innovation and competitiveness in these markets. We shall interrogate further the barriers to widespread adoption and utilization of blockchain-based payment systems and the proposed solutions to address these barriers by amalgamating academic literature on blockchain-based payment systems. Overall, the chapter contributes to advancing knowledge on payment, clearing, and settlement systems and provides policymakers and practitioners with insights into promoting innovation and competition in these markets.

CHAPTER THREE: DISTRIBUTED LEDGER TECHNOLOGY

3.1 Introduction

Distributed ledger technology (DLT) has been recognised as a disruptive technology with the potential to drive radical transformations in payment, clearing, and settlement. Its key inherent properties such as distributed database, consensus mechanism, cryptographic hash functions and digital signatures provide a new paradigm for entities in payment, clearing, and settlement arrangements to transact without relying on a single central authority (Shabsigh et al., 2020). The aim of this chapter is to offer a foundational comprehension of how DLT is utilized in the processes of payments, clearing, and settlement. The chapter contributes to the literature on DLT by adapting an analytical framework for DLT systems, which provides a systematic approach for understanding and evaluating DLT applications. By providing this foundational information, the chapter sets stage for subsequent chapters that provide in-depth analysis and evaluation of specific DLT application in payment, clearing and settlement arrangements.

The remainder of this chapter is structured as follows; Section 2. Provides an overview of DLT applications across multiple domains, focusing on the application in payment, clearing, and settlement processes; Section 3. Introduces the technological components of DLT systems, and DLT applications in payment, clearing and settlement arrangements. This section discusses the core properties of a DLT system and presents an analytical framework for DLT systems, actors, stylized transaction flow and governance; Section 4. Discusses the potential configurations of DLT systems in payment, clearing and settlement arrangements; Section 5 Concludes the chapter with a summary of the chapter, highlighting key takeaways from each section.

3.2 DLT applications across multiple domains

The DLT terminology presents a challenge due to the plurality and conflicting nature of definitions in academic publications and industry reports. This lack of standardization creates an obstacle in integrating DLT into research, policy, and practice (Rauchs et al., 2018). Some proposed definitions in academic journal articles and industry publication focus on core technical attributes and architectural characteristics, while others describe specific use-cases or the purpose of the DLT system (Rauchs et al., 2018). For example, Natarajan et al. (2017) define DLT based on its primary purpose as, “a *novel and fast-evolving approach to recording and sharing data across multiple data stores (or ledgers). This technology allows for transactions and data to be recorded, shared, and synchronized across a distributed network of different network participants* (*DLT and Blockchain*)*.”*

Benos et al. (2017), on the other hand, define it as, *“a database architecture which enables the keeping and sharing of records in a distributed and decentralised way, while ensuring its integrity through the use of consensus- based validation protocols and cryptographic signatures.”*

The definition provided by the World Bank Group omits the unique features that differentiate DLT systems from conventional distributed systems, whereas the definition by Benos et al. (2017) excludes various current and possible applications of DLT systems (Rauchs et al., 2018). The varying definitions of DLT presented by different authors indicate that the concept is still developing and changing over time and the wide range of use- cases being envisaged across different industries (Mills et al., 2016).

In addition to the lack of standardized definition, there is also a lack of systematic approach to differentiate DLT, cryptocurrencies and blockchain, and a flawed confluence of the three terms to describe the same thing. It is important to note that DLT is not a synonym of blockchain, but rather blockchain is a distinct subtype of DLT system (Fanti, 2022) defined by Casino et al., (2019) as, “a *type of distributed ledger systems in which transactions are stored as time stamped blocks that are linked in a chain by cryptographic hashes to achieve security, transparency, privacy, robustness, integrity, and authentication of data.”* Cryptocurrencies on the other hand are applications of blockchain technology designed to be used as mediums of exchange.

There are also misconceptions about the origins of DLT and blockchain, which are linked to the publication of the bitcoin white paper in 2008. The origins of DLT and blockchain, however, predate bitcoin and can be traced back to the 1970s with 'David Chaum's 1979 vault system research work,' which described “the design of a distributed computer system that could be established, maintained, and trusted by mutually suspicious groups” (Sherman et al., 2019). The blockchain concept on the other hand was introduced by Stuart Haber and W Scott Stornetta, having proposed a framework for "timestamping digital documents," which involved calculating unique hash values to identify each document and storing them in timestamped certificates Haber & Stornetta, (1991). The certificates were then linked using a data structure that includes the prior records' hash values. Lastly, DLT is not a new technology by itself, but rather confluence of established mature technological infrastructures including cryptography, distributed data storage and peer-to-peer networks (Rauchs et al., 2018).

This study adopts the definition suggested by Rauchs et al. (2018), which extends beyond describing the fundamental characteristics that explicitly differentiates DLT systems from traditional distributed systems while still articulating some core properties of DLT systems. This definition defines DLT as

"A system of electronic records that enables a network of independent participants to establish a consensus around the authoritative ordering of cryptographically- validated ('signed') transactions."

"These records are made persistent by replicating the data across multiple nodes and tamper- evident by linking them by cryptographic hashes. The shared result of the reconciliation/consensus process the ledger serves as the authoritative version for these records."

The potential use cases of DLT span across multiple industries including but not limited to manufacturing, trade finance, supply chain, energy, health care, and financial services. Sostakaite et al. (2019), classifies DLT use cases into two domains- vertical and horizontal. The vertical domain pertains to the specific applications and services that DLT can offer in various sectors such as finance, health care, ICT, and government. The horizontal domain, on the other hand, encompasses the services enabled by DLT that can be applied across multiple sectors such as identity management, security, and data management.

Example of use cases of DLT in the healthcare industry include medical record management (Leeming et al., 2019), clinical trial data management (Wang, 2020), drugs supply chain management (Uddin et al., 2021), patient identity management (Bouras et al., 2020) and medical research data sharing (Leeming et al., 2019). Similarly, there are several potential use cases of DLT in supply chain management including product tracking and traceability (Straubert & Sucky, 2021), inventory management (Ho et al., 2021), supplier management and contract management (Cole et al., 2019).

In the financial services industry, DLT has been proposed for a variety of applications including payment and remittances, securities trading and settlement, ID verification (KYC/AML), trade finance, insurance, crowdfunding, peer-to-peer lending, tokenization, stable coins, central bank digital currencies (CBDCs), regulatory compliance and audit. This thesis places DLT in the wider context of its envisaged application in the financial services industry and narrows down to the payments vertical of financial services, specifically the backend arrangement constituting payment, clearing and settlement infrastructure. The conventional payment, clearing, and settlement processes involve several intermediaries, leading to deferred settlements, and prohibitive costs. According to Mills et al. (2016), DLT presents significant potential to transform payment, clearing, and settlement processes. It provides a diverse range of potential benefits, including "optimized operations, particularly in cross-border transactions involving multiple parties, improved end-to-end processing, reduced need for reconciliation across various record-keeping systems, increased transparency, and immutability in transaction record-keeping, enhanced network resiliency through distributed data management, and lower operational and financial risks."

The level of disintermediation that may occur in traditional payment, clearing, and settlement arrangements as a result of DLT can vary from incremental to radical, depending on the particular architecture and design of the DLT system (Rauchs et al., 2018). An example of incremental adoption is when incumbent payment, clearing and settlement players adopt DLT to enhance or complement, their underlying enterprise-grade database infrastructure to facilitate specific processes within the transaction flow value chain such as reconciliation, data record or storage or even final settlement. Radical adoption on the other hand could take the form of complete overhaul of the payment architecture causing redundancy of one or several of the intermediating parties along the payment value chain. In between the incremental and radical ranges lie a myriad of potential use cases of DLT in payment, clearing and settlement (Bank for International Settlements, 2017). Earlier DLT systems designs such as the bitcoin blockchain and other altcoins were modelled for cryptocurrency but later generation applications of DLT support smart contracts which enable users to encode and execute arbitrary (Ruan et al., 2021).

3.3 Technological components and application of DLT systems in payment, clearing and settlement.

This section explores the key features and core technological components that make up a DLT system, and how they are applied in the context of payment, clearing and settlement. Additionally, a framework is applied to illustrate common conceptual designs of DLT systems and to provide a stylized logical overview of a payment transaction process flow in a DLT arrangement for payment, clearing and settlement.

3.3.1 Key features of DLT systems

The key features of a DLT system including the distributed database/ ledger, consensus mechanism, cryptographic hash functions and digital signatures, enable a range of capabilities that render DLT particularly well suited for processes in payment, clearing and settlement. To provide a comprehensive understanding of DLT application in payment, clearing and settlement, the following subsection discusses each of these key features.

3.3.1.1 Distributed database/ ledger

One of the fundamental components of the architecture of DLT systems is a distributed database/ledger. A distributed database architecture in a peer-to-peer network enables participants to collaborate in maintaining and verifying data in the ledger, including transaction records, without the need for a single trusted entity (Ferrag et al., 2019). The distributed database/ledger distinguishes DLT systems from other centralized or traditional distributed databases, despite the fact that the architecture and design of DLT systems may vary.

Conventionally, centralized databases are controlled by a single authority and store data in an individual location, creating a single point of failure. Furthermore, while traditional distributed databases, enabled by technologies such as cloud computing and data replication, are comprised of several nodes that store and process data collectively, the nodes are often managed by a single entity (Rauchs et al., 2018). Depending on the type of DLT system, the database/ledger of a DLT system is jointly produced, maintained, and duplicated across many or all network nodes. This distributed architecture makes DLT systems more attack-resistant, transparent, and secure than centralised and conventional distributed databases. It is however essential to note, that security concerns and vulnerabilities may occur in the software application layers built on top of DLT systems.

In the context of payment, clearing and settlement systems, the distributed database can be leveraged to facilitate peer- to- peer settlements between corresponding financial institutions without the need for an intermediary trusted party, such as the central bank. Eliminating the need for an intermediating central authority can have several benefits, including increased end- to- end settlement speed, reduced costs, and improved efficiency in maintaining the ledger and performing subsequent reconciliations. In addition, the transparency and immutability properties enabled by the distributed database/ledger, can allow all financial institutions to access and verify transaction data in real time, hence reducing the risks of errors and fraudulent activity.

3.3.1.2 Consensus mechanism

The consensus mechanism is another core feature of DLT systems as it defines the rules and protocols applied to achieve agreement on the state of the ledger amongst participants in the DLT network. For example, with public blockchains, any network participant can propose a new transaction. Once the transaction is proposed, other users participate in determining its legitimacy using predefined cryptographic validation method and consensus mechanism. The consensus mechanism ensures proper sequencing of transactions and prevent malicious actors from double spending and altering previously confirmed transactions. This safeguards the integrity and security of the DLT system. On the other hand, the distinct properties of private DLT systems, such as controlled access and participation in the network, afford opportunities for utilizing alternative consensus algorithms. For example, some private blockchains may leverage consensus algorithms that prioritize speed and efficiency over security, since access and participation in the network is limited to pre-selected and trusted participants.

Each form of consensus algorithm has its own set of underlying principles, benefits, and drawbacks. The choice of consensus method is dependent on the nature, purpose, and underlying assets of the DLT system, and influences the DLT system's performance characteristics, including scalability, transaction processing speed, finality, and resources used (Andoni et al., 2019). Common forms of consensus algorithms across many DLT systems include proof of work (PoW), proof of stake (PoS), delegated proof of stake (DPoS), and practical byzantine fault tolerance (Bonnet & Teuteberg, 2022). In the financial services industry, where there are high security and trust requirements, the consensus algorithms prioritise these factors. Some common forms of consensus algorithms in the financial services industry consequently include federated byzantine agreement (FBA), ripple protocol consensus algorithm (RPCA), practical byzantine fault tolerance (PBFT), and proof of authority.

Proof of work (PoW) consensus mechanism involves miners or validators competing to add a new block to the blockchain by solving a complex cryptographic puzzle (Andoni et al., 2019). The first node to solve the puzzle adds the block to the blockchain and receives and award in form of cryptocurrency such as bitcoin (Zook & Blankenship, 2018). The PoW imposes high computational cost for network participants hence is majorly suited for DLT systems with untrusting participants. In PoS, the selection of validators who create and validate new blocks is based on a random process and is determined by the amount of cryptocurrency they hold and are willing to stake or lock up as collateral. This consensus algorithm is sometimes preferred in place of PoW because of the resultant environmental effect of the proof of work consensus algorithm. Practical Byzantine Fault Tolerance, on the other hand, employs a multi-round process where nodes send votes for accepting blocks, resulting in a consensus among validators on whether to add a block to the chain permanently (finality) (Andoni et al., 2019). However, the voting process in PBFT must be designed with caution since votes are transmitted over an untrustworthy network, and some validators may not be reliable (Andoni et al., 2019).

PBFT is commonly used in permissioned blockchain networks where there are known and trusted participants, such as in banking. Lastly, the proof of authority (PoAu) is based on the identity of the validators rather than their computing power or stake, and it can provide fast transaction finality while maintaining elevated levels of security. Other consensus algorithms include Delegated Proof of Stake (DPoS), Federated Byzantine Agreement (FBA), Proof of Elapsed Time (PoET), Proof of Activity (PoAc), Proof of Burn (PoB), and Proof of Capacity (PoC) (Rajbhandari et al., 2023).

Consensus mechanisms are important in payment, clearing, and settlement systems because they enable all parties to reach an agreement on the authenticity of transactions before they are added to the distributed ledger without depending on a single central authority (Tran et al., 2022). In conventional payment systems, a central clearinghouse or intermediary is responsible for authenticating and settling transactions; however, this can result in inefficiencies, and a single point of failure. DLT systems therefore offer an alternative in which the consensus mechanisms enable the replication of a shared ledger across several nodes without a central clearinghouse.

3.3.1.3 Cryptographic hash functions and digital signatures

Cryptographic hash functions and digital signatures are also key components of DLT systems, as they provide a means of preserving the integrity of underlying transaction data and ensuring the authenticity of transactions. A cryptographic hashing function is a mathematical algorithm that converts any input data array, of varying size and format, into a fixed output bit string (CrossTower, 2022). The hash functions prevent data tampering by ensuring any changes to the transaction data is immediately detectable, hence rendering it difficult for malicious actors to tamper with the data.

Digital signatures, on the other hand, are cryptographic proof systems that enable the origin of a communication or transaction to be verified. Digital signatures offer greater security features that reduce the possibility of identity theft or impersonation in contrast to handwritten signatures and stamped seals (Iredale, 2022). In DLT systems, digital signatures serve two fundamental goals. First, they assure nonrepudiation by allowing the recipient to authenticate that the communication or transaction was transmitted by the purported sender. Second, digital signatures provide security against malicious intermediaries and unintentional message modifications. Digital signatures inspire confidence and facilitate transactions by providing these security features.

In DLT payment clearing and settlement processes, cryptographic functions and digital signatures play a key role. They protect the validity and integrity of transaction data, hence establishing a trustless environment in which parties can transact securely and without the need for intermediaries. The performance characteristics of the DLT system, such as transaction speed and scalability, are influenced by the consensus algorithm utilized (Mills et al., 2016).

3.3.2 Actors in a DLT system

The operation of a DLT systems is reliant on a network of peer-to-peer nodes that collaboratively produce, maintain, and update an authoritative ledger/database through multi-party consensus (Rauchs et al., 2018). Furthermore, instead of a central database server, data is stored and synchronised across the network's participating nodes (Islam et al., 2019). These nodes can be human participants or representation of technology through coded scripts and can range from individual users to organizations such as companies, banks, regulators, depending on the specific purpose and design of the DLT system (Islam et al., 2019). These actors play multiple roles, with some playing dual roles across different stacks of the DLT systems. The actors highlighted in Rauchs et al., (2018) include developers, system administrators, gateways, and participants.

Developers play a crucial part in the DLT system, with their responsibilities varying according to the layer within the DLT system stack. Core protocol developers are responsible for developing and optimizing the underlying protocol of a DLT arrangement, while client developers build and maintain the interface linking to the DLT system. Applications developers are responsible for the creation, deployment, and maintenance of web applications and smart contracts that run on the DLT system platform (Rauchs et al., 2018).

The system administrators, who can be a company, a consortium, or an open-source community, control access to the core codebase repository (Rauchs et al., 2018). They can add users, assign, and update security permissions to the system protocol, with their rights and governance powers, which are specific to the DLT arrangement. In permissioned DLT arrangements, administrative powers may be delegated to a single entity, whereas in permissionless DLT arrangements, administrators may be volunteer core developers.

The gateways are interface bridges that facilitate compatibility between the DLT system and end users of the system, with examples including gate keepers that controls access to the system: oracles that query, verify, and authenticate external data transmission into the system, and custodians that securely store assets on behalf of the owners. Crypto asset exchanges/digital currency exchanges are platforms that enable customers to trade cryptocurrencies in exchange of other currencies including fiat currencies and other crypto currencies (Rauchs et al., 2018). Issuers are nodes that are permissioned to issue new assets.

Technical nodes in a DLT arrangement are the interconnected participants that communicate with each other. Proposer nodes make suggestions for updating the ledger, data validator nodes check submitted transactions and records for validity and broadcast invalid records to the network, broadcasting invalid records to the network and relaying valid transactions (Rauchs et al., 2018).

In a DLT payment, clearing, and settlement arrangement, the actors involved are specific to the purpose and design of the arrangement. According to Bank for International Settlements, (2017), the actors within this type of DLT system include payment providers, clearinghouses, settlement systems, and custodian nodes. Payment providers are responsible for providing payment services to end-users, including merchants and consumers. Clearing houses act as intermediaries between payment providers and are responsible for reconciling payment transactions and ensuring that there are sufficient funds available to complete a transaction. Settlement systems are responsible for the transfer of funds from the payer to the payee, typically involving the movement of funds between bank accounts. Custodian nodes are responsible for securely storing the assets being transacted on the DLT platform on behalf of the owners. These actors play multiple roles and have varying degrees of power and responsibility within the DLT payment, clearing, and settlement arrangement. For example, payment providers may also act as clearinghouses and settlement systems, while custodian nodes may also act as payment providers. The specific roles and responsibilities of these actors within a DLT payment, clearing, and settlement arrangement will depend on the design and purpose of the system.

3.3.3 DLT systems stack

Several conceptual frameworks have been proposed for evaluating, classifying, and comparing common architecturally designed configurations of DLT systems. Rauch et al. (2018), Shermin (2017), and Yu et al. (2018) are some examples of these frameworks (2018). Shermin (2017) framework divides DLT system technology stack into five layers of abstraction: infrastructure, network, governance, assets, and relations. Yu et al. (2018), on the other hand, propose a framework that divides a DLT system into “multiple abstraction layers, including the data layer, network layer, consensus layer, ledger topology layer, incentive layer, privacy layer, contract layer, and application layer”. In contrast, Rauch et al. (2018) provide a hierarchical, interdependent framework that divides a DLT system into three levels. The following sub section selectively references concepts from Rauch et al. (2018), Shermin (2017), and Yu et al. (2018) conceptual frameworks to discuss the layers of a DLT system stack and provide a stylized logical overview of a transaction process flow in a DLT arrangement for payment, clearing, and settlement.

3.3.3.1 The protocol layer

The foundational layer in a DLT system stack is the protocol layer, also known as the infrastructure layer in Shermin (2017). This layer is the core operating system of a DLT system, and is composed of coded governance pre-defined rulesets, that ensures consensus amongst participating nodes in a peer- peer network (Bellaj et al., 2021). The validation protocols outline the procedure by which transactions are validated and added to the transaction history by designated validators, who may be institutions, individuals, or public/private organizations, as described by Shabsigh et al. (2020). Various alternative protocols have been proposed for payments, clearing, and settlement arrangements. While some protocols utilize a heavily centralized consensus approach based that also limit participation in the network, other protocols, such as the bitcoin-blockchain protocol, enable any nodes to collectively maintain a peer-to-peer network for block and transaction exchange. The utilization of the bitcoin-type protocol's proof-of-work design and transparent transaction database has been deemed inadequate for certain payment, clearing, and settlement systems, such as DLT-based RTGS systems, due to their computational demands and the absence of privacy.

3.3.3.2 The network layer

The second layer in a DLT system stack is the network layer. The layer comprises the actors involved in executing and enforcing the underlying system's protocol through inter-node communication (Rauchs et al., 2018). DLT arrangements differ depending on whether they adopt unstructured peer-to-peer overlay networks or networks that provide anonymity (Neudecker & Hartenstein, 2019). Unstructured peer-to-peer overlay networks such as the bitcoin blockchain have been criticized for payment, clearing, and settlement arrangements due to their inefficiency and the unnecessary overhead incurred.

The network layer plays a crucial role in a DLT system, as it facilitates inter-node communication, transaction processing, and validation.

3.3.3.2.1 Inter-node communication

The Internode communication component constitutes the initial steps preceding transaction processing in a DLT system. The processes within the internode communication component include data broadcast and replication and transaction initiation.

In a DLT system, the internode communication component comprises the initial steps preceding transaction processing. These processes include data broadcasting and replication, as well as transaction initiation.

Data broadcast involves the transmission of data across the nodes within the DLT network of interconnected nodes. Two types of data broadcast have been identified depending on how data is propagated and relayed across the network. In the multi-channel diffusion model, data is propagated selectively to nodes involved in specific network operations (Rauchs et al., 2018). In contrast, data is propagated to all nodes within the peer-to-peer network in the universal diffusion model (Rauchs et al., 2018). Early DLT arrangements such as the bitcoin blockchain adopt a universal data diffusion model to offer high reliability by enabling the data to be propagated and relayed to all participating nodes across the network. There are often trade-offs between the multi-channel diffusion model and the universal model, including transaction processing speed, scalability, and security. The universal diffusion model has been deemed unsuitable for DLT applications in payment, clearing, and settlement pilots and other enterprise solution requirements that require privacy and control in data exchange (Shabsigh et al., 2020).

Transaction initiation on the other hand allows a client to request and cryptographically authenticate a transaction request using private keys. Cryptography is a constituent of the technologies that make up a distributed ledger technology arrangement. Cryptographic tools within the DLT allow for security and privacy within the DLT systems, enable digital signatures through private and public key infrastructure, wallet creation, and secure and transparent transactions. AR and Gupta (2020) provide instances of cryptographic methods employed in DLT, which include hashing, digital signatures, and Merkle trees.

Transaction initiation can be either restricted or unrestricted, where only selective users can propose transactions in restricted DLT arrangements, whereas in unrestricted DLT arrangements, all participants within the network can initiate the transaction.

3.3.3.2.2 Transaction processing

In a DLT system, the transaction processing phase encompasses all the procedures that occur prior to the addition of unconfirmed transactions in the immutable and sequentially ordered ledger. Upon initiation, unconfirmed transactions are consolidated into a candidate record, which then undergoes a consensus algorithm unique to the DLT arrangement. The consensus algorithm is fundamental in ensuring that all nodes in a DLT arrangement agree on the valid state of the ledger (Andoni et al., 2019).

3.3.3.2.3 Validation

A distinctive attribute of distributed ledger technology systems is their ability to allow network participants to validate transactions independently, without the need for a single centralized authority (Rauchs et al., 2018). The validation component of a DLT system verifies that transactions are not malicious, are not double-spent, and are formatted appropriately (Rauchs et al., 2018). This process precedes the submission of the candidate record to the consensus algorithm. When auditors conduct a combination of transaction and record validation, they can compute the entire system's state independently from its genesis, a process known as full audit. Transaction finality is the final stage of transaction processing, and it determines when a record can be considered authoritative and final (Rauchs et al., 2018). In some cases, the finality can be probabilistic, meaning that confirmed records can still be reversed during a transition period before becoming permanently settled. In other cases, the finality is permanent settlement, which means that once confirmed, the record is no longer reversible (Rauchs et al., 2018).

3.3.3.3 Data layer

The data layer in a DLT system stack represents the flow of information through the system and its storage on the unified ledger. This information may take the form of protocol-specified elements, such as tokens, or may originate from external sources (Bellaj et al., 2021). The data layer is composed of two key components: the operations component and the journal component (Rauchs et al., 2018).

The operations component encompasses the processes that govern the input data, how it is executed to generate the authoritative record, and the procedures for modifying the records. The journal component, on the other hand, pertains to the content that comprises the records.

3.4 Governance of Distributed Ledger Technology Systems

The governance of a DLT system encompasses two primary elements, namely operational governance, and managerial/administrative governance (Naudts et al., 2021). In the context of DLT arrangements, operational governance relates to the identification of system ownership and operational responsibilities, as well as the establishment of procedures for resolving disputes that may arise between the participants within the network (Naudts et al., 2021). In contrast to centralized databases, typical DLT systems do not have a single point of ownership for both the infrastructure and the resulting data. For example, the operational governance in some open-source codebases DLT applications such as bitcoin, is regarded as "governed by no one". This is particularly true for open-source codebases, where any node operator can modify the code to fit their specific application. Each node operator has access to a copy of the authoritative ledger and the software necessary to participate in the network, making both the data and software non-proprietary. In contrast, the operational governance of the Ethereum network is regarded as autonomous, with miners serving as nodes responsible for sustaining the system's operation. The miners however have no influence over the software's operation, this is instead enforced by the consensus algorithm and enforced through the "code is law" principle, resulting in an immutable system and the execution of smart contracts by miners (Naudts et al., 2021).

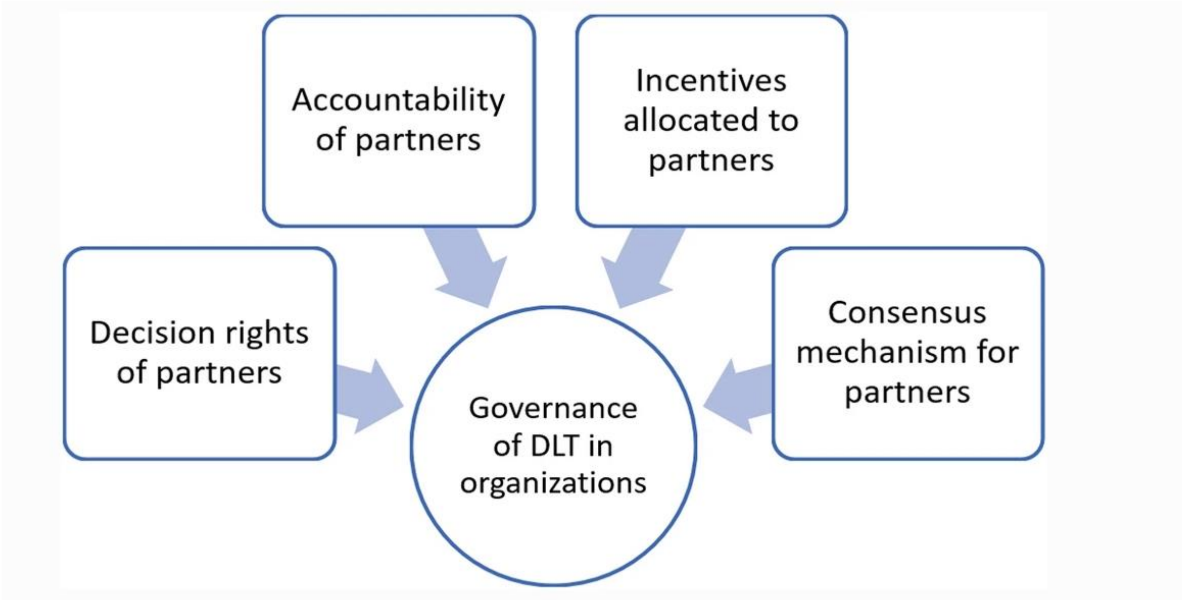


Figure 3. 1 Dimensions for governance of DLT in organizations. Adopted from Anthony Jnr. (2022)

The managerial governance of a DLT arrangement on the other hand entails examining how the underlying core infrastructure of the DLT system develops including the modification and updating the of the systems protocol and codebase. This aspect of governance addresses the need for continual updating and improvement of the system's architecture to enhance its functionality, scalability, and security. It involves managing the various stakeholders involved in the development and maintenance of the system, including developers, contributors, and investors (Naudts et al., 2021).

3.5 DLT design archetypes for applications in payment, clearing and settlement.

The Bank for International Settlements (2017) report presents four design archetypes for DLT systems, in the context of payment, clearing, and settlement. This section delves into each of these designs. Each configuration has distinct properties depending on the originating organization, the operation parameters, access to the arrangement protocols, specification of the roles of the technical nodes, and the underlying validation and consensus protocols.

DLT systems can have different technical configurations and institutional setups depending on their intended use case and specific inefficiencies they aim to address (Shabsigh et al., 2020). Similarly, DLT systems applied to payment, clearing, and settlement processes can exhibit diverse configurations, tailored to address inefficiencies in those processes. For example, while certain DLT arrangements facilitate the entire process that culminates in the final settlement, other arrangements facilitate only specific segments within the payment, clearing and settlement value chain. The variety of proposed DLT configurations for payment, clearing, and settlement reflects the absence of a single DLT solution that can effectively address the persistent challenges in these processes (Bank for International Settlements, 2017).

One potential DLT configuration is the single entity design, in which an authoritative ledger is maintained and updated by a single entity, such as an operator of an interbank payment scheme. Access to the DLT arrangement is limited, except for cases where the single entity can grant permission for an auditor or a regulatory body to access it. The objective of this approach is to establish a unified and definitive source of information (O'Leary, 2017). Consequently, DLT arrangements that employ this approach are not novel innovations, as conventional transaction processing systems already perform this function. This approach can be embedded in the structure of existing interbank payment systems to refine and improve existing infrastructure. Further, this form of incremental innovation reinforces the capabilities of established interbank payment schemes.

The second possible configuration is multiple entities with restricted access and distinct roles, in which multiple independent entities have distinct restricted roles and access to the arrangement is limited. The DLT systems limits the entities eligible to participate in the consensus protocol. By permitting only authorized entities to participate in the consensus protocol, this configuration improves transaction processing speed and scalability of the system. Nonetheless, the network may be vulnerable to a single point of failure, which could potentially compromise the system (Andoni et al., 2019). The inherent properties of this kind of configuration makes it feasible for applications in payment, clearing and settlement.

The third potential configuration is the multiple entities configuration with restricted access, similar to the former configuration. However, unlike the former configuration, the roles of the entities are not restricted, and all authorized entities are capable of validating transactions and candidate records for appending to the authoritative ledger. Augmenting the number of nodes could enhance the resilience of the network, but it could also lead to higher latency (Budeli, 2021). DLT setups that have a higher count of dispersed nodes may present notable challenges for governance, settlement, and operational risk management (Bank for International Settlement.,2017).

The fourth potential configuration is the classic open and public architecture configuration, which is characterised by multiple entities and allows any participant to participate in the network by installing software and running a node. This type of architectural innovation is revolutionary, founded on a unique set of principles that frequently introduce new markets and possibilities, and can serve as the foundation for the prosperous entrance of fresh enterprises into payment, clearing, and settlement fields (Bank for International Settlement.,2017).The main criticism of classic open and public architecture designs is that they can result in excessive wastage of resources, such as electricity consumption, and are often not scalable.

A depiction of the payment process in a classic open and public DLT system configuration for example can be described as follows as described in (Bank for International Settlement.,2017): Entity A initiates a transactional request, and employs cryptographic tools to propose a suggested update to the ledger, which would shift funds from its account to credit Entity B's account. The transaction request is then relayed to all nodes within the network, which initiate a validation process to ensure that the transaction complies with established protocol rules. Once validated, the transaction is stored in the 'mempool', a holding area for pending transactions, until a record producer bundles it with others into a candidate record (Rauchs et al., 2018). The candidate record is then subjected to a consensus algorithm specific to the DLT arrangement and validated by the nodes, the first node to solve the algorithm appends the candidate record to the authoritative ledger, completing the settlement process. Future transactions specific to the asset transferred must be initiated by applying Entity B's cryptographic credentials.

3.6 Summary

In summary, this chapter provides an in-depth discussion of the application of DLT in payment, clearing, and settlement processes. The chapter begins with an overview of the potential use cases of DLT across various industries and highlights the potential benefits of DLT application in payment, clearing, and settlement. The discussion also highlights the key features of DLT systems including the distributed ledger/database, consensus mechanisms and cryptography.

The chapter then delves into the technological components of DLT systems, including the actors in a DLT system, transaction flow, and governance. Finally, it discusses four potential design archetypes for DLT systems in payment, clearing, and settlement, each with distinct properties based on the originating organization, access protocols, roles of technical nodes, and consensus protocols. The first and second configurations involve restricted access, with the second limiting the entities eligible to participate in the consensus protocol. The third configuration is similar to the second but allows for validation by all authorized entities, while the fourth is a classic open and public architecture which permits any participant to install software and run a node. The traditional classic and public architectural designs have been criticized for their inefficiency and lack of scalability in the context of payment, clearing, and settlement. Overall, this chapter lays a foundation for subsequent chapters that will provide in-depth analysis and evaluation of DLT application in payment, clearing, and settlement arrangements.

CHAPTER FOUR: BLOCKCHAIN-BASED PAYMENT SYSTEMS: BARRIERS AND POTENTIAL SOLUTIONS

4.1 Introduction

Modern electronic payment systems such as credit cards, digital wallets, and online banking transactions rely on centralized third parties such as banks or payment processors to securely process payments. The centralization of these systems creates risks inherent in any intermediate structure (Finan et al., 2013). For example, the centralization of these systems creates a single point of failure, that is susceptible to operational risk if one of the correspondent parties involved in a payment transaction ceases to function due to events such as cyber-attacks, system failures, and human errors. Centralized payment systems are also vulnerable to credit risk in case of insolvency of a correspondent party who owes a significant amount of money to other participants in the system, as well as liquidity risk if a participant lacks sufficient funds to make a required payment at a specific point in time.

Blockchain-based payment systems have been proposed to reconfigure and radically transform these conventional payment systems by enabling transactions to be conducted directly between the payer and the payee (Dashkevich et al., 2020), consequently mitigating the credit and liquidity risks. These systems are also designed to offer greater resilience against systemic operational risks compared to conventional payment systems as transactions are validated and recorded across a distributed peer to peer network of nodes. Their capabilities derive from the inherent features of blockchain systems including the distributed ledger, consensus mechanism, and cryptographic mechanisms (Chen et al., 2023). The potential of blockchain-based payment systems to address the limitation of existing centralized payment systems has piqued the interest of researchers and industry participants in uses cases such as micropayments (Klein & Stummer, 2021), cross-border remittances (Rühmann et al., 2020), issuance, and transfer of digital assets. The Bank of England, (2023) predicts that blockchain- based payment systems could steer transformations in financial markets, by facilitating novel and simpler network of relationships within the financial sector, which have the potential to enhance efficiency and resilience of financial market infrastructure, provided that effective governance of the technology is in place.

Despite their potential, significant technological and socio-economic barriers impede widespread adoption and implementation of blockchain- based payment systems. A substantial body of literature has been published discussing the challenges and barriers, both within the financial services sector, as well as in the broader context. Holotiuk et al. (2018) investigated the barriers impeding blockchain adoption in the payment industry through a Delphi study followed up with a series of interviews. The findings of the study identified six primary interrelated barriers including lack of practical use cases that can effectively demonstrate the benefits of blockchain, limited integration of blockchain with legacy systems, lack of standardization, unification, and interoperability, limitation of blockchain in meeting technical prerequisites of uninterrupted high availability, robustness, low latency, and regulatory hurdles. Prewett et al, (2020) discussed the existing barriers to mass adoption of blockchain across various industries such as scalability, system integration, lack of standardization, complexity of blockchain applications and regulatory uncertainty. Chang et al, (2020) identified key challenges to adoption through interviews with experts including scalability, security, privacy leakage, energy consumption and ethical issues such as privacy, regulations, law, and cybercrime.

Despite this growing body of literature addressing blockchain in the financial services sector, there remains a dearth of theory-driven research on its adoption, particularly in the context of payment systems. Holotiuk et al. (2018) notes that while there have been several pilots and proof of concepts trialing the application of blockchain in the payment industry, the technology is not yet fully developed. Researchers are therefore beginning to comprehend the technological, organizational, and social implications of blockchain. Previous studies have consequently mainly focused on exploring the potential applications of blockchain, while paying limited attention to social- technical aspects that influence the widespread adoption and implementation. The scholarly and industry discourse has also centered on cryptocurrencies and the technical capabilities of blockchain rather than the broader concept of blockchain (Wang et al., 2018). As the applications of blockchain-based payment systems move beyond conceptual stages and more empirical evidence emerges, researchers will need robust frameworks to guide theory–driven research. Conducting rigorous theory-driven research is crucial to gaining a better understanding of the technology, its adoption and deployment requirements, and its implications in the payment systems industry.

Furthermore, the review of existing SLRs and surveys on blockchain applications in the financial services sector, reveals extant literature does provide comprehensive evaluation and review frameworks to assess the barriers that impede the adoption and implementation of blockchain-based payment systems (Saheb & Mamaghani, 2021), (Ali et al., 2020) and (Trivedi et al., 2021). Existing literature also exhibits significant gaps as there is no holistic study that aggregates all major barriers of blockchain-based payment systems, ranks them based on their significance, establishes their inter-relatedness, and identify their corresponding proposed solutions. Therefore, a more in-depth investigation which focuses specifically on payment systems while broadening the scope to include proposed solutions is thus a pertinent and timely endeavor that can fill existing gaps in the literature.

Considering the above research gaps, this study aims to fill the gaps in the current literature on blockchain-based payment systems by utilizing theory-driven research to advance the knowledge in this emerging field. More specifically, the research aims to assess the social- technical barriers to adoption and implementation of blockchain-based payment systems, and the solutions that have been proposed in literature to address them. It seeks to contribute to the existing literature on the subject matter by considering the nature of blockchain-based payment systems as complex social-technical systems. By adopting a social-technical systems perspective and drawing on innovation theories, the study aims to provide a preliminary understanding of the interplay between technical and social factors in the adoption and implementation of blockchain-based payment system. The ultimate goal of the research is to provide insights and recommendations that can inform policymakers, industry practitioners, and other stakeholders on the key barriers and proposed solutions of blockchain-based payment systems. To achieve these objectives the following research questions are framed:

(RQ1): What is the current state of research on the barriers to adoption and diffusion of blockchain-based payment systems?

(RQ2): What are the barriers to adoption and diffusion of blockchain-based payment systems?

(RQ3): What solutions have been proposed in the literature to address the identified barriers to adoption and diffusion of blockchain-based payment systems?

The study utilizes a systematic literature review (SLR) methodology based on 55 academic studies published between 2017 and 2022. The systematic literature review was carried out in accordance with the established guidelines for conducting systematic literature reviews initially proposed by (Kitchenham, 2004) as adopted by blockchain papers published by (Ivic et al., 2022) and (Ahmed et al., 2020).

The present study makes several contributions to the existing literature on blockchain-based payment systems. First, it applies the socio-technical systems theory to the context of blockchain to assess the barriers of blockchain-based payment systems. To the best of our knowledge, the social-technical systems perspective has not been used in prior studies to evaluate the barriers of blockchain-based payment systems. The study's findings indicate that the application of the social-technical systems perspective is applicable to the blockchain context, and it offers a structured analysis approach for considering and identifying barriers that may not be apparent on a surface level.

Second, by specifically analyzing blockchain-based payment systems, this study draws targeted insights that are specific to this context. To the best of the researcher's knowledge, this is the first SLR to adopt a narrow focus on blockchain- based payment systems. Other studies take a broad approach to blockchain adoption in the financial services industry or cryptocurrency. This has led to the identification of barriers that are unique to this context. These findings not only provide valuable insights for practitioners on areas that require attention for the development of the technology but also uncovers previously overlooked aspects in academic literature, thus contributing to the field of blockchain research.

Third, in addition to identifying the barriers, the research also presents a significant contribution to literature by considering proposed solutions for each barrier, making it a useful resource for researchers, practitioners, and policymakers interested in this field. The study explores the solutions proposed in existing literature as countermeasures for the barriers to blockchain-based payment systems. This approach sets the study apart as the first SLR on blockchain-based payment systems that considers corresponding solutions proposed for each barrier. This contribution is important because the identification of barriers to the adoption and implementation of blockchain-based payment systems is only one part of the equation. It is equally important to explore potential solutions to overcome these barriers. Lastly, the study outlines potential areas for future research, opening new avenues for scholars to explore.

The remainder of this chapter is structured as follows. Section 2 provides the theoretical context. Section 4 describes the research methodology, including the inclusion and exclusion criteria for the articles, the databases searched and the systematic review process. Section 5 discusses the findings of the review, including the barriers of blockchain-based payment, and the countermeasures proposed to address these barriers. The barriers are grouped based on the social-technical systems framework, which considers both social and technical aspects of adoption. Section 6 further analyzes and synthesizes the findings to draw conclusions and identify trends in literature. Section 7 discusses the review's contribution and novelty, the limitations of the existing research, and highlighting areas for future research.

4.2 The Theoretical Context

This section introduces the theoretical approaches that guide the structure and classification of the barriers of blockchain-based payment systems identified in the review. It describes the chronological progression of innovation theory by reviewing relevant literature, highlighting the different theoretical approaches that can be applied to study and categorise the social-technical barriers that influence the adoption of radical and disruptive systems such as blockchain-based payment systems. Innovation process has been studied from several different perspectives, this section will only review key conceptual approaches and frameworks that are particularly relevant in the context of identifying the barriers of blockchain-Based Payment Systems.

Section 4.2.1 reviews different innovation theories and conceptual approaches that emerged pre- 1950's to 1980 preceding the contemporary social technical perspective approaches of innovation presenting the argument for their rejection in the study of the barriers of blockchain-based payment systems.

Section 4.2.2 introduces two social technical systems (STS) theoretical approaches to innovation, including the technological innovation system (TIS) approach and the social technical transition (STT) approach. Both theories offer comprehensive models to analyse the social, technical, and institutional factors that impact the process of radical and disruptive innovation.

Section 4.2.3 presents the argument in favour of the selection of the lens of social technical perspective as the heuristic conceptual tool operationalised to classify and enhance understanding of the barriers influencing the adoption of blockchain-based payment systems. By adopting these using the social technical theories, this systematic literature review aims to provide a comprehensive analysis and classification of the social and technical barriers and proposed solutions to address these barriers.

4.2.1 Innovation theories and different conceptual approaches to innovation processes

There are many different definitions and conceptions of innovation in economics and business literature as well as in daily life (Žižlavský, 2013). The term innovation often overlaps with other terms such as invention and technological change and can describe the "introduction of new products and processes, to a stage in a product's lifecycle, or to an iterative process of invention and application that links technical, societal and political change (Greenacre et al., 2012)." There are numerous theories that have been used to describe, explain, and investigate the factors that influence innovation process (Chang & Chen, 2004). There is no singular discipline that serves as the foundation for innovation theory, it instead draws upon conceptual strands and analogies from interdisciplinary studies such as "economics of increasing returns, behavioral economics, business school, analysis of competitive advantage, analysis of national systems, and socio-technical regimes (Greenacre et al., 2012)."

The Schumpeter theory of innovation is the foundational theory of innovation and still influences many contemporary theoretical approaches on innovation. The theory provides the foundation for describing the innovation process by positing it as a linear sequence beginning with basic research and progressing to applied research, technology development, and diffusion (Godin, 2006).It posits that scientific progress plays a crucial role in shaping the trajectory and pace of innovation, and that boosting R&D intensity is the most effective means of generating new technologies (Schumpeter et al., n.d.). The theory can be used to examine the various stages of the innovation process, from the source of innovation (basic research) to the diffusion of technology, to analyze the innovation process and the barriers to innovation as in (J, 2015). For example, the theory can be used to investigate the challenges that blockchain-based payment systems face during the early stages of the innovation process, such as technology development and application in the payment system. The theory can also be used to analyze the challenges encountered during the diffusion stage, such as a lack of widespread adoption and acceptance of the technology, as well as scalability and security limitations that must be addressed in order to gain wider acceptance. The approach, however, has been criticized for being overly simplistic. Although the theory describes the origin and direction of technological innovation, it ignores the role of various actors and the links between actors and institutions, as well as the drivers and barriers to innovation (Greenacre et al., 2012).

In the 1950s and 1960s, the "demand pull" perspective gained prominence as a theoretical alternative to Schumpeter's "technology push model" (Trott, 2021). The demand-pull perspective argues that “demand for products and services is more important in stimulating inventive activity than advances in the state of knowledge” (Iffland, 1968). Economic factors thus play a critical role in determining the direction and rate of innovation. Because of its emphasis on demand, this viewpoint is criticized as overly simplistic and better suited to explaining incremental technological innovation than disruptive innovation like blockchain based payment systems (Greenacre et al., 2012). Furthermore, because blockchain-based payment systems are still in their early stages of adoption and market demand for these systems is still low, the demand-pull perspective may fail to capture all the barriers to their adoption and implementation. Another reason for rejecting the demand-pull perspective in this study is that, unlike other innovations, blockchain-based payment systems are frequently driven by a "technology push" perspective, in which the technology itself is viewed as the driver of innovation rather than market demand.

Moving towards the 1970s to the 1990s, the discourse shifted from linear innovation models to non-linear: systemic, and dynamic processes of innovation framed by different conceptual approaches to innovation such as the evolutionary economics perspective, path-dependent models, and induced innovation approach (Greenacre et al., 2012). The central argument of evolutionary economics and the path dependency model of innovation is that technological change is "path dependent" on past and existing decisions that may constrain innovation, thereby tying technological change to relatively well-defined technological trajectories (Essletzbichler & Winther, 1999). These two approaches are therefore well-suited for analyzing incremental innovations, but they do not provide a thorough explanation for radical innovations (Schienstock, 2011). Consequently, they are not considered in this study for blockchain-based payment systems, which are considered to be radical and disruptive innovations. The induced innovation approach on the other hand focuses on the economic conditions driving technological change and the incentives for innovation (Grubb et al., 2021). It posits that an increase in the relative price of a production factor promotes innovative activity that aims to reduce production costs (Greenacre et al., 2012). This approach therefore does not fully capture the complexities of the innovation process, as well as the social and technical barriers that influence the adoption and diffusion of new technologies. In the case of blockchain-based payment systems, the adoption and diffusion is influenced by a range of social, technical, and regulatory factors. The induced approach therefore does not provide a comprehensive framework for understanding these barriers and their interplay, making it unsuitable for identifying and classifying the barriers of blockchain-based payment systems.

Regimes and trajectories, life cycle and dominant design, the chain linked model, and the four-level taxonomy of innovation are other conceptual strands that emerged between the 1970s and 1990s. These approaches are regarded as seminal in the development of the contemporary systemic theory of innovation used in the study (Greenacre et al., 2012). Regimes and trajectories, life cycle and dominant design conceptual strands posits innovation as a cumulative and paradigmatic process in which the structure, performance, context, path, and dynamics of the innovation system are all interconnected (Castellacci, 2008). The innovation process is viewed as evolving over time and being shaped by existing technological and institutional systems (Castellacci, 2008). This viewpoint emphasizes the importance of looking at the entire innovation system rather than just individual components such as research and development. By taking into account the interplay between different elements of the innovation system, it is possible to gain a more comprehensive understanding of the innovation process and the factors that influence it.

These approaches can shed light on the stages of technological innovation and the relationship between structure, performance, context, and path. However, because they do not provide a comprehensive understanding of the larger socio-technical landscape, they are not well suited for studying the social and technical barriers of blockchain-based payment systems. A complex interplay of technological, economic, social, political, and regulatory factors influences the adoption and diffusion of blockchain based payment systems. The chain-linked mode, on the other hand, contradicts the older linear models by connecting multiple drivers beyond R&D to induce innovation (Greenacre et al., 2012). The innovation process begins with identifying unmet consumer needs, then moves on to research and design, redesign, production, and distribution (Micaëlli et al., 2014). Complex feedback loops exist within each stage of the innovation process (Micalli et al., 2014). Maintaining effective links between different stages of the innovation process is a crucial requirement for the success of an innovation (Greenacre et al., 2012). Though the chain-linked model is a more comprehensive approach to innovation than the linear models, it focuses on the process of innovation and the connections between different phases of the innovation process, rather than the challenges that can impede successful technology implementation. As a result, it may not provide a comprehensive analysis of the social and technical barriers to the adoption and implementation of blockchain-based payment systems. Lastly, the four-level taxonomy of innovation provides a comprehensive framework for understanding and categorizing the types of innovation and their impact on the existing technological and economic systems (Greenacre et al., 2012). While these conceptual strands provide valuable insights into the nature of innovation, they do not provide comprehensive explanation of the barriers and challenges confronting new technologies such as blockchain-based payment systems.

In the latter half of the twentieth century, an emergent framing of the innovation process from the older linear model to nonlinear fully systemic approach that more accurately reflect the complex iterative enactment and interdependency of the innovation process converging the aforementioned conceptual strands with other perspectives was observed (Greenacre et al., 2012). The following section focuses on two systemic theories that view innovation as a complex and dynamic process shaped by the interplay of multiple factors, as we are specifically interested in radical innovation processes. The TIS (Technological Innovation System) approach analyses the interactions between technological and economic systems in the innovation process, whereas the STT (Social Technical Transition) approach analyses the social and technical interactions and interdependencies that shape the innovation process and the transition to a new technology.

4.2.1.1 Technological Innovation Systems (TIS)

The concept of 'technological innovation systems' was developed within the systemic innovation approach umbrella with the goal of enhancing the analysis of systems and comprehending the innovation process of radical technologies or niche technologies that emerge outside the incumbent paradigm (Greenacre et al., 2012). A technological innovation system is defined as "*a network of agents interacting in the economic/industrial area through a specific institutional infrastructure and involved in technology generation, diffusion, and utilization*" (Carlsson & Stankiewicz, 1991).

The technological innovation systems approach posits that “the emergence and development of new technologies is not only determined by technological innovation but also strongly influenced by the social system in which the innovation arises (Markard et al., 2015).” It therefore emphasizes the importance of studying both the structural components and the interactions between the various actors and institution and functions that drive the system to understand how technological innovations emerge and diffuse (Planko et al., 2016).

The structural components of a technological innovation system are its relatively stable interdependent aspects, which include actors, networks, institutions, and technological factors (Bergek et al., 2008). The actors in the system are the various organizations and individuals that contribute to the creation, adoption, and utilization of technology, such as developers, adaptors, regulators, and funders (Markard & Truffer, 2008). The networks on the other hand are the channels for the transfer of knowledge (Greenacre et al., 2012), while the institutions are “the humanly devised constraints that structure political, economic and social interaction (North, 1991).” Lastly the technological factors consist of “artifacts and the technological infrastructures in which they are integrated (Bergek et al., 2008)”. Although analyzing the structural elements of a technological innovation system can reveal the systemic characteristics that create facilitators and obstacles for the diffusion of technology at a specific moment or within a specific period, it has been shown that this is insufficient for understanding the determinants of change in innovation systems (Hekkert et al. 2007). This is because, while structural components play an important role in shaping innovation systems, they do not fully capture the dynamic and evolving nature of innovation. To understand the determinants of change in innovation systems, it is necessary to examine the key processes that drive innovation and how these processes interact with the system's structural components. This is where the concept of system functions comes into play.

Hekkert et al. (2007) defined seven functions of innovation systems. The premise is that a well-functioning innovation system fulfils all seven functions positively. However, depending on the context and stage of the innovation process, the relative importance of each function may vary.

The seven functions of an innovation system as described by Hekkert et al. (2007) are:

F1 - Entrepreneurial activities: Entrepreneurs play a central role In the process of enacting radical innovation in a technological innovation system. The entrepreneurs recognize and exploit the potential of radical innovations through translating ideas into business opportunities. The entrepreneurs could either be startups, spin offs or incumbent pivots that emerge as a result of technological advancement and Changing consumer preferences . Active entrepreneurial activities are a key prerequisite for the success of technological innovation system.

F2 - Knowledge development: Learning mechanisms, particularly regarding the emerging technology but also regarding markets, networks, users, etc., are crucial components of an innovation system. The underlying premise is that the advancement of the technological system is contingent upon the development of knowledge. The three forms of learning include "learning by searching, learning by doing and Knowledge Diffusion (Greenacre et al., 2012)".

F3 - Knowledge diffusion: This function involves the dissemination of knowledge about new technologies to potential users, such as firms, individuals, and other organizations. Technology transfer offices, industry associations, and other intermediaries are key actors in this function.

F4 - Market formation: The coherence and stability of dominant technologies and incumbent firms as a result of factors such as sunk costs, long development times and cultural lag limits the development and diffusion of emerging technologies. The market formation function relates to the activities that shield emerging innovations from the selection pressures of dormant technologies for example through the use of economic instruments to influence market condition such as taxation, quotas etc. A classic example of the market formation function in sustainability context is favorable tax regime for the emerging technology and unfavorable tax regime for the dormant technology. Example of the metrics that can be used to assess the market formation function include quantifying the number of niche markets introduced in Favor of the emerging technology or the tax regimes introduced in favor of the emerging innovation.

F6 - Resource mobilization: The Resource Mobilization function is a basic prerequisite for the successful development of an innovation system, and it represents the assembling and readying of financial and human capital resources that crucial for supporting innovation in an innovation system. Some quantitative measures of the resource mobilization function include the number of seed and venture capital, as well as the volume and quality of human resources.

F7 - Technology diffusion: This function involves the adoption and use of new technologies by firms, individuals, and other organizations. Factors such as the availability of complementary assets, the cost of adoption, and the perceived benefits of the technology are key drivers of technology diffusion.

The TIS approach is frequently used to research the emergence and development of new technologies, especially radical or niche technologies, by examining the interactions between various system actors and institutions and how they affect the development and diffusion of the technology (Markard, 2020). By analyzing these interactions, this approach seeks to identify the factors that contribute to the success or failure of a technology within a particular system, and how these findings can be used to formulate policy recommendations to support technology development and diffusion (Markard, 2020). As a result, it has been used as a heuristic tool to study disruptive innovations and to propose policy changes in light of the identified systemic drivers and constraints of radical innovation (Markard et al., 2015).

4.2.1.2 Social Technical Transition Approach (STT)

Recent research on innovation systems has adopted the broader systems innovation lens, which aims to understand the complex process of shifting from one socio-technical system to another and identify the factors that facilitate or hinder this transition (Papachristos, 2014). Geels & Schot, (2010) defines social technical transitions as “a set of processes that lead to a fundamental shift in socio-technical systems.” This shift involves the interplay and co-evolution of multiple components of the system including “changes *in technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and supply networks*” (Geels, 2005). These complex and dynamic interactions necessitate an in-depth comprehension of the underlying social-technical system and the interplay of the various components to understand the complex innovation process (Schot & Geels, 2008). Geels (2002) suggests that in order to envision future scenarios of systems change and determine appropriate policy interventions to steer the system towards the desired direction, a thorough examination of innovation processes must take into account the integration of these factors. By considering all these dimensions when examining radical innovations, researchers can gain an understanding of the complex social-technical systems that underpin innovation and identify and address potential barriers to the adoption and diffusion of radical innovations. The following section describes the various dimensions of the socio-technical system and their impact on the diffusion and adoption of radical innovations in guiding a social technical transition.

The technology dimension in a socio-technical systems refers to the technical artefacts that are part of the innovation process (Geels, 2002). These comprises the software, hardware, methods, and tools required for the implementation process. Geels et al. (2008) posits that technological advancements are recognized as a key driver of social-technical transitions in the field of transition studies. However, such changes may also give rise to potential barriers that can hinder the transition process (Geels et al. 2008). The understanding and consideration of this dimension is therefore a key component of the social-technical system, as it impacts on the functionality of the innovation, and its potential adoption and diffusion. However, it is deeply interwoven with the social, environmental, and institutional dimensions, highlighting the need for an integrated analysis of the interaction between these dimensions in the innovation process (Cherp et al., 2018). In the context of blockchain based payment systems, the blockchain protocol and other software and hardware components, as well as the supporting infrastructure required for implementation, the design and architecture of the blockchain system, would fall under the technological dimension of blockchain-based payment systems. All these components impact on the functionality and performance of the system, and ultimately on its potential for adoption and diffusion. It is important to note that these factors would be deeply interwoven with the social, environmental, and institutional dimensions. Therefore, it's important to adopt an integrated analytical approach when classifying and evaluating the barriers to the adoption and diffusion of blockchain-based payment systems.

The infrastructure dimension of a socio-technical system refers to the physical and technical infrastructures that support the effective functioning of the system (Geels, 2005). However, in the broader context of socio-technical systems, it also encompasses knowledge infrastructures that facilitate the transfer of knowledge and expertise, such as national university systems (Weber and Rohracher, 2012), and financial infrastructures, which include the technical systems used for the flow of money (Edler et al., 2020). Geels (2004) argues that infrastructures play a crucial role in facilitating systemic change. They are considered sunk costs by the regime. This implies that existing infrastructures can act as a constraint, making it difficult to switch to other alternatives systems (Edler et al., 2020). In the context of blockchain-based payment systems, the physical infrastructure constitutes components such as nodes, networks, and storage systems that are required for the system to operate effectively. The financial infrastructure on the other hand constitutes the payment systems and other financial platforms used to transfer funds within the system whereas the knowledge infrastructure constitutes the knowledge and skills needed to operate and maintain the system. Since blockchain-based payment systems are still in their infancy, the infrastructure that supports them is still developing. As a result, this can act as a barrier to the adoption and diffusion of blockchain based payment systems. For example, the absence of a robust physical infrastructure can cause network latency, system downtime, and slow processing times, which can make it less attractive to potential users. Similarly, the lack of supportive financial infrastructure can make it difficult to transfer funds seamlessly, limiting the adoption and diffusion. Moreover, the availability of a comprehensive knowledge infrastructure is crucial in ensuring that users have the skills to operate and maintain the system effectively.

The user practices of a socio-technical system refers to the “social norms, values, beliefs, attitudes, and behavior of the various actors involved in the innovation process such as users, stakeholders, and decision-makers" (Geels, 2002). These factors are critical in determining and influencing users' and stakeholders' perceptions and opinions about an innovation, which impacts on its potential adoption and diffusion consequently informing how a transition unfolds (Edler et al., 2020). Understanding these factors and the interplay with the other dimensions is therefore important for identifying potential barriers and proposing countermeasures to address them. In the case of blockchain-based payment systems, factors such as the technological trust level towards blockchain payment systems or resistance to change from conventional payment systems among potential users can potentially slow the uptake of the technology. This therefore highlights the importance of integrating the factors when classifying and evaluating the barriers to the adoption and diffusion of blockchain-based payment systems.

The markets dimension refers to the economic context in which innovation is introduced and includes a range of factors that influence the pace and direction of systemic change (Greenacre et al., 2012). These factors include supply and demand factors such as competition, consumer preferences, and economic conditions which can either facilitate or constrain the adoption and diffusion of radical innovations. For instance, changes in market demands can create opportunities for firms, incentivizing them to innovate new technologies that address the changing market conditions (Greenacre et al., 2012). Furthermore, the adoption and diffusion of new innovations can be either steered or hindered by customer preferences and expectations. Understanding the markets dimension factors and the interplay with the other dimensions is therefore crucial in identifying potential barriers and proposing countermeasures to facilitate social-technical transitions. In the context of blockchain based payment systems, the markets dimension factors play a crucial role in facilitating or hindering the adoption and diffusion of blockchain-based payment systems. An increasing demand and consumer preference for efficient, secure, and convenient payment systems can drive the transition towards blockchain-based payment systems. However, there are also market factors that can constrain their adoption and diffusion. For example, regulatory frameworks and lack of regulatory clarity can deter the willingness of institutions to implement blockchain based payment systems. Moreover, the dominance of conventional payment systems may create resistance to change or create network effects that constrain the adoption and diffusion of blockchain based payment systems. This therefore highlights the importance of integrating these factors when classifying and evaluating the barriers to the adoption and diffusion of blockchain-based payment systems.

The regulation dimension of the social-technical system refers to the formal and informal rules, regulations, policies, and governance structures that influence the development, implementation, and use of a technology (Geels, 2002). This also encompasses the legal and regulatory frameworks, and power structures that impact on the potential adoption and diffusion of new technologies (Geels, 2002). The factors within the institutional dimension can either be supportive or inhibitive, can influence the behavior of various actors involved in the innovation process (Janssen et al., 2020); therefore, impacting and shaping the directionality of a transition (Edler et al., 2020). Examining the institutional dimension and how the factors interplay with factors in other dimension is therefore critical when classifying and evaluating the barriers to the adoption and diffusion of blockchain-based payment systems. In the context of blockchain based payment systems, failure to consider factors within the institutional dimension can result in development and implementation of blockchain based payment systems which are not aligned to existing regulatory frameworks which may present a barrier to the adoption and diffusion of blockchain-based payment systems.

The cultural meaning dimension of the social technical system refers to the cultural context in which innovations emerge and are adopted, and encompass factors such as "societal norms, values, beliefs, and practices that shape people's attitudes and behaviours towards technology" (Geels, 2002). These factors influence the development, implementation, and use of new technologies. In the context of blockchain – based payment systems, factors such as the perception of cryptocurrencies often associated with blockchain as speculative, volatile, and risky could potentially constrain the adoption and diffusion of blockchain based payment systems. It is therefore crucial to integrate the cultural meaning dimension when identifying and classifying the barriers to the adoption and diffusion of blockchain-based payment systems.

The social-technical systems lens offers a useful framework to analyze the complex process of shifting from one socio-technical system to another and identifying the factors that facilitate or hinder this transition. Researchers can adopt this framework to identify and classify social-technical barriers that impede the adoption and diffusion of radical new technologies by considering the various dimensions and components within those dimensions. This research draws and operationalize the social-technical systems lens to analyze the barriers of blockchain-based payment systems with the basic premise being the consideration of blockchain- based payment systems as social-technical systems, and their potential of steering social technical transition in the payments sector does not solely depend on technological change, rather an interplay and co-evolution of a broad range of dimension factors. Although the social technical transition approach has been predominantly applied in sustainability studies, the transformation of payment systems is contextualized in this thesis as a socio technical transition and likened to other sustainability transitions that have been studied from the social technical transition lens. Although the transition towards sustainability and transitions beyond sustainability are logically distinct, there are generic characteristics that cuts across both. These include the fact that socio technical transitions are slow and occur incrementally along fixed trajectories because of the rigidity of the regime emanating due to the quasi-(co) evolutionary structural factors (Geels, 2002).

Despite the similarities between the technological innovation systems and the social- technical systems in their systemic approach of analyzing innovation processes and conceiving systemic innovation to constitute multiple factors beyond technological change, the research adopted the social-technical systems framework to analyze and classify the barriers of blockchain based payment systems. The choice was guided by the research focus which is to analyse and classify the barriers of blockchain based payment systems. The social –technical systems offer a suitable and structured reference point to map barriers across each dimensions including the changes in "technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and supply networks dimensions" (Geels, 2005). The Technological Innovation Systems (TIS) in contrast focuses on understanding the role of actors and institutions shaping the innovation process. By adopting the social technical systems lens, the researcher is able to classify the barriers and corresponding countermeasures for each barrier. Table 4.1 illustrates the various dimensions and sub-components of a blockchain-based payment system operationalized from the socio-technical system lens in (Geels, 2002).

Dimensions	Barriers
Technology dimension	1. Technical artefacts including the software, hardware, methods, and tools required for the implementation process.
Infrastructure dimension	2. Physical and technical infrastructure 3. knowledge infrastructures 4. Financial infrastructures
User practices/ market dimension	5. Social norms, values, beliefs, attitudes, and behavior of the various actors 6. Supply and demand factors 7. Consumer preferences 8. Economic conditions
Regulations dimension	9. Formal rules and regulations 10. Informal rules and norms 11. Governance structures 12. Power structures
Cultural dimension	13. Cultural factors such as such as societal norms, values, beliefs, and practices that shape people's attitudes and behaviours

Table 4. 1 Dimensions and sub-components of a blockchain-based payment system, adopted from Geels, (2002)

4.3 Research design and method

4.3.1 Overview

This section describes the research methodology adopted in this chapter. It first outlines the rationale for the research design and the background of SLR approaches. The section then outlines how the methodology was implemented to identify the barriers and proposed solutions of blockchain-based payment systems, and describes the stages of planning, conducting, and reporting the review. The section then concludes with an outline on the limitations of the research and ethical considerations.

Section 4.3.2 provides an overview of the research design and the rationale for adopting the systematic literature review methodology for identifying the barriers and countermeasures of blockchain-based payment systems. *Section 4.3.3.1* describes the planning process adopted for the SLR, including the research objectives and research questions formulated to guide the study. *Section 4.3.3.2* discusses the search strategy applied to identify the relevant literature, including the search string applied, the databases searched, and the inclusion/exclusion criteria used to select articles. *Section 4.3.3.3* outlines the quality assessment process used to evaluate the articles included in the SLR. *Section 4.3.3.4* discusses the approach employed to synthesize and analyze the data gathered from the included studies. *Section 4.3.3.5* discusses the limitations of the research and ethical considerations.

4.3.2 Research design

Research design refers to the plan or blueprint specifically created to answer research questions (Corbin & Strauss, 2008). Research designs differ from research methods in that the former does not delineate the process of collecting data, rather, it outlines the research process's framework. To develop an appropriate research design, it is imperative to first determine the research objectives.

Research designs are categorized into four major categories based on the research objectives and the nature of the research topic including descriptive, exploratory, explanatory, and evaluative designs. Descriptive research refers to research that aims to provide a detailed description of a population, event or phenomenon and its attributes (Nassaji, 2015). The primary objective of this type of research is to answer questions related to “what is happening,” rather than the “how” or "why” it is happening in the context of what is being studied (Creswell et al., 2007). Exploratory research is a type of research that aims to gain “insights into the nature of a particular issue and generate questions that can be further investigated. This type of research is commonly used to explore new topics and is often a preliminary step to more in-depth studies. However, exploratory research can also be valuable as a standalone form of research (Strydom, 2014).” Inductive qualitative methods are commonly utilized for collecting data in exploratory research. Descriptive and exploratory research have several similarities and are often combined in practice. Both approaches involve starting with a clearly defined topic and conducting research to provide an accurate portrayal of the phenomenon. In a descriptive study, the outcome should be a thorough and detailed description of the subject being examined (Strydom, 2014). Finally, explanatory research design is used to establish the causal relationship between variables and understand the effects of a social phenomenon on behavior while evaluative research designs are used to assess the effectiveness of a specific intervention or practice such as a program, or policy in real-world settings within the social context.

Based on the information presented above, a qualitative exploratory research design was considered most suitable for achieving the research objectives. To reiterate here, the aim of this chapter is to identify the various barriers to adoption and diffusion of blockchain-based payment systems and the proposed solutions to address these barriers. This issue is multifaceted and intricate, encompassing various contextual technological, social, economic, and institutional factors that cannot be measured or quantified through quantitative data alone. For example, regulatory frameworks and rigidity of user preferences and routines on conventional modes of payments can influence adoption and implementation of blockchain-based payment systems. These factors are often better explored through qualitative methods, as they allow a researcher to collect diverse and comprehensive data required to understand the phenomena under investigation. Additionally, the nascent stage of blockchain technology makes qualitative research particularly suitable, as it allows for an in-depth exploration of the phenomenon under investigation, including its context and the perspectives of different stakeholders.

4.3.2.1 Unit of analysis

Selecting the unit of analysis that the researcher will focus on is a key aspect of any research design, since it defines the level of specificity and detail of the data collected. It can also affect the generalizability of the research findings to various contexts and populations. The choice of unit of analysis in the context of research on blockchain application study may vary on various characteristics such as the examined industry, country, or location depending on the scope of the research.

With respect to the industry under investigation, the focus is on exploring applications of blockchain in the financial services industry, specifically the payment systems industry at the infrastructure level. Although there are many envisaged applications of blockchain technology in the financial services industry, it has garnered significant interest in the context of payments, and the feasibility of blockchain-based payment systems has been demonstrated through pilot projects and live implementations.

While it is possible to focus on a specific country or region within the payment industry, the decision was made to approach the research from a global level. The reason for this is that the adoption and diffusion of blockchain-based payment systems is a global issue that is not limited to any specific country or region.

A global perspective is therefore necessary to gain a comprehensive understanding of the barriers and proposed solutions of blockchain- based payment systems.

4.3.3 SLR as a research approach

This thesis aligns with Snyder’s (2019) perspective in support of using SLR as a research methodology to evaluate the collective evidence on a specific research question, extending beyond its conventional role of providing a descriptive summary of available evidence and identifying gaps on a research topic. The SLR approach is now widely used across a range of disciplines, including medicine, social sciences, management, and industrial engineering, and there is growing confidence in its effectiveness as an independent research approach (Tranfield et al., 2003). The SLR approach involves a transparent, objective, and reproducible approach of selecting, analyzing, and synthesizing data that addresses specific research questions. It is defined in Liberati (2009) as a “a research approach that involves identifying and evaluating relevant studies in a thorough and structured manner, and then synthesizing and analyzing the data gathered from those studies." By utilizing systematic and explicit techniques to review articles and all available evidence, researchers can reduce bias and produce dependable results from which conclusions can be drawn (Liberati., 2009).

The adoption of an SLR approach offers several potential benefits and contributions as discussed in Snyder (2019). One potential benefit of utilizing an integrative or critical SLR methodology is that it can combine and analyze research findings to offer evidence at a meta-level. Specifically, in the case of new and emerging topics, where there may not be a well-established body of literature or theoretical framework to build upon, researchers can identify and synthesize existing literature from various fields, allowing for the creation of preliminary conceptualizations and theoretical models. These preliminary conceptualizations and theoretical models can then serve as a starting point for further research and development in the field. Such reviews may however require a more creative data collection approach as the goal is often to integrate perspectives and insights from various fields. Second, an SLR can also provide an overview of interdisciplinary and disparate research areas. This can be particularly important for interdisciplinary research on complex, multifaceted topics where insights from different fields or perspectives may be necessary to fully understand the phenomenon being studied. Third, by synthesizing and analyzing existing literature, SLRs can identify gaps or less explored areas in existing research, which can be valuable in shaping future research priorities and directions. Fourth, SLRs (SLRs) offer insights into the impact of the phenomenon under investigation across various empirical methods and diverse settings (Kitchenham, 2004).

They can therefore provide evidence for generalizability of a phenomenon if the literature consistently produces comparable results, or highlight need for investigation of variability, if the studies produce inconsistent results. Finally, an SLR typically documents the search strategy, inclusion/ exclusion criteria and quality assessment criteria applied to the relevant potential literature hence can be replicated by other researchers which can promote future meta- analyses.

In this present study, the SLR approach was justified, as it offers a rigorous and structured approach for comprehensively evaluating the current state of research on barriers and countermeasures of blockchain-based payment systems. Through the SLR the researcher can gather and synthesize a wide range of studies, which provides insights into existing research gaps and areas that require further investigation therefore responding to RQI: “What is the current state of research on blockchain-based payment systems barriers and proposed solutions? In addition to the rigorous and structured approach provided by the SLR, the multidisciplinary nature of blockchain which intersects with various fields such as computer science, social sciences, economics, and law necessitates the adoption of an approach that enables a range of literature across disciplines to be analyzed and synthesized enabling a more holistic perspective on the barriers and proposed of blockchain based payment systems. By incorporating literature from various disciplines, the SLR approach can reveal the different perspectives and insights from each field, which may be necessary to fully understand the barriers and countermeasures of blockchain-based payment systems. This multidisciplinary approach is particularly important in the case of emerging technologies like blockchain, where there may not be a well-established body of literature or theoretical framework to build upon. It is important to note that other research methods and individual studies may not incorporate various disciplines, resulting in a limited view of the barriers and countermeasures of blockchain-based payment systems.

Several studies have applied this methodology to examine the barriers of blockchain in different contexts including supply chains, e-government, and healthcare. For example, Batubara et al. (2018) conducted an SLR to understand the research areas, barriers, and future research directions of blockchain-based applications in e-government. The study identified several barriers including technical barriers such as security, scalability, and flexibility. Furthermore, from an organizational perspective, acceptance of the new technology and the requirement for novel governance models are key barriers to adoption. Also, the absence of adequate legal and regulatory frameworks is regarded as another barrier to blockchain- based adoption in this area. Mohammed et al. (2023) similarly employs the SLR methodology to identify blockchain barriers in food supply chain. The study identified scalability, interoperability, cost, lack of expertise and regulations as the key barriers to adoption of blockchain in this area. Within the financial services sector, Ali et al. (2020) employs an SLR to propose a categorization framework that includes three dimensions: financial benefits enabled by blockchain, challenges related to blockchain adoption, and the functionality of blockchain technology. The identified challenges include "scalability, total time for the verification of the transactions (latency), security, meeting regulatory challenges and transaction cost." The adoption of the SLR approach was therefore deemed sufficient for addressing the research questions of the present study.

4.3.3.1 SLR methodology Research Method

To pursue this, the research follows the SLR guidelines proposed by (Kitchenham, 2004). The suggested approach includes seven steps subdivided into three main phases including 1) planning the review, (Section 3.2) (2) conducting the review (Section 3.3), and (3) reporting the review (Section 3.4). Each phase has subsets as illustrated in figure 4.1.

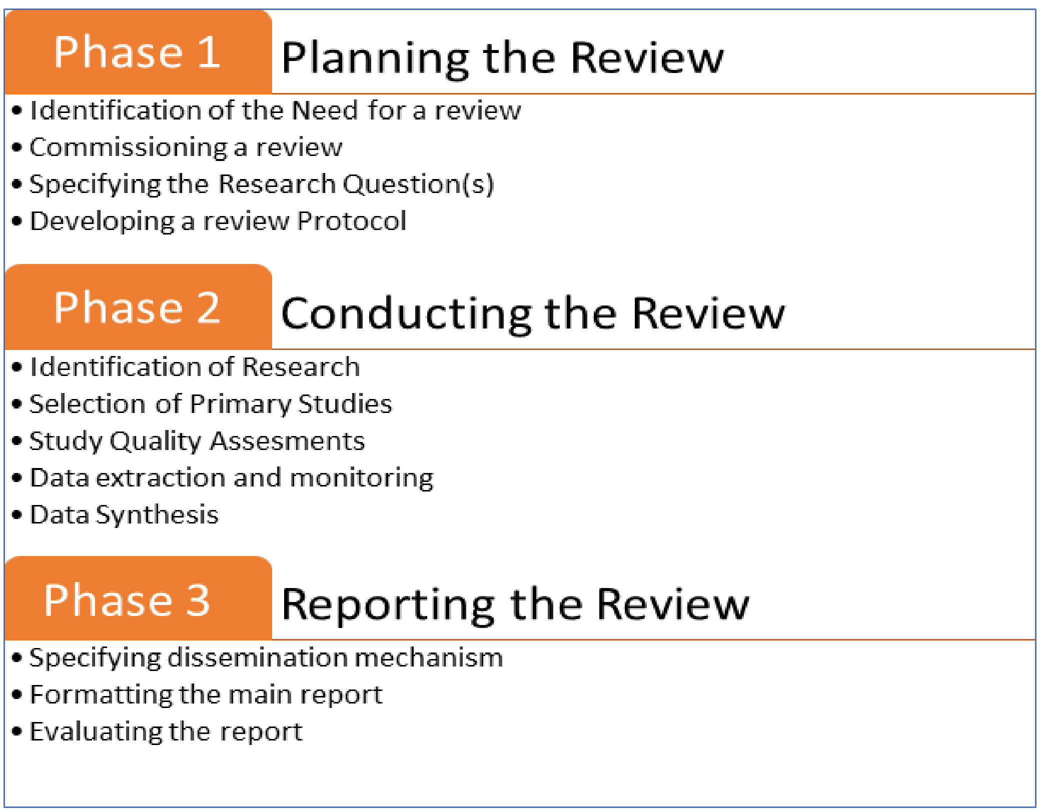


Figure 4. 1 illustrates the process model used for this research, which is based on the SLR guidelines proposed by Kitchenham and Charters (2004).

4.3.3.1.1 Planning the review.

The initial phase of planning a SLR involves identifying the need for conducting the SLR (Ivic et al., 2022). The criterion for assessing the need of the SLR should be guided by the consideration on whether there is there a need to summaries all existing relevant literature on the phenomenon of interest in an unbiased manner. This could be motivated by a need to draw overall conclusions on the phenomenon that cannot be obtained from individual studies, or as a preliminary step for further research activities. This SLR on barriers and countermeasures of blockchain payment systems is driven by the need to create an integrated perspective of the barriers and countermeasures identified from all relevant studies on blockchain payment systems. Because of the multidisciplinary nature of blockchain and barriers, depending on only a single research method may offer a limited view.

4.3.3.1.2 Related studies

Once the need for an SLR has been established, researchers should verify the necessity of conducting the review by evaluating existing systematic reviews related to the topic of interest, using a suitable evaluation criterion (Kitchenham, 2004). This step helps to guarantee that the SLR addresses research gaps not covered by existing reviews hence avoiding the duplication of efforts. After establishing the need for conducting the review, the second step involved appraising the existing SLRs on blockchain barriers in the financial services sector. The iterative process started with a search of SLRs on the barriers of blockchain in financial services, which is then narrowed down to barriers of blockchain in payments and subsequently barriers of blockchain based payment systems on Google Scholar and Scopus. The papers that do not adhere to the guidelines and protocols for systematic literature reviews are excluded in the iterative selection process.

Four existing SLRs related to the research scope were chosen. The following assessment criteria was adopted from Ivic et al., (2022) to guide the review of existing SLR studies on blockchain barriers in the financial services sector.

CC1: Are the review's objectives related to the identification and analysis of existing literature on barriers of blockchain-based payment systems?

CC2: Did the researchers conduct a comprehensive search of all relevant databases and were there restrictions?

CC3: How was the data from the primary studies synthesized?

Table 4.2 illustrates these studies, with columns for publication year, number of articles evaluated, scope of literature review and additional columns depicting how this research is comparable to and different from the systematic literature reviews in answering the research questions.

Articles	Number of reviewed articles	Publication year	Scope	Comparability with the present study
Systematic Literature Review on Application of Blockchain Technology in E-Finance and Financial Services	59 articles	2021	"The study explores the applications, adoption, and challenges of blockchain technology in the financial sector. It identifies barriers including technical challenges like scalability, interoperability, and security issues. Regulatory challenges- Lack of legal framework, standardization, and governance."	The study considers blockchain application in e-Finance and Financial Services without narrowed focus on any segment of financial services. The identified barriers are limited to just two dimensions of a social-technical system.
The state of play of blockchain technology in the financial services sector: A systematic literature review	87 articles	2020	"The study investigates the impact of blockchain technology on the financial sector and creates a framework with three dimensions: Blockchain-enabled financial benefits, challenges, and functionality. The identified barrier includes financial challenges, regulation challenges, operational challenges, and adoption challenges."	The study considers blockchain application in the financial services sector broadly without narrowed focus on any segment of financial services.

Exploring the barriers and organizational values of blockchain adoption in the banking industry	35 papers	2021	“The study explores the organizational values and hindrances in the banking industry through semi-structured interviews and systematic literature review.”	The scope of the study on the banking industry is different from the present study scope on blockchain-based payment systems.

Table 4. 2 Comparison to the systematic literature reviews in answering the research questions.

Overall, this study differs from the three SLRs in that the present study focuses on identifying and evaluating barriers of blockchain-based payments while the other three studies have a broader focus on exploring the potential of blockchain technology in the broader financial services sector. The study also analyses the potential solutions to address these barriers which are out of scope of the rest of the studies.

4.3.3.1.3 Conducting the review.

This section describes the stages of the "search process, selection of primary studies, study quality assessment, data extraction and synthesis" as outlined in Ivic et al., (2022). These steps are sequentially discussed.

i) **Search process**

The search process was carried out using Ivic et al., (2022) guidelines on generating a search strategy. The guidelines recommend a three-stage approach for conducting the search for primary literature which includes (1) constructing a search string, (2) selection of databases, (3) applying the string on chosen search engines.

Step 1: Constructing a search string.

In line with these guidelines, the first step involved constructing the search string, which was then applied to the selected databases to identify the relevant studies. The Population Intervention Comparison Outcome (PICO) approach proposed by Kitchenham et al., (2009) was adopted to guide the identification of the key that should be used in the search string construction. This approach helps to make the search more specific and targeted which improves the accuracy of the search. The PICO approach focuses on the population (P) and intervention (I) variables, as including the others could overly restrict the search and eliminate useful articles. In the initial iterative search, different terms for the population and intervention dimension were tested to evaluate the most relevant search terms and combination. The population variables included terms such as "*Payment*," "*Payment System*," and "*Payment industry*," while the intervention variables included terms such as "*Blockchain*," "*Bitcoin*," "*Crypto currency*," and "*Distributed Ledger Technology*." The yielded results were evaluated to determine the optimal search terms. Based on the aggregated results, a simple search string [*Blockchain* AND *Payment*] was developed.

Step 2 and 3: Selection of databases and applying the string on chosen search engines.

The data sources for this study were academic databases including IEEE Xplore, Emerald Insight, Elsevier/Science Direct, Sage Journals, Oxford University Press, Wiley, and Taylor & Francis and Scopus These databases were chosen because they offered a comprehensive range of publications that generated relevant results pertaining to blockchain-based payment systems. The decision to utilize these databases was informed by the results generated for the search string on blockchain-based payment systems, which demonstrated their relevance and suitability for the study's objectives. The multiple use of databases allowed for a more diverse of the topic, which ensured the study's findings were grounded in a wide range of evidence increasing the reliability of the study. While databases some focus on technical aspects such as the IEEE Xplore, others cover topics on accounting and finance, economics, and management. Therefore, the integration of the perspectives ensured the researcher has access to a diverse range of articles that are relevant to their research questions.

To conduct the search, the search strings outlined in Table 4.3 were applied to the respective databases' search engines. The final search was updated in March 2022. The application of the search string was adapted to suit the syntax, indexing, and search algorithms of each database.

Database	Search string link	Results
IEEE Xplore	("All Metadata": Blockchain AND "All Metadata": Payments)	112
Emerald Insight	(Content-type: article) AND (abstract: "Blockchain AND Payment")	23
Elsevier/Science Direct	("All Metadata": Blockchain AND "All Metadata": PAYMENT)	122
Sage Journals	for [Abstract blockchain] AND [Abstract payment] within Research Article	4
Oxford University Press	Abstract: Blockchain AND Payment	5
Wiley	"Blockchain AND Payment" in Abstract	27
Taylor & Francis	[Keywords: blockchain] AND [Keywords: payment]	23
Scopus	{blockchain AND payment}in Article title, abstract, key words	3

Table 4. 3 The specific search strings, and the yielded results for each database

ii) Selection of primary studies

After retrieving the initial sources that could be potentially relevant for the study, they must be assessed to determine their actual relevance. The guiding principle in determining the selection criteria should be an inclusion/exclusion criterion that filters out sources that directly respond to the reviews research questions. To ensure a focused research approach, this study adopted the selection criteria proposed by Garousi et al. (2019). The checklist includes questions on the novelty of the source and whether it provides a unique contribution to the research and the language used. The steps taken to establish the inclusion criteria are summarized below.

Inclusion criteria:

- The sources that focused on blockchain-based payment systems,
- The sources that discuss challenges and barriers to adoption and diffusion of blockchain based payment systems,
- The sources that provide insights into the countermeasures for the challenges of blockchain based payment systems,
- The sources that are written in English

An initial screening was done on the 316 sources retrieved based on title, abstracts, and keywords to identify papers that could be rejected based on fact that they did not respond to the research question. We obtained full copies of the remaining 229 papers and undertook a more detailed second screening that involved the whole journal reading. During this second screening process, 174 papers were rejected based on the pre-established inclusion criteria, leaving a final set of 55 papers for analysis in the study.

Database	Search string link	Results	Initial Abstract Screening	Journal reading
IEEE Xplore	("All Metadata": Blockchain AND "All Metadata": Payments)	112	92	20
Emerald Insight	(Content-type: article) AND (abstract: "Blockchain AND Payment")	23	14	3
Elsevier/Science Direct	("All Metadata": Blockchain AND "All Metadata": PAYMENT)	122	100	23
Sage Journals	for [Abstract blockchain] AND [Abstract payment] within Research Article	4	3	1
Oxford University Press	Abstract: Blockchain AND Payment	5	5	2
Wiley	Blockchain AND Payment" in Abstract	27	6	2
Taylor & Francis	[Keywords: blockchain] AND [Keywords: payment]	23	9	4
Scopus	{blockchain AND payment}in Article title, abstract, key words	3	0	0

Table 4. 4 Articles inclusion criteria

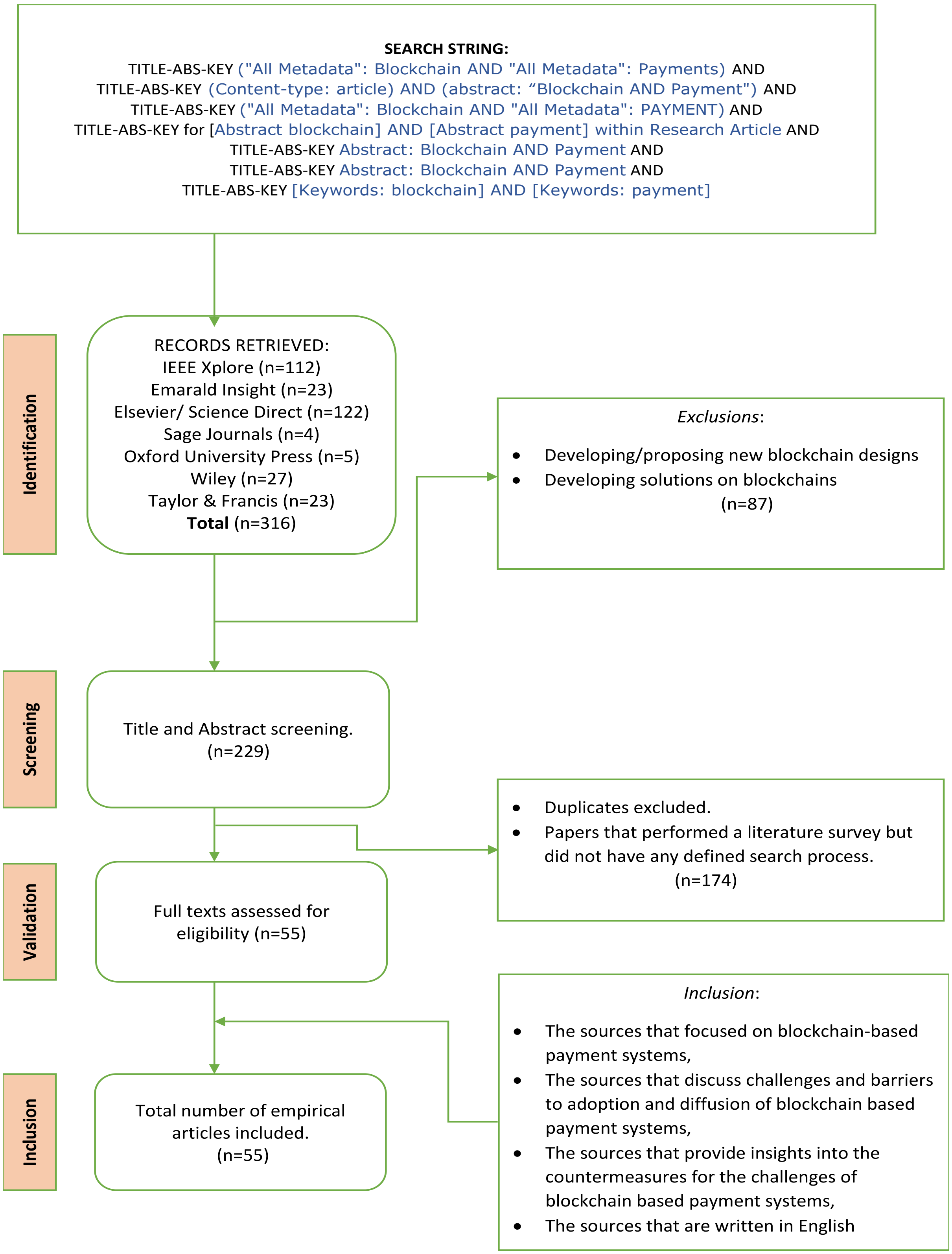


Figure 4. 2 Articles selection, assessment, and exclusion/ inclusion (presented using PRISMA flow diagram).

iii) **Data extraction and synthesis**

To retrieve data, a spreadsheet hosted drive was used to create a data extraction form. A snapshot of the online repository, which is the spreadsheet hosted on Google Docs, is shown in Table 4.5. The data extraction form is included in the appendix.

In the initial stages of the data extraction, the researcher retrieved bibliometric data (i.e., publication type and year, research type and the outlet type based on the classification proposed by Garousi et al. (2019). The bibliometric data was used to develop the descriptive section of the analysis, which helps identify trends in blockchain-based payment systems research. Data synthesis was conducted using a framework synthesis approach. The framework synthesis approach is based on the framework analysis method introduced by Ritchie and Spencer in the 1980's, which involves analyzing primary research data by systematically organizing and categorizing qualitative data based on a predefined framework or set of codes (Brunton et al., 2020). (Advantages of framework synthesis) and (other studies that have used framework synthesis). The framework synthesis method involves a series of five steps. The next section discusses each stage in the context of this research.

The first step in framework synthesis is data familiarization, which is aimed at offering the researcher a preliminary comprehension of the data. This initial step can reveal wide ranging insights that consistently recur across the data and respond to the research question. To conduct the data familiarization step, the researcher read each source included in the final pool. This step helped to develop the categories used in the subsequent stage of framework synthesis.

The second step in the framework synthesis involves developing a thematic framework, with the aim of establishing a framework or an analytic structure. This analytic structure can emerge from pre-existing themes, from the data collected or a combination of both (Goldsmith, 2021). Typical analytical structures consist of the major themes or concepts which constitute the major components and are then divided further into subcomponents. The themes and concepts are then structured in a way that facilitates addressing the study's research question. The overarching themes in this study were the social- technical systems dimension described in section 2 including the technology dimension, infrastructure dimension, user practices/market dimension, regulations dimension and cultural dimension. These themes were further divided into subcomponents based on the social-technical systems perspective.

The third step of the framework synthesis is indexing, which involves systematically coding and categorizing the data to facilitate analysis and interpretation (Brunton et al., 2020). In this stage, the researcher read each source in the final pool to identify relevant extracts that correspond to each theme in the framework, then organized the identified barriers and corresponding proposed solutions into the appropriate categories to provide a foundation for identifying the barriers and proposed solutions to the adoption and implementation of blockchain-based payment systems.

The fourth step in framework synthesis is charting, which involves summarizing and condensing the indexed data according to the analytic structure. This step enables a researcher to visualize the themes and sub themes, facilitating the identification of patterns and inferences from the data. In this stage, the identified barriers within each category were manually mapped to the overarching themes on the table.

In the last step of the framework analysis, which is mapping and interpretation, the researcher combines the insights gathered from the earlier stages, as well as any assumptions or theories that need to be tested against the data (Brunton et al., 2020). This stage involves comparing data within and across the framework components. During the synthesis stage, the researcher identified themes based on the features of the studies included. These themes were assessed in the context of the research questions, and the review's original context to provide a comprehensive and structured overview of the barriers that impede the adoption and implementation of blockchain- based payment systems and the proposed solutions to address them.

4.4 Descriptive analysis

The descriptive analysis in this section is aimed at providing insights into the evolution and current research trends on blockchain-based payment systems.

4.4.1 Distribution of research articles

The study analyses 55 studies published between 2017 and 2022. Distribution of academic publications per year is illustrated in Figure 4.3. Notably, all the extracted papers that met the predefined inclusion criteria were published after 2017, despite performing a systematic search for papers that dates to 2009. This suggests that academic interest in blockchain technology, particularly in areas beyond cryptocurrencies started to emerge after 2017, which is nine years after Satoshi published the bitcoin white paper “Bitcoin: A Peer-to-Peer Electronic Cash System.” Additionally, the fact that there were no publications meeting the inclusion criteria prior to 2017 suggests that the initial perception of blockchain technology being exclusively linked to cryptocurrencies may have limited research efforts in exploring other applications. However, this trend is changing as there is now an increasing focus on blockchain's potential applications in payment, clearing and settlement. The limited number of publications on blockchain as a payment system can be attributed to the challenges posed by the volatility of bitcoin prices, which incentivize users to hold the cryptocurrency for speculative purposes rather than using it for payments. This may have discouraged researchers from exploring this aspect of blockchain technology in depth.

Overall, the upward trend in the number of academic publications on blockchain payment systems since 2017 suggests that there is a growing interest in exploring the potential of blockchain technology beyond cryptocurrencies, and this is likely to lead to more innovative applications of the technology in the future.

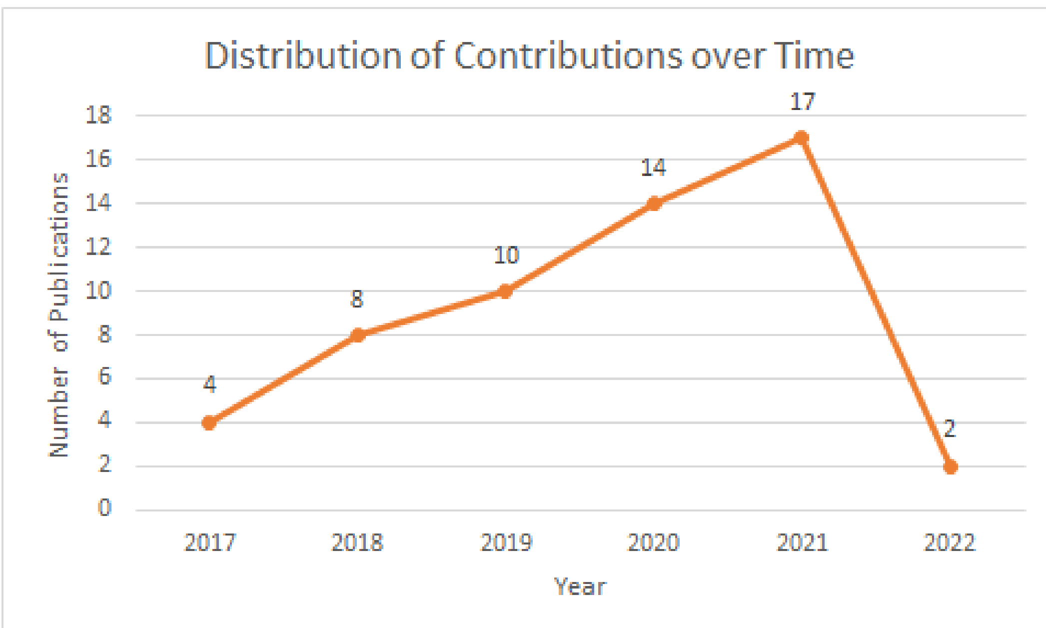


Figure 4. 3 Distribution of academic publications per year

4.4.2 Types of Articles

Figure 4.4 provides a comparison of the diverse types of academic articles included in this research study. These include technical papers, empirical studies and survey papers. The highest composition of the academic corpus is technical papers (33) followed by empirical research (15). The high number of technical research papers is indicative of the growing interest amongst academic researchers in proposing solutions to address the challenges in blockchain-based payment systems.

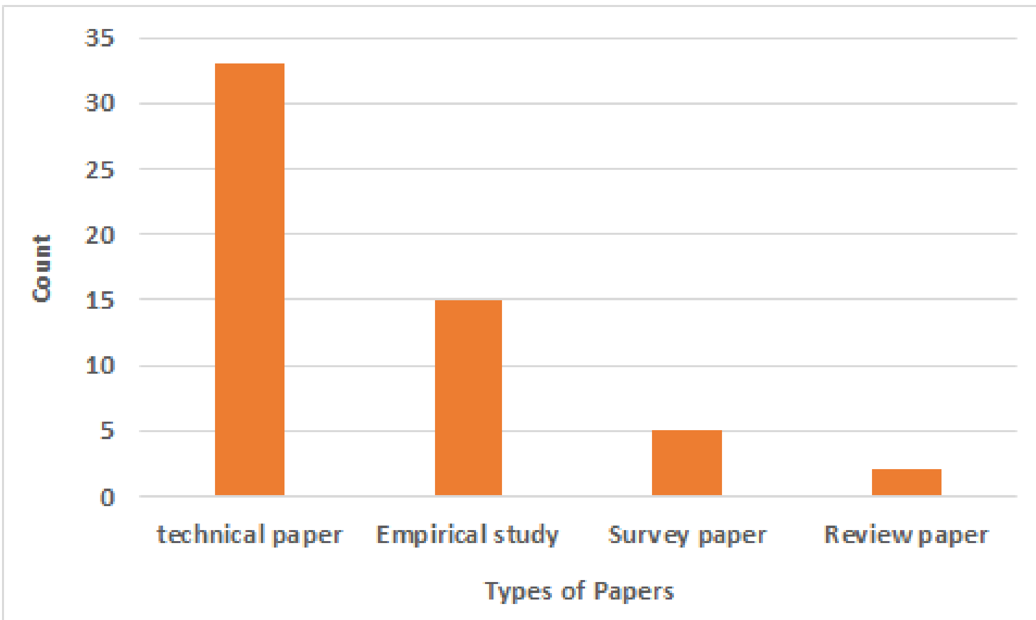


Figure 4. 4 Comparison of the diverse types of academic articles

4.4.3 Distribution of articles by database sources

Figure 4.5 presents a comparison of the distribution of academic articles by database source. The figure shows that most of the selected articles were obtained from two major databases, Elsevier, and IEEE, which accounted for around 76% of the total selected articles. This suggests that these two databases are the primary sources of academic literature on blockchain-based payment systems. It is worth noting that the use of multiple databases in the systematic review process helped to ensure a comprehensive coverage of relevant literature in the field.

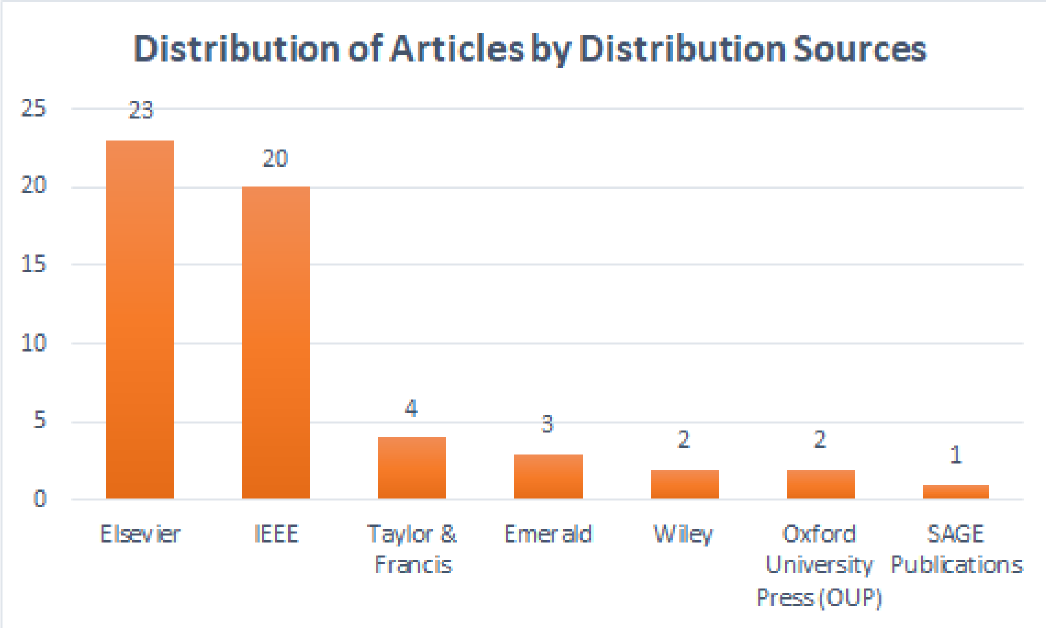


Figure 4. 5 comparison of the distribution of academic articles by database source

4.5 Blockchain-based payment systems barriers and countermeasures

This section presents the findings of the SLR on the barriers of blockchain-based payment systems and their countermeasures. We use the conceptual framework presented in Section 2 to analyze the blockchain-based payment systems articles mapped in Section 3. Through the SLR, we identified a comprehensive list of barriers that impede the adoption and widespread diffusion of blockchain-based payment systems. These challenges have been classified into six main themes technical, infrastructural, user practices, markets, regulatory and cultural barriers based on the dimensions of a social- technical systems as discussed in section.

The section presents the identified barriers and their corresponding potential countermeasures under each main theme and provides a brief summary of the key findings of each theme. Furthermore, the section identifies the research gaps and future research opportunities in each of the identified themes. Overall, this section responds to the formulated research questions by providing a comprehensive overview of the most recent literature on blockchain-based payment systems, as well as discussing the barriers that must be overcome in order to facilitate widespread adoption and diffusion. The reviewed articles are summarized in Table 4.5 below.

Aspects		Challenges	Authors
Technological dimension	Immature technological designs	Scalability	(Zhang & Yang, 2021), (Ryu et al., 2020), (Conoscenti et al., 2019), (Ye et al., 2021), (Varma & Maguluri, 2021), (Podgorelec et al., 2020), (Lin et al., 2020), (Zhong et al., 2019), (Mohanty & Tripathy, 2021), (Zhong et al., 2019), (Robert et al., 2020), (Erdin et al., 2020)
		Inefficiency of public blockchain in processing micropayments	(Rezaeibagha & Mu, 2018), (Yan et al., 2020), (Erdin et al., 2021), (Konashevych & Khovayko, 2020), (Erdin et al., 2020)
		Security threats and vulnerabilities in blockchain-based payment systems	(Rahouti et al., 2018) (Li et al., 2021)
		Challenges in maintaining both transparency and privacy in blockchain-based payment systems	(Lin et al., 2020) (Jia et al., 2022) (Zhang et al., 2020) (Kus Khalilov & Levi, 2018) (Alqassem et al., 2020) (van Dam & Abdul Kadir, 2022) (Jawaheri et al., 2020) (Ziegeldorf et al., 2018) (Wang et al., 2021)
		Volatility of cryptocurrencies as a barrier to adoption in blockchain payment systems	(Saito & Iwamura, 2019)
		Storage requirements for low-performance devices	(Dai et al., 2018) (Ying et al., 2021)

		Undesirable environmental effects of blockchain-based payment systems	(Huberman et al., 2017)
Infrastructure dimension		Network connectivity requirements	(Hu et al., 2019 (Igboanusi et al., 2021)
Institutions dimension		Lack of adequate regulatory frameworks	(Lin et al., 2020) (Ferrari, 2020) (Politou et al., 2021)
		Requirement for regulatory compliance	(Politou et al., 2021)
		Lack of clear governing structure	(Zachariadis et al., 2019), (Ziolkowski et al., 2020)
Cultural dimension		Societal norms, values, beliefs, and practices that shape people's attitudes and behaviours towards technology	(Salcedo & Gupta, 2021)
Users/Market Preferences dimension		Rigidity of user preferences and routines on dominant modes of payments.	(Nadeem et al., 2020), (Szumski, 2020), (Presthus & O'Malley, 2017) (Kewell & Michael Ward, 2017)
		Negative perception on the perceived usefulness and ease of use of blockchain-based cryptocurrencies	
		Lack of trust	
		Lack of knowledge and awareness of blockchain-based payment systems	

Table 4. 5 Summary of reviewed articles findings of the SLR on the barriers of blockchain-based payment systems

4.5.1 Technological Dimension

The barriers in this theme pertain to the limitations of the technical components of blockchain-based payment systems which are conceptualized as social-technical systems in this study. These include the technical artefacts of blockchain based payment systems including the software, hardware, methods of implementation, and tools in the technological dimension of the blockchain based payment system. Since innovation within the technical dimension of a social technical system is a considered as a necessary pre-condition for transitions, the barriers within this dimension are particularly significant and can hinder the transition from conventional payment systems towards blockchain-based payment system.The subsections that follow discuss the broad categories, as well as the subcategories of barriers that fall within each category and the corresponding proposed solutions.

4.5.1.1. Immature technological designs

The immature technological design is a sub theme of technical barriers that encompasses barriers faced by modern technologies as they navigate through the early development phase, which may be characterized by low yield due to low-scale production and defects in meeting user needs, as suggested in Kemp, Schot and Hoogma (1998). The technical artefacts in the early development phase may have not yet been fully optimized and may require further research and development to improve their functionality (Kemp, Schot and Hoogma (1998). Notably, these initial faults and inherent challenges are likely to be resolved or reduced as technology develops further or becomes widespread as noted in Kemp, Schot and Hoogma (1998). Based on the reviewed articles, the immature technological barriers of blockchain-based payment systems include scalability, inefficiency in processing micropayments, security threats, challenges in maintaining both transparency and privacy, and volatility of the cryptocurrencies used as means of payments as shown in Table 4.6.

A key finding of the SLR is that the immature technological designs is a major and leading barrier to the widespread adoption and diffusion of blockchain-based payment systems as evidenced by the number of academic articles discussing these barriers in Table 4.6. In retrospect, many academics propose countermeasures discussed in the following section to overcome these barriers which may infer ongoing efforts are being made to improve the technological design of blockchain-based payment systems. As a result, these barriers will be removed or reduced as technology develops further. The following sections discuss the barriers within this sub-theme and their proposed countermeasures.

4.5.1.1.1. Scalability

Barrier: The SLR identifies scalability as a significant barrier to the adoption of block-chain based payment systems. Out of the 55 reviewed articles, 12 (21% of all reviewed articles) identify or discuss scalability as a barrier impeding the adoption of blockchain payment systems. The most used metric to describe scalability is transaction throughput which is the number of transactions processed by blockchain network per second (Zhang & Yang, 2021; Ryu et al., 2020; Conoscenti et al., 2019; Ye et al., 2021; Varma & Maguluri, 2021; Podgorelec et al., 2020; Lin et al., 2020; Zhong et al., 2019; Mohanty & Tripathy, 2021; Robert et al., 2020). Several studies compare blockchain networks' transaction throughput to that of conventional payment networks, highlighting the significant differences in the number of transactions that can be processed by each. For instance, Visa can process 2000 transactions per second (TPS) with a peak rate of 40,000/56,000 TPS (Ye et al., 2021) (Zhong et al., 2019) (Mohanty & Tripathy, 2021) while the bitcoin network can only process 3/7TPS (Ye et al., 2021) (Zhong et al., 2019) (Varma & Maguluri, 2021) (Lin et al., 2020) rendering it incapable of operating as a high capacity and high-frequency payment system. This limitation makes it difficult for blockchain-based payment systems to compete with conventional payment systems. Other interdependent vita metrics used to describe or contribute to the scalability challenge include slow confirmation time (Mohanty & Tripathy, 2021) (Robert et al., 2020) (Erdin et al., 2020), high transaction fees (Mohanty & Tripathy, 2021) (Zhong et al., 2019), network congestion (Zhong et al., 2019) block creation rate and the block size (Zhong et al., 2019). For example, a block creation time in the bitcoin blockchain is by design around 10/11 minutes and the general heuristic for the final validation of a block is after the confirmation of the 6th subsequent block, which yields the confirmation of a transaction to be around 60 minutes (Erdin et al., 2020).

The 12 papers reviewed on blockchain scalability attribute the scalability challenge to the inherent design feature of the distributed consensus mechanism in public blockchains. In addition, Conoscenti et al., (2019) identifies the maximum block size as another contributing factor to the scalability challenge.

Countermeasures: Based on the SLR findings, researchers have proposed scaling solutions to address the scalability challenge of blockchain-based payment systems. These solutions can be broadly categorized as either on-chain or off-chain solutions. On-chain scaling solutions resolve the scalability challenge of blockchain by modifying elements within a blockchain stack, such as consensus, network, and data structure, and are executed on-chain. An example of an on-chain scaling solution is the segregated Witness (SEGWIT) which is designed as protocol improvement of the bitcoin blockchain network which can increase the bitcoin throughput by up to 1.7 - 4 times more TPS. Another on-chain scaling solution is the bitcoin-cash fork which resolves the scalability challenge by increasing the block size of the bitcoin network (Zhou et al., 2020). Notably, none of the reviewed technical papers adopt on-chain scaling solution as a countermeasure to the scalability challenge beyond discussion. An inference for this could be that the implementation of on-chain solutions may not be practical, or feasible or academic researchers may have focused on off-chain solutions that are more adaptable.

Off-chain solutions on the other hand, resolve scalability challenges of a blockchain by processing transactions outside the core blockchain platform (Zhou, Huang, Zheng, and Bian, 2020). An example of an off-chain solution is the payment channel network which is designed to scale the bitcoin network by performing some transactions outside the core blockchain platform consequently improving the systems throughput (Zhou, Huang, Zheng, and Bian, 2020). Most of the reviewed articles focus on upgrading or addressing the limitations of existing off-chain solutions rather than introducing novel forms of scaling solutions, except for Zhong et al. (2019), who propose a novel light payment system based on blockchain.

Table 4.6 presents the scalability barrier of blockchain-based payment systems and the currently proposed solutions.

Barrier	Description of barrier	Proposed Solutions	Authors
Scalability	**Scalability of payment channel networks (PCN)** The payment channel networks (PCN) concept touted as a promising solution to blockchain scalability, is on its own vulnerable to external attacks or unexpected conditions that would result in transaction failure.	**Improvement to payment channel network** A payment routing protocol to resist transaction failure in payment channel networks	Zhang & Yang (2021)
	Incentive mechanisms for payment service providers in payment channel networks are not optimized	Design a routing protocol in payment channel network to discover a feasible path and derive the optimal incentive for payment channel network	Ryu et al. (2020)
	Channel economic capacity, channel unbalancing and uncooperative behavior nodes in Lightning network which cause increased payment time and failure.	N/A	(Conoscenti et al., 2019)
	Performance, scalability, privacy, and security challenges of off-blockchain payment systems	Design a payment hub for off chain coin transfers	(Ye et al., 2021)
	Challenges in scaling throughput of distributed financial transaction networks	N/A	(Varma & Maguluri, 2021)
	Transparency, transaction traceability and incapability Challenges of existing state channel solutions	Design a state channel solution that lowers transaction fees, increases speed of transaction processing consequently enabling scalability	(Podgorelec et al., 2020)

	Overload issue of existing lightning network	Design a “multi-path off chain payment mechanism to address overload and privacy leaking issues to scale blockchain”	(Lin et al., 2020)
	Capacity challenges in current off-chain payment systems	Design a “secure large scale payment system to improve the capacity of blockchain system.”	(Zhong et al., 2019)
	Capacity and privacy issues on payment channel networks	Design a privacy –preserving payment channel network	(Mohanty & Tripathy, 2021)
	Transaction costs, network congestion and transaction rates in blockchain systems.	Design a light payment system to relieve blockchain transaction costs, network congestion and transaction rates.	(Zhong et al., 2019)
	Survey the performance of lightning network against other traditional blockchain technologies in respect to scalability	N/A	(Robert et al., 2020)
	Bitcoin is unfeasible for micro and real time payments as result of high transaction fees and confirmation times	Design of a scalable bitcoin payment network that exploits lightning network	(Erdin et al., 2020)

Table 4. 6 Findings of the SLR on the barriers of blockchain-based payment systems

The findings of the SLR identify scalability which is primarily attributed to the inherent design feature of the distributed consensus mechanism in public blockchains as a significant barrier to the widespread adoption of blockchain payments systems. The scalability challenge of public blockchains is not unique to payment systems but is a typical barrier in blockchain applications across multiple domains. To this end, several scaling solutions have been proposed. The off-chain solutions are more popular as demonstrated by the substantial number of articles proposing upgrades to the existing off-chain solutions. The different upgrade proposals on the existing off-chain solutions may infer that none of the scaling solutions proposed so far is optimal. The findings identify several future research opportunities for improving scalability of blockchain-based payment systems including the introduction and exploration of novel scaling solutions, comparing the effectiveness of on-chain solutions versus off-chain solutions, and evaluating the effectiveness of currently proposed solutions.

4.5.1.1.2 Inefficiency of public blockchain in processing micropayments

Barrier: The findings of the SLR indicate that the public blockchain design, in its current form, is unsuitable for micropayments. Out of the 55 reviewed articles, 5 (9% of all reviewed articles) identify or discuss inefficiency in processing micropayments as a barrier impeding the adoption of blockchain payment systems for this use case. Micropayment systems are defined as "payment schemes which enable payments of small amounts e.g., a fraction of a penny. These schemes can be used in a range of applications including "advertisement-fee, content delivery, spam protection, rewarding nodes of P2P networks or payments for each website visit (Chiesa et al., 2017)". The high fees incurred to process micropayments (Rezaeibagha & Mu, 2018; Erdin et al., 2021; Erdin et al., 2020), and slow transaction speeds (Rezaeibagha & Mu, 2018) (Erdin et al., 2021) (Erdin et al., 2020) are cited as fundamental barriers to the widespread use of blockchain payment systems. This inefficiency contradicts the initial value proposition of the Bitcoin network, which was to enable efficient peer-to-peer micropayments.

Rezaeibagha & Mu, (2018) attributes the inefficiency in processing micropayments to the fact that all transactions on the blockchain regardless of whether small or large expend a minimum threshold of computing resources and incur a transaction fee. The transaction fee is the amount paid to miners as an economic incentive to contribute their computing power to confirm transactions. The bitcoin protocol orders transactions on a "rank- by- fee mechanism" and employs a pay-as-bid transaction fee mechanism (Yan et al., 2020). Transactions with higher bidder fees are ordered first (Yan et al., 2020). The miners then decide which transactions should be included in it. Typically, miners are inclined to prioritize transactions that bid high fees (Erdin et al., 2020). The present model results in users bidding disproportionally high fees on transactions to achieve their desired ranking and faster confirmation (Yan et al., 2020). The transaction fees mechanism and fees render blockchain systems uneconomical for micropayments. In addition, several micropayments contribute to blockchain bloat due to the enormous number of entries they generate (Konashevych & Khovayko, 2020).

Countermeasures: To address this challenge, researchers have proposed various solutions that often overlap with the solutions discussed above to address the scalability challenge of blockchain payment systems. One such approach is the implementation of payment channel networks that leverage off-chain scaling solutions. This approach creates payment channels between two corresponding parties, hence enhancing the scalability of a blockchain network by allowing the transacting parties to conduct multiple off-chain transactions, without broadcasting these transactions to every participating node on the blockchain network (Rezaeibagha & Mu, 2018). Another approach is the upgrade to the blockchain core proposed in Konashevych & Khovayko, (2020) to enable the core blockchain platform to process micropayments at reduced transaction fees and transaction speed. For instance, Konashevych & Khovayko (2020) proposed a modified blockchain platform that leverages an optimization algorithm to enhance the scalability of the platform. Alternative models for ranking transactions such as the "random fee market" mechanism, which randomly selects transactions to be confirmed, regardless of the fee paid, to ensure fairness and prevent users from bidding disproportionately high fees (Yan et al., 2020) have also been proposed. These models are aimed at reducing the transaction fees charged for micropayments.

Overall, the SLR findings suggest that the current blockchain-based payment system designs are not optimal for processing micropayments because of the high transaction fees and slow transaction speeds. Researchers have, however, proposed various solutions to address this challenge. It is however evident that more research and development of blockchain based payment systems is required to address the challenges and evaluate the effectiveness of the proposed solutions.

Table 4.7 presents the inefficiency in processing micropayments barrier of blockchain-based payment systems and the currently proposed solutions.

Barrier	Description of barrier	Proposed Solution	Author
Micropayments capabilities	In practice, many transactions are small therefore they add computation and transmission overhead to the systems.	"Design efficient micro payment systems cost- saving approach which significantly reduces transaction time and storage amount of payment."	(Rezaeibagha & Mu, 2018)
	The transaction fees resulting from bitcoin's rank: – "By fee mechanism and the payment rule pay – Bid mechanism render the system uneconomical for micropayments."	"Propose a dynamic game model of bitcoin transactions ranking."	(Yan et al., 2020)
	Bitcoin application for micropayments is challenged by long transaction times and high fees	Proposes a private bitcoin payment channel network to scale micro payments	(Erdin et al., 2021)
	The initial blockchain design cannot support micropayments without payment channel network	Designs a blockchain protocol to require the payee to sign the transaction by their private key.	(Konashevych & Khovayko, 2020)
	High transaction fees and confirmation times make bitcoin unfeasible for micro payments that require instant approval	Designs a decentralized payment network by exploiting lightning network	(Erdin et al., 2020)

Table 4. 7 Inefficiency in processing micropayments barrier of blockchain-based payment systems and the currently proposed solutions

4.5.1.1.3 Security threats and vulnerabilities in blockchain-based payment systems

Barriers: The findings of the SLR suggest that despite the desirable features of blockchain-based payment systems that enable secure transfer of value, the various layers of the blockchain stack are vulnerable to security threats (Rahouti et al., 2018) and (Li et al., 2021). For example, a review study conducted by Rahouti et al., (2018) identifies the security threats and vulnerabilities within each layer of the bitcoin blockchain stack.

Table 4.8 presents the security threats at each layer of the bitcoin blockchain stack as identified in Rahouti et al., (2018).

Blockchain component	Description of threat	Countermeasures	Author(s)
System and protocol level	Office of global support Office of backtrack analysis Block withholding attack Race attack (Double spending) Fork attack after withholding Single confirmation attack Selfish mining attack Gold finger attack Brute force attack	Design an anti-quantum lattice-based blind signature authentication scheme	(Rahouti et al., 2018) (Li et al., 2021)
Network Level	DoS attack DDoS attack Bribery Attack Time jacking attack Refund attack		

	Sybil attack Transaction malleability attack Eclipse attack Wallet theft Routing Attack Feather forking attack Tampering attack Propagation broadcast delay Bait and switch		
Cryptographic level	Brute force attack Private key storage Man-ware based key store Exhaustive key search Keystroke capture Dictionary attack Ransomware threats The loss of a private key		
Consensus Layer	51% attack – An attacker (single miner or group of miners hashing power exceeds 50% of the blockchain system)	Designs and proposed solutions that employ machine learning to counteract security threats.	(Li et al., 2021)

	Pool hopping attack – The results of miners exploiting the network to achieve more financial rewards than the computational power they contribute by "leaving the pool when it offers fewer financial rewards and joining back when the rewards of mining yield higher rewards." Bribery attack - An attacker acquires most of the mining nodes in the network through bribing. Gold finger attack – A single/group of adversaries collude with the explicit intention of breaking the network Feather –forking threat – Using much less than "50% of the hashing power to influence the network."		
Transactions	Double spending – Defined as the same funds being in multiple transactions at the same time		

Table 4. 8 Security threats at each layer of the bitcoin blockchain stack as identified in Rahouti et al., (2018)

At the system and protocol level, there are several security vulnerabilities identified by (Rahouti et al., 2018). These include office of global support (a group of miners collaborate to control the blockchains office of global support leading to centralization), office of backtrack analysis (a malicious user attempts to reverse blockchains transaction history), block withholding attack (a miner or group of miners e.g. a mining pool withhold newly mined block to gain an unfair advantage), double spending (a malicious user attempts to spend the same digital token more than once), fork attack after withholding (a miner or group of miners withhold newly mined block, then releases it after a fork occur), single confirmation attack (a malicious user attempts to spend the same digital token more than once, with the consideration that some merchants accept transactions with only one confirmation on the blockchain), selfish mining attack (selfish miners withhold a newly mined block and only broadcast it when other miners find new blocks to boost their reward) and brute force attack (Using trial- and- error to crack login info or encryption keys to gain unauthorized access to the system usernames).

At the network level, Rahouti et al., (2018) identifies several vulnerabilities including DDoS (a malicious attack to overload the network of a targeted server), bribery attack (attacker attempts to control the network by offering other miners' financial incentive in exchange for collusion), time jacking (an attacker alters the blocks timestamp to trick other nodes to accept an invalid block), refund attack (an attacker leverages a vulnerability of the blockchain network to trick merchants to release goods without actually paying), sybil attack (an attacker creates multiple nodes in the network to attempt to gain control of the network), transaction malleability attack (an attacker exploits the vulnerability of the blockchain by modifying a transaction ID, resulting in the transaction being rejected), eclipse attack (an attacker isolates a specific node from the rest of the network and eclipse their view from the rest of the network), wallet theft (a hacker gets unauthorized access to a user wallets and transfer the digital tokens), routing attack (an attack that targets the internet service provider to redirect network to a malicious node), feather forking attack (a malicious miner forks the blockchain to generate new digital tokens and thereafter discards the fork and rejoin the main blockchain), tampering attack (an attacker manipulates data on a blockchain network to create false transactions), propagation broadcast delay (a transaction is not broadcast to the entire network within a timely manner hence can enable double spending).

At the cryptographic level, Rahouti et al., (2018) identifies several vulnerabilities including brute force attack (an attacker uses trial- and- error to crack login info or encryption keys to gain unauthorized access to a user's wallet), private key storage (an attacker steals the private keys, to gain unauthorized access to a user's wallet), exhaustive key search (an attacker systematically tries all possible keys through trial and error to decrypt the private key of a user's wallet), keystroke capture (an attacker intercepts the keystrokes made by a user on a keyboard, to identify a private key and gain unauthorized access to a user's wallet), dictionary attack (similar to a brute force attack where an attacker uses trial- and- error to crack login info or encryption keys to gain unauthorized access to a user's wallet), ransomware threats (an attacker encrypts the private key associated with a user's wallet in order to extort payment in exchange of decryption key). In addition to the aforementioned security threats at the cryptographic level, Li et al. (2021) identifies that some of the cryptographic methods employed by existing blockchain payment systems to authenticate users and transactions may be susceptible to quantum-based attacks (attacks that exploit quantum mechanical properties to break cryptographic systems that are currently considered secure).

The vulnerabilities in blockchain-based systems are interconnected across the different layers of the system and often overlap (Rahouti et al., 2018). For example, an attack at the network level, such as a sybil attack, can cause double spending at the system protocol level. This means that the security threats are not mutually exclusive and can have cascading effects across the blockchain architecture.

Countermeasures: Rahouti et al. (2018) and Li et al. (2021) propose two potential countermeasures to mitigate the security threats and vulnerabilities of blockchain-based payment systems. The first countermeasure is the implementation of an anti-quantum lattice-based blind signature authentication scheme (a scheme that leverages the properties of lattices I.e., mathematical structures to provide enhanced security against quantum attacks) (Li et al. 2021). The second one proposed countermeasure involves leveraging machine learning algorithms that can detect anomalies and patterns in blockchain data, to identify potential security threats and vulnerabilities such as fraud, double-spending, and malicious attacks (Rahouti et al. 2018). While proposed solutions can mitigate against some threats, certain vulnerabilities are inherent to a blockchain platform, hence can only be mitigated but not eliminated. For instance, a 51% attack (that relates to a malicious attacker gaining control of the majority of the networks computing power) is inherent to the blockchain protocol, therefore it can only be mitigated but not eliminated.

In summary, the SLR findings indicate that there are significant security threats and vulnerabilities at each layer of the blockchain stack. Notably, there are fewer articles discussing the security threats of block-chain-based payment systems compared to other barriers such as scalability and inefficiency in processing micropayments. Some plausible reasons for this could be a perception amongst researchers that the technology is inherently secure, limited security breaches for blockchain-based payment systems as compared to conventional payment systems and limited adoption of the technology leading to a lack of interest to explore security threats and propose solutions to address them. The SLR therefore highlights the need for future research on potential solutions to address the security threats and vulnerabilities of blockchain- based payment systems.

4.5.1.1.4 Challenges in maintaining both transparency and privacy in blockchain-based payment systems.

Barrier: The SLR revealed that while blockchain is proposed as a secure and tamper-proof payment system that provides transactional data anonymity for its users, there are concerns associated with the anonymity and traceability of blockchain transactions. For example, while transactions on the bitcoin blockchain are pseudonymous (i.e., participants do not divulge their identities, such as their names), all transaction data such as the amount of bitcoin transferred, and the public address of the sender and recipient are recorded permanently and transparently on the distributed ledger. This data can be used to monitor and track transactions to their corresponding users, potentially revealing their balances (Jia et al., 2022). Furthermore, when this data is supplemented with external data, such as an IP address, it can reveal the user's identity, profile, and balances, resulting in privacy breaches (Lin et al., 2020) (Jia et al., 2022) (Zhang et al., 2020) (Kus Khalilov & Levi, 2018) (Alqassem et al., 2020) (van Dam & Abdul Kadir, 2022) (Jawaheri et al., 2020) (Ziegeldorf et al., 2018). Eight out of 55 reviewed articles identified or discuss privacy intrusion as a barrier to the widespread adoption of blockchain technology for payments. This significant coverage can infer that the privacy concerns are a significant barrier to the widespread adoption of blockchain-based payment systems.

Table 4.9 presents the privacy barrier of blockchain-based payment systems and the currently proposed solutions to address these barriers.

Barrier	Description of barrier	Proposed Solution	Author
Privacy	Early decentralized payment systems are pseudonymous and transaction data can be deanonymized: completely anonymous decentralized payment systems on the other hand can be criminally exploited.	Design a decentralized conditional anonymous payment system that offers anonymity and meets regulatory requirements.	(Lin et al., 2020)
	Bitcoin transactions can be deanonymized through transaction graph analysis: proposed anonymity solutions are limited by scalability and inefficiency.	Designs a privacy preserving payment protocol	(Jia et al., 2022)
	The transparency and traceability inherent properties of blockchain hinder the privacy of users.	Designs an anonymous off-blockchain micropayment scheme	(Zhang et al., 2020)
	The bitcoin blockchain is the most transparent network. The bitcoin transactions can be anonymized.	N/A	(Kus Khalilov & Levi, 2018)
	Payments conducted over the lightning network are not private and can be tracked using the balance discovery attack.	Designs mechanism to hide payments in payment channel network by applying approximate differential privacy	(van Dam & Abdul Kadir, 2022)
	Bitcoin lacks operational security. The study demonstrates the analysis of bitcoin transactions to deanonymize users	N/A	(Jawaheri et al., 2020)
	Bitcoin users can be reidentified and payments can be linked to their users as result of the public ledger	Design a decentralized mixing service	(Ziegeldorf et al., 2018)

Table 4. 9 Privacy barrier of blockchain-based payment systems and the currently proposed solutions

Countermeasures: The SLR identified several privacy-enhanced solutions including new cryptographic schemes, and protocols that have been proposed to address the privacy intrusion challenge. For example, Lin et al., (2020) proposes a decentralized anonymous conditional payment mechanism (DCAP) a type of payment protocol used in blockchain networks that allows users to make conditional payments without disclosing their identity hence achieving a balance between privacy, anonymity, and regulation. Jia et al., (2022) on the other hand proposes a privacy-preserving payment protocol that conceals transaction quantities and identities of counterparties in a payment transaction while Ziegeldorf et al. (2018) proposes a decentralized mixing service, an alternative to the centralized to obscure the source of funds. These propositions are however challenged by factors such as inefficiency, high communication costs and regulatory compliance issues, making them difficult to implement (Lin et al., 2020).

In summary, the SLR findings identify privacy intrusion as a barrier to the widespread adoption of blockchain-based payment systems. The proposed solutions to address this challenge are limited, which indicates research opportunities to develop more efficient and effective privacy- enhanced solutions that can balance privacy and adhere to the regulatory requirements.

4.5.1.1.5 Volatility of cryptocurrencies as a barrier to adoption in blockchain payment systems

Barrier: The SLR identifies the volatility of cryptocurrencies used as means of payments on blockchain platforms as a barrier to their adoption as a payment method. This is due to the prospect of long-term price increases and short-term price swings, which encourages users to hoard the currency for investment and speculation purposes rather than use it as a means of payment (Saito & Iwamura, 2019).

Countermeasure: Saito & Iwamura (2019) proposes the modification of the blockchain architecture to incorporate an automated market maker (a smart contract that automatically prices and trades assets based on supply and demand) that stabilizes prices by reacting to changes in demand for the cryptocurrency.

There is just one article on volatility of cryptocurrencies amongst the reviewed articles, which highlights the need for more research to address the barrier of cryptocurrency volatility that that impedes their acceptance as a payment method on blockchain platforms.

4.5.1.1.6 Storage requirements for low-performance devices

Barrier: The SLR highlights that the lack of functional Integration with existing hardware and software infrastructures which necessitates expensive expenditures and complementing technologies can impede the widespread adoption and utilization of blockchain based payment systems (Ying et al., 2021). In particular, the need for supplementary hardware for data storage poses a barrier for adoption in public blockchains where significant storage and computational resources are required (Ying et al., 2021). For instance, full nodes which validate transactions and blocks in public blockchains require extensive storage capabilities to maintain the entire data records and blockchain headers, expending hundreds of terabytes for high-volume networks like Bitcoin (Ying et al., 2021). The minimum hardware requirements for hosting a complete bitcoin node are “125 GB of free disc space, 2GB of memory RAM, an unmetered connection, and a 6-hours-per-day running time "Running A Full Node - Bitcoin", (2022) which may not be practical for all users.

Table 4.10 presents the storage requirements for low-performance devices barrier of blockchain-based payment systems and the currently proposed solutions to address these barriers.

Barrier	Description of barrier	Proposed Solutions	Authors
Blockchain storage	Current storage mechanism will not have the capacity to store an entire blockchain as the blockchain size grows exponentially	Designs a network coded distributed storage to save on storage room	(Dai et al., 2018)
	Devices without the capacity to store a full blockchain copy	Design a low-overhead payment verification method that enables light client nodes to verify transactions	(Ying et al., 2021)

Table 4. 10 Storage requirements for low-performance devices barrier of blockchain-based payment systems and the currently proposed solutions

Countermeasure: Potential solutions proposed in the reviewed literature include allowing devices with limited storage capacity to join the blockchain network as light client nodes through the limited-overhead payment verification mechanism (Ying et al. 2021). Light client nodes do not store the entire blockchain ledger, but rather only the block headers (Ying et al. 2021). They rely on full nodes to verify the transactions' validity. This mechanism is however not optimal as the light nodes still require significant computing and storage resources, which are currently insufficient in low performance devices. Ying et al. (2021) also proposes the implementation of limited-overhead payment verification mechanism as a solution for low performance devices.

Another potential solution proposed in Dai et al., (2018) is the implementation of network coded distributed storage (NCDS) which reduces the amount of storage space required by individual nodes to store the blockchain ledger hence allowing devices with limited storage capacity to join in the network as full nodes. The network coded distributed storage divides the blockchain data into fragments and distributes them across the network hence a node can store a subset of the blockchain data but still access the entire blockchain data on request.

In summary the SLR findings identify the lack of functional integration with existing hardware and software infrastructures as a barrier to the widespread adoption and utilization of blockchain-based payment systems. The minimum requirements for hosting full nodes in public blockchain such as the bitcoin network are impractical for users with low performance devices with limited storage and computational capacity. The limited coverage of this barrier by only two papers in the reviewed literature sources suggests a need for more research and development to enable low performance devices to participate as nodes in the blockchain.

4.5.1.1.7 Undesirable environmental effects of blockchain-based payment systems

Barrier: The SLR identified that the proof of work consensus algorithm, used in bitcoin blockchain to secure the systems and verify transactions, consumes intense amount of energy, resulting in undesirable environmental effects such as carbon emissions (Huberman et al., 2020). This may impede the widespread adoption and utilization of blockchain-based payment systems due to concerns around sustainability and environmental impact.

Countermeasure: A potential solution proposed by Huberman et al. (2020) to reduce energy consumption is the modification of the blockchain protocol design. They also proposed an upgrade to more efficient mining hardware to reduce the environmental impact of mining in bitcoin networks. There is already significant research and development of alternative consensus algorithms such as proof of stake that have been adopted to reduce energy consumption and environmental impact of blockchain- based payment systems. Future research could focus on evaluating the effectiveness of proposed more efficient mining hardware.

4.5.2 Infrastructure dimension

The infrastructure dimension encompasses the physical and technical infrastructures that support the effective functioning of the blockchain-based payment systems and the knowledge and financial infrastructure that facilitate the transfer of expertise and the flow of money (Edler et al., 2020). The subsection that follows discusses the barriers within this dimension as identified in the SLR, including research gap and future research direction.

4.5.2.1 Network connectivity requirements

Barrier: The SLR identified one barrier within the infrastructure dimension which is the requirement for network connectivity for blockchain-based payment systems. As highlighted in Hu et al., (2019), blockchain-based payment systems require network connection to enable data exchange across the participating nodes that validate transactions. In addition, corresponding parties in a payment transaction also need internet connection at the point of transaction to initiate, confirm or redeem transactions. The lack of consistent connectivity can therefore impede the widespread adoption and utilization of blockchain-based payment systems, particularly in remote regions with unreliable and intermittent network connectivity (Hu et al., 2019).

Countermeasures: To address this challenge, Hu et al., (2019) propose a solution to augment blockchain transactions to function even in intermittently connected environments. They propose an intermediary node mechanism, in which intermediary nodes which have more reliable network connectivity can validate transactions even when other nodes in the network are disconnected. The disconnected nodes can thereafter synchronize with the intermediary nodes once they are reconnected to update their transaction records. This approach can improve the functioning of blockchain-based payment systems and extend their reach to areas with intermittent network connectivity (Hu et al., 2019). Igboanusi et al. (2021) also propose the implementation of an offline transaction's mechanism, in which transactions are initiated, signed, and stored on an offline device and later broadcast when the device reconnects to the network.

In conclusion, the SLR identified network connectivity requirement as a barrier within the infrastructure dimension of blockchain-based payment systems, that can impede the widespread adoption and utilization of blockchain-based payment systems. It is worth noting that while the articles reviewed identified only network connectivity requirement, there are other potential aspects not covered within the physical and technical infrastructures dimensions such as sunk investment costs in existing infrastructure. Geels, (2004) suggests that existing infrastructures are considered sunk costs which by implies that existing infrastructures can act as constraints, making it difficult to switch to other alternatives systems. Additionally, the review did not identify barriers on other components of the broader social-technical systems context such as the financial and knowledge infrastructure components, indicating a gap in research. Future studies could therefore explore the barriers within these components as well as evaluate the effectiveness of the proposed solutions.

4.5.3 Institutions' dimension

The institutions' dimension relates to the formal rules and regulations, informal rules and norms, governance structures and power structures that impact on the potential adoption and diffusion of new technologies (Geels, 2002). The components of this dimension can influence the behavior of various actors in the innovation process and ultimately impact and shape the directionality of a transition, based on whether they are supportive or inhibitive. This section explores the barriers within this dimension as identified in the SLR, including the research gaps and future research direction.

4.5.3.1 Lack of adequate regulatory frameworks

Barriers: The lack of adequate regulatory frameworks, which is a sub-component of the formal rules and regulations in the institutions dimension is identified in the SLR as a barrier to the widespread adoption and utilization of blockchain – based payment systems. Ferrari (2020) and Lin et al. (2020) both highlight the potential risks associated with blockchain payment systems and associated cryptocurrencies including harm to consumers and investors risks, risks to market integrity and financial crimes such as money laundering. Lin et al. (2020) notes that the pseudonymous nature of bitcoin transactions has made them susceptible to use for criminal's activities such as ransomware extortion and money laundering. Although the transaction data on the public blockchain can be deanonymized through network analysis, address clustering, and transaction graph analysis, determining the identity of a user is still challenging (Lin et al., 2020). Privacy-enhancing solutions such as centralized mixing technologies, decentralized mixing technologies have also been proposed to obfuscate the payers and the payees in bitcoin transactions, thus presenting a regulatory challenge and creating opportunities for exploitation for criminal activities (Lin et al., 2020). The potential risks can create a lack of trust in the system, which can lead to reluctance of adoption and utilization of blockchain-based payment systems. Furthermore, the absence or insufficiency of regulatory frameworks creates legal uncertainty amongst consumers and institutions, therefore creating a barrier to their widespread adoption and utilization.

4.5.3.2 Requirement for regulatory compliance

The SLR also identifies the requirement for regulatory compliance as another barrier to the widespread adoption and utilization of blockchain – based payment systems. Politou et al. (2021) highlights that blockchain-based payment systems may be unable to comply with data protection requirements due to their intrinsic immutability. The tension between blockchain-based payment systems and data protection is evident in an area such as the GDPR's "Right to be Forgotten (RtbF)" provision that gives individuals the right to erasure of their personal data (Politou et al., 2021). The inability to comply with regulatory requirements may cause tension, and hesitancy amongst organizations to adopt the systems because of legal and reputational risks therefore impeding widespread adoption and utilization of blockchain-based payment systems.

4.5.3.3 Lack of clear governing structure

The SLR identifies the lack of clear governing structure as a barrier to the widespread adoption and utilization of blockchain-based payment systems. Public blockchains are by design governed in a distributed manner which means that there is no centralized legal organization that bears accountability for the system. This poses accountability and decision–making problems when changes need to be made to the system (Zachariadis et al., 2019), (Ziolkowski et al., 2020). The problems may be especially amplified during times of system failure or update when the developers need to agree on software code modifications to address the problem or update the software. The past bitcoins 'governance issues, as outlined in Ziolkowski et al. (2020), shows major disputes, relating to factors such as modifying the block size to scale the bitcoin blockchain, could not be resolved through online forums, resulting in recurrent bitcoin forks.

Countermeasures: To enable regulatory compliance, Lin et al. (2020) proposes the design of a decentralized and anonymous payment system (DAP) that achieves a reasonable balance between privacy protection and functionality, while still allowing regulatory oversight. The system implements privacy—preserving policy-enforcement mechanisms allowing for regulatory oversight such as the ability to trace users, and transactions in suspicious activities such as ransom payments.

In conclusion, the SLR identified barriers to the widespread adoption and utilization of blockchain-based payment systems, within the formal rules and regulations and governance structures components of the institution's dimensions. The institutions dimension has however received less coverage amongst the reviewed literature, compared to the technology dimension which infers that the focus of research in blockchain-based payment systems, has been on the technical aspects. This highlights the need for future research to explore the institutions dimension further, narrowing the focus to also include components beyond the formal rules and regulations components, such as the informal rules and norms, governance structures and power structures. Additionally, future research should also on the interplay between the institution and technology dimension to provide a more integrated perspective on the barriers of widespread adoption and utilization of blockchain- based payment systems.

4.5.4 Cultural dimension

The cultural dimension encompasses factors such as “Societal norms, values, beliefs, and practices that shape people's attitudes and behaviours towards technology (Geels, 2002)”. These factors influence the development, implementation, and use of new technologies. The subsection that follows discusses the barriers within this dimension as identified in the SLR, including research gap and future research direction.

Barrier: The SLR identified that some cultural factors may be barriers to the widespread adoption and utilization of blockchain-based payment systems. If a particular cultural group has low willingness to adopt blockchain-based cryptocurrencies as a means of payment, it may impede the widespread adoption and utilization of blockchain-based payment systems. Salcedo & Gupta, (2021) examined the impact of national culture on the willingness to adopt blockchain-based cryptocurrencies amongst users in the US and India. The study found that “people in a collectivist culture (I.e., individuals that prioritize other people's interest over their individual interest) may be more inclined to use blockchain-based cryptocurrencies as compared to people from an individualist culture (I.e., cultures where individuals are encouraged to prioritize their own interest over the needs of the group). Additionally, the acceptance of blockchain-based cryptocurrencies was found to be correlated with masculinity-related cultural attitudes, “while individuals that hold power distance and long-term focused cultural norms were more likely to pay using blockchain-based currencies. On the other hand, people who are risk averse, were found to be less likely to pay using blockchain-based cryptocurrencies” (Salcedo & Gupta., 2021).

Overall, the SLR highlights the need for considering cultural factors while examining the barriers of blockchain-based payment system. While Salcedo & Gupta, (2021) study provides insights into the influence of cultural factors on the widespread adoption and utilization of blockchain-based payment systems, the findings cannot be generalized because they are context specific and may vary across countries and regions. More empirical research is therefore needed to explore how cultural factors influence the adoption and utilization of blockchain-based payment systems.

4.5.5 Markets and user preferences dimension

The markets and user preferences dimension encompasses various components including the “market structure, economic actors and organizations that impact on the development, adoption, and utilization of a technology. It also encompasses factors such as the demand for the technology, users’ needs, preferences and behavior towards the technology, and the social and economic contexts within which the technology is used (Geels, 2002).” These factors influence the development, implementation, and use of new technologies. The subsection that follows discusses the barriers within this dimension as identified in the SLR, including research gap and future research direction.

Barriers: The SLR identified several factors within the demand for the technology, users’ needs, preferences and behavior towards the technology components of the markets and user preferences dimension that can influence and impede the adoption and utilization of blockchain-based cryptocurrencies.

4.5.5.1 Rigidity of user preferences and routines on dominant modes of payments.

The SLR findings identify users' resistance defined as the unwillingness amongst users try new innovations and routines on dominant modes of payments as barriers to the adoption and utilization of blockchain-based cryptocurrencies which can impede the widespread adoption of blockchain payment systems. The findings from (Szumski, 2020) study evidence resistance amongst users surveyed to adopt blockchain-based cryptocurrencies as a means of payment. Most users indicated preference for conventional modes of payments including credit/debit cards, cash, and online banking over the use blockchain-based cryptocurrencies. The resistance amongst users to try blockchain-based cryptocurrencies can hinder their growth and utilization, impeding the widespread adoption of blockchain- based payment systems.

4.5.5.2 Negative perception on the perceived usefulness and ease of use of blockchain-based cryptocurrencies

The SLR also identifies that the perceived usefulness influences the intention of users to use blockchain-based payment systems. The dimension considered to contribute to the perceived usefulness of cryptocurrencies for electronic payments, include speed of transactions, convenience, reliability, protection from theft, privacy, points rewarded, and simplicity of expenses control (Szumski, 2020). The findings from Szumski (2020) study suggest that the users surveyed perceived other modes of payments to be more useful than blockchain-based payment systems. Nikbakht et al., (2019) also identifies that users who perceive cryptocurrencies to not be user friendly, and do not expect operational benefits of blockchain-based payment systems are less likely to adopt them as a mode of payment therefore impeding the widespread adoption and utilization of blockchain-based payment systems (Nikbakht et al., 2019).

4.5.5.3 Lack of trust

The SLR identified that trust influences the adoption and utilization of blockchain-based payment systems. If users do not trust the safety of their funds in blockchain-based payment system, they are less likely to use them. Szumski, (2020) study identifies that the level of trust assigned to blockchain-based cryptocurrencies is lower than to other modes of payment, indicating a lack of trust on blockchain-based payment systems.

4.5.5.4 Lack of knowledge and awareness of blockchain-based payment systems

The SLR identified lack of knowledge and awareness of blockchain-based payment systems can impede the widespread adoption of blockchain-based payment systems. Nikbakht et al.'s (2019) study, identifies that there are still users who are not aware of blockchain-based payments and associated cryptocurrencies, this can impede the widespread adoption of blockchain- based payment systems.

In conclusion, the SLR identifies barriers within the markets and user preferences dimension that can impede the widespread adoption and utilization of blockchain –based payments and associated blockchain-based cryptocurrencies. It is important to note that the findings of the literature reviewed within this dimension may not be generalizable to all contexts. Future research should therefore consider the context-specific barriers within the markets and user preferences dimension. Additionally, future research can focus on identifying strategies to address the identified barriers.

4.6 Conclusion

This chapter analyses the barriers to widespread adoption and utilization of blockchain- based payment systems, and the proposed potential solutions to address these barriers by synthesizing academic literature on blockchain-based payment systems. Blockchain-based payment systems are in this study contextualized through a social- technical systems perspective which recognizes that technological innovation cannot drive social-technical transitions in isolation, as technologies are embedded in other social and economic contexts. The adoption and utilization of technologies is therefore influenced by complex and dynamic interplay of factors within other dimensions including the technological, infrastructure dimension, institutions', cultural, and markets and user preferences dimensions of a blockchain- based payment system. A comprehensive evaluation of the barriers to the adoption and utilization of blockchain-based payment systems of the barriers to widespread adoption and utilization of blockchain-based payment systems therefore an analysis that considers each of these dimensions.

The study identified several barriers to the widespread adoption and utilization of blockchain-based payment systems which were classified into five dimensions: technological, infrastructure, institutions', cultural, and markets/user preferences dimension.

In the technological dimension, the SLR identified several barriers including scalability, inefficiency of public blockchain in processing micropayments, security threats and vulnerabilities in blockchain-based payment systems, challenges in maintaining both transparency and privacy in blockchain-based payment systems, volatility of cryptocurrencies as a barrier to adoption in blockchain payment systems, storage requirements for low-performance devices and undesirable environmental effects of blockchain-based payment systems. However, to address each of these barriers, the SLR identified various proposed solutions. This technological dimension has received most coverage across the literature reviewed. This could be because the technology is still at its initial stages of implementation and adoption, and the technological components are critical for their successful implementation and adoption. Furthermore, the barriers within this dimension can have significant implications for other dimensions such as the institutions and markets/user preferences dimension hence addressing these barriers is crucial for adoption and utilization of blockchain-based payment systems. As such, it is crucial that future research continues to evaluate the barriers within this dimension and propose solutions to address them.

In the infrastructure dimension, the SLR identified network connectivity requirements as a barrier that can impede the adoption and utilization of blockchain-based payment systems, particularly in areas with unreliable and intermittent network connectivity. To address this challenge researchers, propose solutions such as the intermediary node mechanisms Hu et al., (2019), and offline transaction mechanisms Igboanusi et al. (2021). However, it is important to note that there are other barriers within the physical and technical infrastructures, as well as the financial and knowledge infrastructure components, that were not covered in the SLR, indicating a gap in research. Future studies could therefore explore barriers within these other components.

The institutions dimension also plays a critical the widespread adoption and utilization of blockchain-based payment systems. The SLR identifies the lack of adequate regulatory frameworks, requirement for regulatory compliance and lack of clear governing structure as barriers to the widespread adoption and use of blockchain-based payment systems within this dimension. The design of a decentralized anonymous payment (DAP) system that strikes a balance between achieving reasonable privacy protection, while still allowing regulatory oversight is proposed as a solution to address the challenge regulatory oversight (Lin et al. 2020). Overall, the institution dimension has received less coverage compared to the technological dimension and has also not received any coverage for components such as informal rules and norms, and power structures in the literature reviewed, highlighting gap in research. Future research could therefore explore this dimension further, and investigate the interplay between the institution, technological and markets/ users' preference dimension to offer a more integrated perspective on the barriers to the widespread adoption and utilization of blockchain-based payment systems.

The SLR identified that cultural factors such as such as societal norms, values, beliefs, and practices that shape people's attitudes and behaviours towards technology may also impede the widespread adoption and diffusion of blockchain- based payment systems. For instance, Salcedo & Gupta (2021) found that national culture may influence people's willingness to adopt blockchain-based cryptocurrencies. More empirical research is required to investigate how cultural factors influence the adoption and utilization of blockchain-based cryptocurrencies in specific contexts such as at country levels. The SLR also identified several barriers within the markets/user preferences dimension including rigidity of user preferences and routines on dominant modes of payment, negative perception on the perceived usefulness and ease of use of blockchain-based cryptocurrencies, lack of trust and lack of knowledge and awareness of blockchain-based payment systems. There is need for more empirical research that evaluates these barriers in specific-contexts and the interplay of this dimension with other dimensions. Overall, addressing these barriers is key to the widespread adoption and utilization of blockchain-based payment systems.

This study contributes to the current literature on blockchain-based payment systems by providing a comprehensive analysis of the barriers to the widespread adoption and diffusion of blockchain-based payment systems. The study synthesized the barriers identified through a SLR of academic literature on blockchain-based payment systems and classifies them using the dimensions of blockchain- payment systems which is contextualized as a social-technical system. By analyzing barriers within each dimension and proposed solutions to address the challenges, the research offers a nuanced integrated perspective on the barriers that could hinder the adoption and utilization of blockchain-based payments. This perspective can inform academic researchers, industry participants and policy makers on the barriers hindering the adoption of blockchain-based payment systems and help them in formulating strategies to address them.

Furthermore, the study also identifies gaps in the literature. By highlighting these gaps and making recommendations for future research within each dimension, the study provides valuable insights that can guide researchers to address the gaps and advance the body of knowledge in this field.

CHAPTER FIVE: DISTRIBUTED LEDGER TECHNOLOGY (DLT) NICHES AND EXPERIMENTATION IN CENTRAL BANKS PAYMENT SYSTEMS FUNCTIONS: A THEMATIC ANALYSIS

5.1 Introduction

Distributed Ledger Technology (DLT) provides novel ways of processing payment transactions and related transaction data management. Unlike centralized systems that depend on a centralized authority, this technology has the capability to utilize a decentralized network of nodes for validating and processing transactions, leading to more efficient, transparent, and almost real-time transactions (Centobelli et al., 2022). In terms of transaction data management, DLT provides a resilient and secure platform for the recording and management of transaction data providing higher levels of trust and security in transactions relative to some conventional distributed database management systems. Furthermore, DLT enables the implementation of smart contracts, which are autonomous software protocols that execute the terms of an agreement between two or more parties without the need for intermediaries (Zetzsche et al., 2021).

DLT unique properties and potential use cases have piqued the interest of central banks, who are researching the technology's potential to both reconfigure or transition from the conventional payment system functions. This has resulted in more DLT experimentation and adoption in central bank various payment systems functions such as through the “issuance and distribution of central bank issued digital currencies (CBDCs), regulatory compliance and payment clearing and settlement systems” (Dashkevich et al., 2020). According to a survey conducted by the Bank for International Settlements (BIS) in 2021, most central banks are currently investigating the potential use of CBDCs, with 86% of respondents indicating active research in this area. Additionally, 60% of central banks surveyed were found to be experimenting with CBDC technology, while 14% reported having already launched pilot projects (Bank of International Settlement, 2021). As central banks play a critical role in preserving financial stability and efficiency of the financial system (Ahiabenu, 2022), the integration of DLT into the payment systems functions of central banks is regarded as a significant development.

While there has been noticeable increase in academic research on DLT applications by central banks, particularly in the area of DLT as infrastructure for CBDCs (Dashkevich et al., 2020), there is a gap in research efforts between industry practitioners and academics in other areas of DLT application such as DLT-based interbank payment rails operated by central banks, information registry and data sharing, and digital KYC/AML processes. A google scholar search on DLT applications in central banks also corroborates the inference that there are gaps in research efforts between practitioners and academics in other areas of DLT application beyond CBDCs. Furthermore, Dashkevich et al.'s (2020) systematic mapping study on blockchain applications for central banks revealed that there is a disparity between the prevalence of discussions on DLT in non-academic sources such as blogs and online publications and the limited academic research on the topic. The bridging of these research gaps is crucial and timely as academic research provides crucial theoretical foundation for practical implementation in any field. In the case of DLT implementation in central bank payment system functions, academic research can provide insights into the underlying social, technical, and economic principles and implications of DLT applications in central bank payment systems functions. These insights can then be used to guide practical implementation and address potential challenges that may arise. Furthermore, bridging the research gap between industry practitioners and academics can help to ensure that practical implementation is informed by sound theoretical foundations and can better achieve its intended goals.

Considering the aforementioned gap, this study aims to contribute to the emerging body of knowledge on DLT applications by central banks, by conducting a systematic analysis of DLT applications in central bank payment systems functions. The ultimate goal is to contribute to the development of a more nuanced and complete understanding of DLT applications in central bank functions. This not only fills the gap between industry practitioners and academics in this area but also helps to advance the knowledge and application of DLT beyond CBDCs. To achieve these aims, we established the following research objectives.

(RO3) To identify current DLT applications in central bank payment system functions using central banks' white papers, industry reports, policy documents, and other relevant sources.

(RO4) To systematically classify and synthesize the state-of-the-art and practice in DLT applications in central bank payment system functions. This objective aims to focus on identifying the motivation behind adopting DLT in each applicable use case, and the specific DLT platforms and consensus algorithms used.

To achieve these objectives, four research questions were formulated.

(RQ4): What is the current state of the art of research and development of DLT applications in central bank payment system functions?

(RQ5): What are the specific applications of DLT in central bank payment system functions?

The subset research questions for each identified application are:

(RQ5.1): What is the motivation behind adopting DLT in the specific use case?

(RQ5.2): What DLT platforms are used, and what algorithm consensus are implemented in the proof of concepts, pilots, and projects considered in the literature pool?

It is important to highlight that these research questions narrow the scope of investigation to the specific uses of DLT by central banks in payment system functions, rather than the broader scope of DLT applications by central banks.

We employed a thematic analysis methodology to conduct a qualitative analysis on a range of documents that encompassed grey literature, such as central bank white papers on DLT applications in central bank payment system functions, industry reports, policy document manuals, and relevant academic literature on the topic, as the primary data source. The first step in this process involved employing a multivocal literature review approach (MLR) to select and screen the relevant documents for analysis. This approach ensured that the analysis considered a broad range of perspectives and viewpoints on the subject matter and allowed for a comprehensive and thorough understanding of the research topic. It is particularly well-suited for emerging topics where academic literature may not yet fully capture industry trends and insights as it ensures that research is not limited to one viewpoint, and that all relevant perspectives are considered.

The approach adopted for the data extraction was a multi-stage approach. In the first stage, a data extraction form, in the form of a spreadsheet hosted on Google sheet, was created to extract bibliometric data and deduce specific DLT applications in central bank payment system functions. Subsequently, we utilized Braun and Clarke (2006), guidelines for conducting thematic analysis to conduct a qualitative analysis on the collected data. The coding process was carried out using NVivo software. The findings are presented in a descriptive manner, and NVivo code extracts and tables are used to summarize the data and highlight some key findings.

This study contributes to literature by identifying and classifying the various applications of DLT in central bank payment systems functions, presenting a consolidated view of the field. This approach provides a more comprehensive and nuanced understanding of how DLT is being used in this context, which can be valuable for policymakers and practitioners who are interested in implementing DLT-based solutions in central bank payment systems. By understanding the different ways in which DLT can be used, they can make more informed decisions about which applications to prioritize and how to address the potential benefits and challenges associated with each one. The analysis of the motivations, DLT platforms, and consensus algorithms for applicable use cases in central bank payment systems is also a relatively new area of research. By compiling evidence from various sources and presenting a ranking of the most common motivation, DLT platforms and consensus algorithms employed, this study can be useful for researchers and industry practitioners seeking to understand the current trends and make informed decisions regarding DLT adoption in central bank payment systems.

The paper is structured as follows: Section 2 provides a background on central bank payment system functions and delineates the scope of the study and its focus on 'DLT application on central banks payment system functions. Section 3 explains the Multivocal Literature Review methodology approach adopted to screen and select the documents. Section 4 presents the results of the research through bibliographic data and thematic distribution of the published literature. Section 5 discusses the identified applications and themes for each specific use case. Section 6 provides a conclusion and presents suggestions for future research directions.

5.2 Background: Role, Responsibilities, and Functions of Central Banks in payment systems

Central banks have strategic interest and functions in payment systems as part of their responsibilities for financial stability and monetary policy implementation (Pijeivibol, 2013). Interbank clearing and settlement are in particular a major area of interest in the payment system cycle. This is because the stability of interbank clearing and settlement systems is critical to ensure that financial institutions fulfill their obligations in the transfer and settlement of transactions with each other. This in turn ensures the overall financial system's stability, which is critical for ensuring the smooth functioning of the economy. Instability in the interbank clearing and settlement system can have negative contagion effects leading to financial crises and loss of confidence in the banking sector in extreme crises. Reflecting this, regulatory and supervisory functions, and the operation of settlement systems, are increasingly being undertaken by central banks in various countries (Norman et al., 2011). Furthermore, the global monetary systems have converged on a common characteristic where central bank money is used as a settlement asset for interbank settlement.

Central banks' roles in payment systems can be divided into two broad facets as operational and regulatory. One of the primary operational functions of a central bank is to provide and operate the infrastructure necessary for the safe and timely settlement of high-value and time-sensitive transactions between financial institutions, such as the real-time gross settlement systems (RTGS). Additional operational functions of central banks in payment systems are to issue and manage the circulation of physical central bank money to consumers and maintain reserves for payment system providers, such as commercial banks, which are used as a settlement asset for interbank settlement. In addition, the central bank serves as a provider of liquidity to the participants in the payment system, acting as a lender of last resort that serves to ensure interbank transactions are settled in a timely manner, reducing the risk of settlement failure, therefore ensuring the stability of the financial system, and enhancing the efficiency of the payment system (Pijeivibol, 2013). The overarching regulatory responsibilities of central banks in payment systems are also intended to encourage innovation and competition in the sector. Among its specific responsibilities are oversight of the payment and clearing systems, the development and implementation of payment system policies and regulations, and the issuance of licenses to payment system providers.

This study focuses exclusively on DLT applications in central banks payment system functions. These functions include both the operational and regulatory functions. Although there are other explorations and implementations of DLT in central bank functions and the financial sector at large such as post-trade securities clearing and settlement systems and asset transfers (Shabsigh et al., 2020), the current research focuses on the use of DLT for central banks payment systems functions as they relate to payments market infrastructures (PMIs) that facilitate funds-only transfer between (or among) participants in the conventional centralized payment system models. Therefore, this study excludes other potential use cases, including privately issued cryptocurrencies and other financial services verticals, such as lending and savings.

5.3 Research methodology

This methodology section outlines the methodology used in conducting research on (DLT) Niches and Experimentation in Central Banks Payment Systems Functions. It describes the research design, data collection, and data analysis methods used in the study.

Research design

This chapter employs an exploratory research design to provide responses to research enquiries. To reiterate here, the overarching aim of this chapter is to provide a systematic analysis of DLT applications in central bank payment systems functions. Exploratory research involves examining an issue to gain a deeper understanding and generate questions that can be subjected to further examination. This research design is particularly well- suited for examining "what is happening," seeking new insights, and assessing phenomena in a new light (Saunders et al., 2009). Although it is often used as a preliminary step for further studies, it is also a valuable research method on its own (Strydom, 2014). In the context of researching DLT applications in central bank payment system functions, the phenomenon is relatively new and there is limited existing research on the topic. Furthermore, there are few live implementations of such projects in production environments, making it difficult to obtain data that would enable explanatory and correlational research designs. Therefore, an exploratory research design is a suitable approach to investigate this relatively new and under-explored phenomenon, as it allows for the collection of qualitative data that can help to provide a better understanding of the topic. Exploratory research can also aid in identifying potential research questions and avenues for further investigation in this area, which is one of the study's objectives.

5.3.1 Data Collection

For this study, we utilized a range of documents that encompassed grey literature, including central bank white papers on DLT applications in central bank payment system functions, industry reports, policy document manuals, and relevant academic literature on the topic, as the primary data source. The purpose of collecting data from diverse forms was to ensure that the analysis conducted through thematic analysis seeks convergence and corroboration of the various industry and academic sources, providing insights into the current state of DLT applications in central bank payment systems functions. According to Bowen (2009), document analysis is a form of qualitative research that involves a systematic approach to reviewing or examining documents. This methodology can serve various purposes including contextualizing data, generating research questions, supplementing additional research data, tracking changes over time, and validating information derived from other sources. It can function as a standalone method, for instance, to analyze the evolution of particular types of policies across different geographic regions. However, when utilized in combination with other research methods, document analysis can provide added value by cross-validating, or triangulating, the findings from multiple sources and thereby enhancing the overall research output. Document analysis is considered especially suitable for qualitative analysis of non-technical grey literature, including statutory documents and materials from the public domain. The analytical process involves identifying, selecting, interpreting, and integrating data from these documents. Through document analysis, researchers can categorize and synthesize data, which can include excerpts, quotations, or complete sections of text, into major themes and case examples (Honkanen et al., 2021).

Several studies have utilized various forms of document analysis, including systematic literature reviews (SLRs) and systematic planning designs, to investigate topics related to the applications, challenges, and potential of DLT in various domain such as supply chain (Chang & Chen, 2020), transportation sector (Astarita et al., 2019), agri-food sector (Antonucci et al., 2019), and the health domain (Baysal et al., 2022). These forms of secondary research that involve summarizing and synthesizing data published by others are currently prevalent in DLT research for several reasons. First, the complexity of DLT, and the specialized knowledge and technical expertise required to understand it, can make it difficult for researchers to conduct primary research in this field. In contrast, secondary research methods which involve summarizing and synthesizing data published by others can provide valuable insights into DLT applications, without requiring extensive technical expertise or specialized resources. Second, since the development of DLT applications is still in its early stages, and there are limited pilots and live implementations, it can be challenging to conduct experimental or case study research. Third, the interdisciplinary nature of DLT across disciplines – such as computer science, cryptography, economics, and law - makes it difficult to conduct research that covers all facets of this technology. Lastly, due to the novelty and emerging nature of this technology, there is limited empirical data available for researchers to analyze. This can make it difficult to conduct empirical studies, which require a large amount of data for analysis.

In the context of DLT applications in central bank payment systems functions document analysis was chosen because, first, many central banks are still in the pilot stages of exploring the potential applications of DLT and conducting proof-of-concept studies. Consequently, there are limited live implementations of DLT applications in production stages which makes primary research methods such as case studies impractical. Second, central bank payment systems and DLT are both highly specialized fields, requiring a deep understanding of complex financial and technological concepts. As a result, it can be challenging to identify and reach out to the relevant experts and stakeholders in these areas. These experts may be scattered across different institutions and organizations and may not have the time or resources to participate in lengthy interviews or surveys. Moreover, their expertise may be in high demand, which could further limit their availability for research purposes Third, even if key stakeholders were to be reached, the depth and detail provided by these research methods such as interviews may not be sufficient to address the formulated research questions effectively. For example, the identification of themes on the motivation for adoption of DLT in specific use cases would require corroboration of evidence from several central banks. This would make it impractical to gather all the necessary participants and data needed to conduct a comprehensive study. Documents, specifically central bank white papers and policy documents from government organizations, on the other hand are considered authoritative documents that efficiently provide valuable insights into the perspectives, strategies, and priorities of central banks with respect to the adoption of DLT. These white papers undergo review and rigorous quality control by central bank management, adding to the credibility and trustworthiness of the insights they offer.

5.3.2 An overview of the concept of grey literature

Grey literature (GL) is defined in Farace & Schöpfel, (2010) as "*literature produced on all levels of government, academics, business and industry in print and electronic formats, but which is not controlled by commercial publishers, i.e., where publishing is not the primary activity of the producing body*." In contrast, academic literature includes peer-reviewed research articles, conference proceedings, and other scholarly publications that have undergone a formal academic review process. Garousi et al., (2019) adopts Adams et al., (2016) model of classifying several types of sources of literature to devise a two-dimensional model that classifies the grey literature sources based on expertise and outlet control metrics (Figure 5.1).

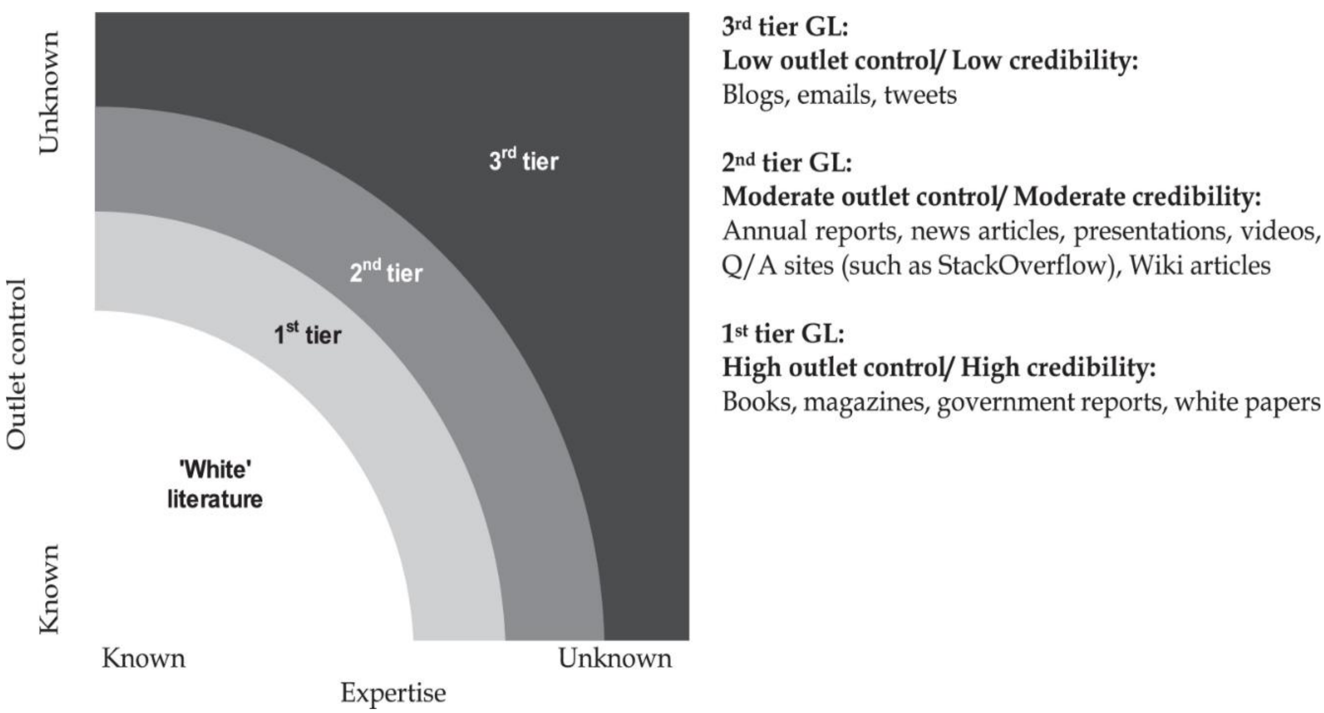


Figure 5. 1 classification of the grey literature sources based on expertise and outlet control metrics, adopted from Garousi et al., (2019)

The horizontal "expertise" metric defines *"the extent to which the authority and knowledge of the producer of the content can be determined." and ranges linearly from known to unknown. The vertical metric "outlet control" defines "the extent to which content is produced, moderated, or edited in conformance with explicit and transparent knowledge creation criteria. Rather than having discrete bands." Academic literature illustrated in the matrix as "white literature" is graded as "the source where both expertise and outlet control are fully known." whereas grey literature is graded as "with moderate outlet control and credibility and tiered into 1st, 2nd and 3rd tier."* This study adopts this spectrum of classification when classifying data sources as either academic or grey literature.

5.3.3 Screening and Selecting Relevant Documents

SLRs and other secondary research designs such as meta-analyses have conventionally been used to provide a useful starting point for exploring the current state of a field, offer background to support framework development, support or challenge theoretical hypotheses and identify areas for further investigations (Li & Kassem, 2021). SLRs are useful, but they are criticized in some contexts because they are conventionally based on a predefined set of criteria and a structured search of only academic literature. This explicit protocol and exclusive reliance on academic literature may result in a limited perspective on the topic under study and a loss of context in the data. Some researchers therefore opt for an MLR approach that allows for the inclusion of a wider range of perspectives with an aim of providing a more holistic and nuanced understanding of emerging research fields. In Garousi et al.'s (2019) definition, an MLR is a type of SLR that incorporates both academic and non-academic literature. The primary distinction between SLRs and MLRs is that while SLRs only include academic papers that have undergone peer review, MLRs include sources from the grey literature such as blogs, videos, white papers, and web pages (Garousi et al., 2019). An elaborate definition of MLR cited in Ogawa & Malen (1991) is quoted below:

"*Multivocal literatures are comprised of all accessible writings on a common, often contemporary topic. The writings embody the views or voices of diverse sets of authors (academics, practitioners, journalists, policy centers, state offices of education, local school districts, independent research and development firms, and others). The writings appear in a variety of forms. They reflect different purposes, perspectives, and information bases. They address various aspects of the topic and incorporate different research or non-research logics*."

An MLR approach that synthesizes academic perspectives, and evidence from the industrial community (Baysal et al., 2022) is regarded as valuable, particularly in practitioner- and application-oriented fields, to incorporate the vision of practitioners and identify emerging research topics. Considering the topic and purpose of our study, an MLR approach was chosen for the study. The approach is motivated by industry research on DLT applications in financial services currently outpacing academic research. Furthermore, industry practitioners have direct experience of applied solutions and, hence, can provide valuable insights into the applications, benefits, and challenges of DLT application in central bank payment system functions. Academic research, on the other hand, can also contribute valuable perspectives and introduce rigor. An optimal approach to synthesizing the state-of-the-art and practice of DLT in central bank functions is considered a balanced approach that includes empirical and non-empirical grey literature. This approach can help identify research trends, gaps for future research, and provide valuable insights for researchers and practitioners in this area.

This search and screening process is carried out based on the best practices and guidelines for conducting MLRs as proposed by Garousi et al, in (Garousi et al., 2019). In accordance with Garousi et al., (2019) guidelines, the process underpinning an MLR can be divided into three phases which include (1) planning the review, (section 3.4) (2) conducting the review (section 3.5), and (3) reporting the review (section 3.6). Each phase has subsets as illustrated in figure 5.2.

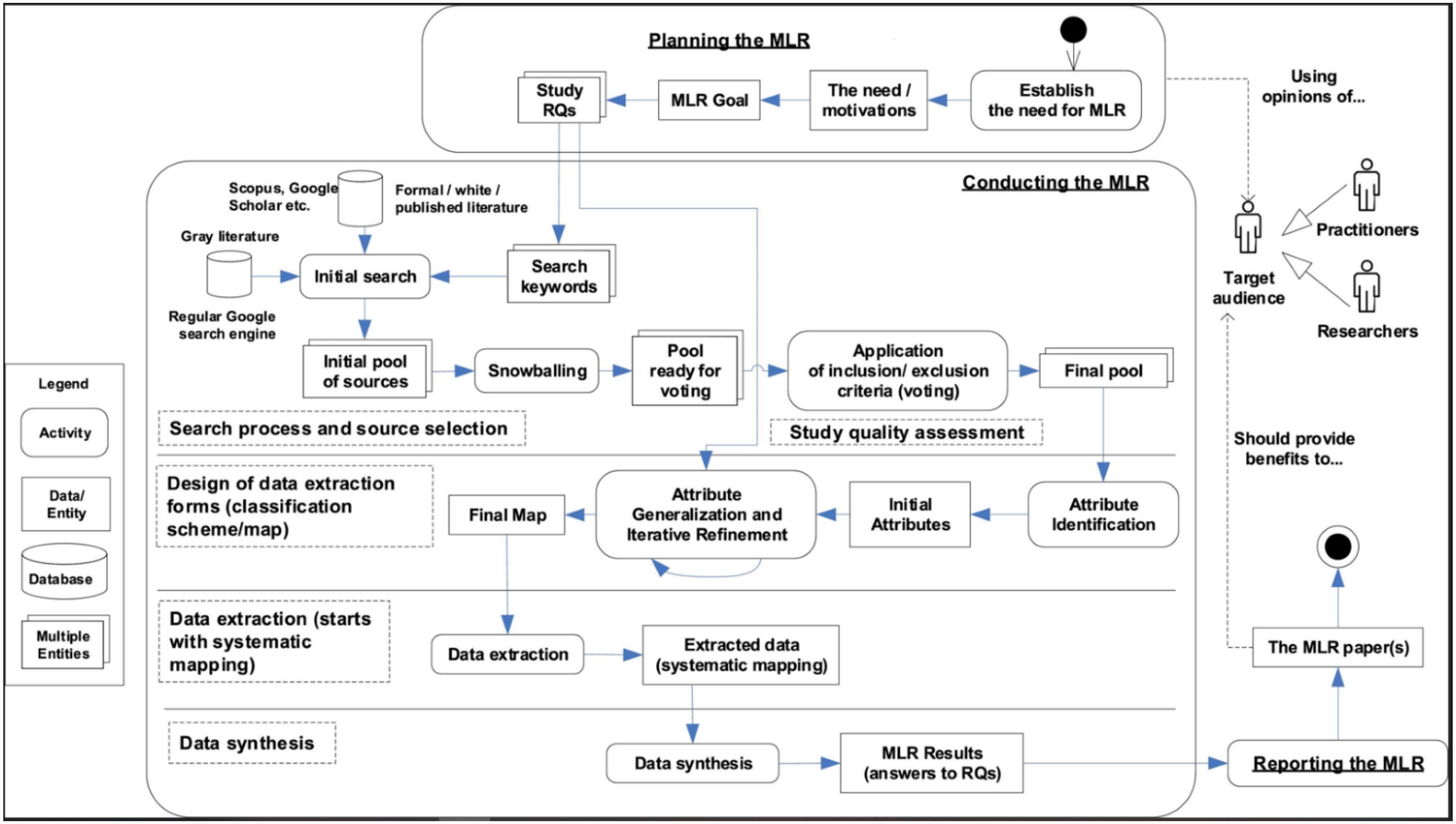


Figure 5. 2 illustrates a process model of the methodology used for this research (Adopted from Garousi et al., (2019))

5.3.3.1 Planning the review: Establishing the need for an MLR for DLT application in central bank payment system functions.

The initial phase of planning a MLR should involve identifying the need for conducting the MLR. As noted by Garousi et al. (2019), it is important for researchers to consider the targeted audience of the research (researchers and/or practitioners) and ensure that the review is designed and conducted in a way that meets the needs and expectations of the intended audience.

Several guidelines could be used to determine the need for an MLR, including identifying any existing reviews to avoid duplicating efforts, and ensure that the MLR provides value to its target audience. Subsequently, it is crucial for researchers to evaluate whether to conduct an MLR as opposed to a traditional SLR, a grey literature review, or their mapping review counterparts using a well-defined set of criteria or questions (Garousi et al. 2019). This study adopts the checklist in Garousi et al. (2019) illustrated in Figure 5.1 to appraise the need of conducting an MLR for DLT application in central bank payment system functions instead of conducting a SLR.

Question	Possible answers	MLR - Auto Test
1. "Is the subject "complex" and not solvable by considering only formal literature?"	Yes/No	Yes
2. "Is there lack of volume or quality of evidence, or a lack of consensus of outcome measurement in the formal literature."	Yes/No	Yes
3. "Is contextual information important to the subject under study?"	Yes/No	Yes
4. "Is the goal to validate or corroborate scientific outcomes with practical experiences?"	Yes/No	Yes
5. "Is it the goal to challenge assumptions or falsify results from practice using academic research or vice versa?"	Yes/No	Yes

6. "Would a synthesis of insights and evidence from the industrial and academic community be useful to one or even both communities?"	Yes/No	Yes
7. "Is there a large volume of practitioner's sources indicating high practitioners' interest in a topic."	Yes/No	Yes
**One or more "yes" response suggest inclusion of grey literature*		

Table 5. 1 Checklist to appraise the need of conducting an MLR. Adopted from (Garousi et al. 2019)

The topic area and focus of the study checklists the criteria on inclusion of grey literature, in Table 5.1. Following the above checklist, the initial phase involved appraising the existing reviews on DLT/Blockchain in the financial services sector. The papers that do not follow the systematic review guidelines and protocols are excluded in this iterative phase. Six studies related to the research scope were chosen. The following comparison criteria (CC) were devised to compare these studies:

CC1**:** Studies related to application of DLT in the financial services sector.

CC2**:** Studies that report the DLT platform and consensus algorithms applied.

CC3**:** Studies that report on the motivation of using DLT in that particular use case.

CC4**:** Studies that report on the challenges and risks of DLT in the financial services sector.

Previous SLRs have been conducted on DLT/blockchain applications in the financial services sector, but none of them have encompassed the extent and comprehensiveness of this MLR in terms of scope and coverage. We list the most relevant here and highlight the novelty of this study. Table 5.2 illustrates these studies, with columns for publication year, number of articles evaluated, number of grey literature papers included, and additional columns depicting how our research is comparable to and different from the systematic literature reviews in answering the research questions.

Systematic Literature Review Studies on DLT/Blockchain in the Financial Services Sector

Number	1	2	3	4	5	6
In- text citation	(Dashkevich et al., 2020)	(Luz & Farias, 2020)	(Albeshr & Nobanee, 2020)	(Ali et al., 2020)	(Trivedi et al., 2021)	(Del Río, 2017)
citation	Dashkevich, N., Counsell, S., & Destefanis, G. (2020). Blockchain application for Central Banks: A systematic mapping study. *IEEE Access*, *8*, 139918–139952. https://doi.org/10.1109/access.2020.3012295	Luz, M. A., & Farias, K. (2020). The use of block chain in financial area: A systematic mapping study. *XVI Brazilian Symposium on Information Systems*. https://doi.org/10.1145/3411564.3411579	Albeshr, S., & Nobanee, H. (2020). Blockchain applications in banking industry: A mini-review. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3539152	Ali, O., Ally, M., Clutterbuck, & Dwivedi, Y. (2020). The state of play of Block chain technology in the Financial Services Sector: A Systematic Literature Review. *International Journal of Information Management*, *54*, 102199. https://doi.org/10.1016/j.ijinfomgt.2020.102199	Trivedi, S., Mehta, K., & Sharma, R. (2021). Systematic literature review on application of blockchain technology in E-finance and Financial Services. *Journal of Technology Management & Innovation*, *16*(3), 89–102. https://doi.org/10.4067/s0718-27242021000300089	Del Río, C. A. (2017). Use of distributed ledger technology by Central Banks: A Review. *Enfoque UTE*, *8*(5), 1–13. https://doi.org/10.29019/enfoqueute.v8n5.175
Title	Blockchain Application for Central Banks: A Systematic Mapping Study	The Use of Blockchain in Financial Area: A Systematic Mapping Study	Blockchain Application in Banking Industry: A Mini-Review	The state of play of blockchain technology in the financial services sector: A systematic literature review	Systematic Literature Review on Application of Blockchain Technology in E-Finance and Financial Services	Use of distributed ledger technology by central banks: A review
Publication date	2020	2020	2020	2020	2021	2017
# papers included	72	23	26	87	59	
# Gray literature included	31	0	0	0		
Years covered	2016-2020		2016-2019	2011-2019		
RQ 1 (What is the current state-of-the-art research and development of applications for DLT in payment, clearing and settlement for central banks?)	Do not match	Do not match	Do not match			
RQ 2: What are the specific applications of DLT in payment, clearing and settlement, and has the research moved from proposing the conceptual/insights level into development and testing in a relevant environment?	Partially match	Do not match	Do not match			
RQ2.1 What platforms were studied? And what consensus algorithm were applied	Do not match	Do not match	Do not match			
RQ2.2 Why DLT was considered for each of those use-cases?	Partially match	Do not match	Do not match			
RQ2.3: What challenges and risks the application of blockchain posed for those use-cases?	Do not match	Do not match	Do not match			

Table 5. 2 Number of grey literature papers included.

Luz and Farias (2020) conducted a systematic mapping review of blockchain applications in the broad financial domain. The study identifies and categorizes applications on an elevated level in the financial sub-areas such as bank or fintech, loan, investments, payment system, insurance, and tax payment. However, it does not focus on exploring in depth any of the use cases or separating the motivation for exploring DLT in each of the specific use cases. Additionally, the study did not consider grey literature. Following similar objectives, Ali et al., (2020) conducted a systematic review with the aim of providing an understanding of the potential applications of DLT in the broad financial services sector. The study identified five key "blockchain-enabled financial functions, which were point-to-point transmission, data ownership, data sharing, data protection, and distributed innovations." The authors also proposed a three-dimensional classification framework for blockchain-enabled financial functions, which was based on benefits, challenges, and blockchain-enabled financial functions. The focus of the study was on the broad financial services sector and not specifically on payment systems, and the authors did not consider grey literature.

Trivedi et al., (2021) similarly conducts a systematic review to explore the development, adoption, challenges, and application of blockchain technology in the financial services sector. The authors identified seven key applications, including cryptocurrency, bitcoin, collaborative economy, startup capital transaction cost, smart communities, trade finance, and climate finance. The focus of their study and the identified applications differ from the focus of the study being discussed.

Albeshr & Nobanee (2020) conducted a mini SLR to examine applications of blockchain in the banking industry. While the study provides an overview of the use of blockchain in the banking sector, it does not specifically focus on payment systems. The study also does not consider grey literature sources. In contrast, the most closely related systematic literature review studies to this MLR are Dashkevich et al., (2020) and Del Río, (2017). Del Río, (2017) aims to review the stage and central banks of advanced economies in exploring and adopting DLT in their functions based on a review of central banks' publications. The study outlines limited use cases without specifically focusing on payment systems with the scope of this MLR. Dashkevich et al., (2020), on the other hand, is the most elaborate study and aims to classify and provide a thematic analysis of "(DLT) use-cases for services, operations and functions performed by central banks.

The study identifies: 1) Central Bank issued Digital Currency (CBDC), 2) Regulatory Compliance, 3) Payment Clearing and Settlement Systems (PCS) operated by central banks, 4) Assets

Transfer/Ownership, and 5) Audit Trail," as the major use cases. It does not focus on the specific topic of payment systems. These two studies provide valuable contribution to the understanding of DLT applications by central banks, but they do fully provide elaborative discussion of DLT applications in these specific applications. In addition, this study contributes by also offering insight into the DLT platforms and algorithm consensus implemented in applicable proof of concepts, pilots, and projects.

Overall, this study differs from these studies in three ways:

i. It includes academic literature and grey literature searched using a systematic approach, to provide a more inclusive and comprehensive understanding of the topic.
ii. It is the first MLR performed systematically in DLT application in central bank payment system functions. It explores the use of DLT in central bank payment system functions from a broader perspective covering DLT -based payment and settlement systems operated by central banks, oversight of payment systems functions, and DLT as infrastructure for CBDCs.
iii. It offers In-depth exploration of the motivations, DLT platforms and algorithm consensus implemented in applicable proof of concepts, pilots and projects considered in the literature pool.

5.3.3.2. The MLR Process

This section details the search process, source selection, assessment of study quality, extraction of data, and synthesis of data stages as laid out in Garousi et al. (2019). The initial search and source selection phases for academic literature and grey literature are separated with the selection of grey literature being the first step in the search process. The steps outlined by Garousi et al. (2019) for conducting an MLR are implemented in sequence during this phase.

5.3.3.2.1 Search process

The MLR protocol proposed by Garousi et al. (2019) was employed to conduct the search process, which includes three stages: (1) constructing search strings, (2) selecting databases, and (3) applying the search strings to the chosen search engines.

Search String construction

Step 1 involves constructing the search string. The Population Intervention Comparison Outcome (PICO) approach suggested in Kitchenham et al., (2009) was adopted in the development of the search string for this study. The PICO approach has been proposed to help create and structure the search strings by breaking down a research question into the various components, which makes it easier to identify the key terms and concepts that should be included in the search string used to search for relevant studies. The resulting search string is more specific and targeted, which can improve the efficiency and accuracy of the literature search (Petersen et al., 2015). According to (Petersen et al., 2015), the population (P) and intervention (I) variables are the most important for a review, as including the others could overly restrict the search and eliminate useful articles. In the current research context, the population dimension (P) is central banks and their corresponding payment system functions while the intervention dimension (I) is DLT/Blockchain. According to Garousi et al. (2019), the search string construction process is an iterative process that involves using pilot searches to identify more relevant search strings.

The results of the pilot search strings employed in the informal search and their yielded results are presented in Table 5.3

	Search string	Yielded results
1.	("distributed ledger technology" or dlt or blockchain) and ("payment systems" or "payment clearing and settlement")	1,520 results
2.	(distributed ledger technology or dlt or blockchain) and ("payment systems" or payment clearing and settlement)	11,800 results
3.	(distributed ledger technology or dlt or blockchain) and ("payment systems" or payment clearing and settlement) AND "CENTRAL BANKS"	6,710 results
4.	(distributed ledger technology or dlt or blockchain) and ("payment systems" or payment clearing and settlement OR INTERBANK) AND "CENTRAL BANKS"	6,860 results

Table 5. 3 Pilot search strings results

The iterative approach and skimming through the yielded articles guided an optimal search string for the grey literature which is shown below:

(distributed ledger technology or dlt or blockchain) and ("payment systems" or payment clearing and settlement OR INTERBANK) AND "CENTRAL BANKS"

The search strings needed to be adapted to suit the specific requirements of the different databases. The specific search strings for each database are shown in Table 5.4

Database	Search string link
Scopus	(distributed AND ledger AND technology OR dlt OR blockchain) AND ("payment systems" OR payment AND clearing AND settlement OR interbank) AND "CENTRAL BANKS" AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "p"))
Web of science	(distributed ledger technology or dlt or blockchain) and ("payment systems" or payment clearing and settlement OR INTERBANK) AND "CENTRAL BANKS"

Table 5. 4 Database search strings

Selection of databases and applying the string on chosen search engines.

The grey literature was identified by applying the search string provided in Table (x) to a general web search engine, I.e., Google. The final search was updated on 14 November 2022 and yielded 6,860 results. Because of the sizable number of results initially yielded, the search process was stopped using the Effort bounded approach, which included only the top N search engine hits, as recommended in Garousi et al. (2019). An effort-bounded approach involves setting a specific limit on the amount of time or resources that will be dedicated to searching for and reviewing the literature, and then using that limit to guide the search process and the selection of studies to include in the review. As a result, we conducted a review of the search results' first 10 pages, and 98 pieces of grey literature were exported and merged into a single file. To ensure comprehensive coverage, we conducted both forward and backward snowballing on the pool of merged articles. Snowballing in an MLR refers to a sampling technique that involves using reference lists of papers and citations to identify additional relevant sources. The process involves searching the reference lists of the studies already included in the review and the citations of these studies to identify additional sources that meet the review's inclusion criteria (Garousi et al. 2019). Forward snowballing involves using the references cited in the articles included in the review to identify additional sources, while backward snowballing involves using the reference lists of the articles included in the review to identify additional sources. A further eight grey literature sources were added through this technique.

To identify formally published literature, researchers can search full-text databases, such as IEEE Xplore, the ACM digital library, ScienceDirect, or broad-coverage abstract databases, such as Scopus, Web of Science, or Google Scholar (Garousi et al. 2019). We applied the search strings in Table 5.2 to the respective search engines of the broad-coverage abstract databases, i.e., Scopus, and Web of Science because of their wide coverage of relevant literature on DLT. The final search was updated on 14 November 2022. The results of the informal search and the yielded results are given in Table 5.3. Unlike grey literature, there are clear stopping conditions for this type of search process (Garousi et al. 2019). The final search yielded academic literature in broad-coverage abstract databases (i.e., Scopus and Web of Science) resulted in only 40 and three publications, respectively. The results of the informal search and the yielded results are given in Table 5.5.

Database	Search string link	Result
Scopus	(distributed AND ledger AND technology OR dlt OR blockchain) AND ("payment systems" OR payment AND clearing AND settlement OR interbank) AND "CENTRAL BANKS" AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "p"))	40 document results
Web of science	(distributed ledger technology or dlt or blockchain) and ("payment systems" or payment clearing and settlement OR INTERBANK) AND "CENTRAL BANKS"	3 results

Table 5. 5 Informal search results

i) **Source selection**

Once the initial sources that could be relevant are retrieved, they must be assessed for their actual relevance. Garousi et al. (2019) propose a two-phased source selection process: (1) determining the selection criteria, and (2) performing the selection process. They further note that the source selection processes for grey literature and formal literature should be coordinated in an MLR. The guiding principle in determining the selection criteria should be an inclusion/exclusion criterion that filters out sources that directly respond to the MLR's research questions. To present better scoped research, the study adapted and applied the selection criteria from Garousi et al. (2019) checklist encompassing questions on: (1) Novelty: Does the source enrich or add something unique to the research? and (2) outlet type and added two additional questions on language and whether the study conformed to the quality assessment criteria. Steps followed for inclusion criteria are summarized below:

Inclusion criteria:

- *The sources presenting DLT solutions for application in central bank payment system functions,*
- *The sources describing the value proposition, challenges, and risks of DLT application in central bank payment system functions,*
- *The sources that conform to specified quality assessment criteria*,*
- *The sources that are written in English,*
- *Outlet Type: 1st tier and 2nd tier international development institutions: high outlet control/high credibility: Books, magazines, theses, government reports, and white papers.*

Both the grey and formal literature were evaluated using the same criteria. The inclusion criteria was also applied on the articles retrieved in the forward and backward snowballing. The sources were first screened based on the source titles, and then evaluated in incrementally based on their abstract, introduction and the full content to determine whether they met the criteria and assigned a score.

ii) **Study quality assessment**

Quality assessment of sources is conducted to determine the validity and reliability of the sources suitable for inclusion in the final synthesis of the MLR (Garousi et al. 2019). The study adapted and applied the quality assessment checklist of grey literature from Garousi et al. (2019) checklist encompassing questions on:

- Methodology: *Does the source have a clearly stated aim?*
- Date: *Does the item have a clearly stated date?*
- Authority of the source: *Is the publishing organization reputabl*e?
- Novelty: *Does it enrich or add something unique to the research?*

The decision to include or exclude a source in an MLR quality assessment can be made either through a binary decision (yes" or "no" based on guiding questions) or by using a scoring system where scores are assigned to assessment questions. A scoring system that can be used is the Likert scale (yes = 2, partly = 1, and no = 0). A threshold for including sources can be set. The scoring scheme was used for this study to ensure consistency and reliability in the selection process. The threshold for including sources was set at 7 as 7 has been considered appropriate in other MLRs including (Baysal et al., 2022). Table 5.5 shows a snapshot of the results of applying the quality assessment checklist.

Source	Source Link	the sources presenting DLT application in payment, clearing and settlemen;	the sources describing the value proposition, challenges and risks of DLT application in payment, cleraing and settlement	the sources that conform to specified quality criteria* (the studies with 4 or higher rating)	the sources that are written in English and accessible	Outlet Type: 1st tier: High outlet control/ High credibility: Books, magazines, theses, government reports, white papers	Inclusion Status		*Quality Assessment Questions				Quality Score
									Q1. Methodology - Does the source have a clearly stated aim?	Q2. Date - Does the item have a clearly stated date?	Q3. Authority of the source - Is the publishing organization reputable?	Q4. Novelty- Does it enrich or add something unique to the research	
Google	Care.pdf	Yes	Yes	Yes	Yes	Yes	No		2	1	2		5
Google	https://www.imf.org/-/media/Files/Publications/FTN063/2020/English/FTNEA2020001.ashx	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	https://www.bis.org/publ/work1015.pdf	Yes	Yes	Yes	Yes	Yes	NO	Duplicate	1	2	2	2	7
Google	https://www.bis.org/speeches/sp190207.htm	Yes	NO	NO	Yes	NO	No						
Google	money-successfully-tested-861444	NO	NO	NO	Yes	Yes	No						
Google	https://www.accenture.com/bg-en/services/blockchain/rtgs	NO	NO	NO	Yes	NO	No						
Google	https://www3.weforum.org/docs/WEF_Central_Bank_Activity_in_Blockchain_DLT.pdf	Yes	Yes	Yes	Yes	Yes	Yes		1	2	2	2	7
Google	https://www.redalyc.org/jatsRepo/5722/572261717001/html/index.html	Yes	Yes	Yes	Yes	Yes	Maybe		2	2	0	2	6
Google	https://www.r3.com/blog/blockchains-and-central-banks-what-have-we-learnt/	Yes	Yes	NO	Yes	NO	No						
Google	https://www.bankofcanada.ca/research/digital-currencies-and-fintech/projects/	Yes	Yes	Yes	Yes	NO	NO						
Google	blockchain-based-payments	Yes	NO	NO	Yes	NO	NO						
Google	https://www.nthexception.com/2021/07/dlt-in-payments-and-settlements.html	Yes	Yes	NO	Yes	NO	NO						
Google	fnality.html	NO	NO	NO	Yes	NO	NO						
Google	https://www.ecb.europa.eu/pub/pdf/other/ecb.stella_project_report_september_2017.pdf	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	72/gs-16-1-distributed-ledger-technology.pdf	NO	NO	Yes	Yes	Yes	NO						
Google	https://thecommonwealth.org/sites/default/files/inline/CFT%20Chapter%203.pdf	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	https://www.banque-france.fr/sites/default/files/media/2021/11/09/rapport_mnbc_0.pdf	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	https://www.fnality.org/fnality-global-payments-insights	Yes	Yes	Yes	Yes	NO	NO						
Google	https://www.boj.or.jp/en/research/wps_rev/rev_2022/data/rev22e08.pdf	Yes	Yes	Yes	Yes	Yes	Yes		1	2	2	2	7
Google	idadFinanciera/22/4_FSR42_Divisas.pdf	Yes	Yes	Yes	Yes	Yes	Yes		1	2	2	2	7
Google	T/focusgroups/dfc/Documents/FGDFC_RA%20WG_Reference%20Architecture%20and%20Use%20	Yes	Yes	Yes	Yes	Yes	Maybe		1	2	2	2	7
Google	Ledger-Technology-and-Blockchain-Fintech-Notes.pdf	NO	NO	Yes	Yes	Yes	NO		2	0	2	2	6
Google	https://www.bankofengland.co.uk/financial-stability-in-focus/2022/march-2022	NO	NO	Yes	Yes	Yes	NO						
Google	payments.pdf	Yes	Yes	Yes	Yes	NO	maybe						
Google	https://www.icmagroup.org/assets/ICMA-DLT-and-blockchain-in-bond-markets-FAQ-220922.pdf	NO	NO	Yes	Yes	NO	NO						
Google	digital-currency-20220203.html	Yes	Yes	Yes	Yes	NO	NO		1	2	2	2	7
Google	system-f98f9a6de013	NO	NO	NO	Yes	NO	NO						
Google	https://www.degruyter.com/document/doi/10.1515/ael-2019-0095/html?lang=en	NO	NO	Yes	Yes	Yes	NO		2	2	2	2	8
Google	https://www.snb.ch/en/mmr/reference/project_jura_report/source/project_jura_report.en.pdf	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	Clearing_and_Settlement	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	https://www.bbvaresearch.com/wp-content/uploads/2019/11/Banking-Lab-DLT-CBDCs_edi.pdf	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	https://consensys.net/blockchain-use-cases/finance/project-khokha/	Yes	Yes	NO	Yes	NO	NO						
Google	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8751668/	NO	NO	NO	Yes	NO	NO						
Google	https://www.iosco.org/library/pubdocs/pdf/IOSCOPD685.pdf	NO	NO	NO	Yes	NO	NO						
Google	april-2021.pdf	Yes	Yes	Yes	Yes	NO	maybe						
Google	https://www.sama.gov.sa/en-US/News/Documents/Project_Aber_report-EN.pdf	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	istituzionali/2021-010/N.10-MISP.pdf	Yes	Yes	Yes	NO	Yes	NO		2	2	2	2	8
Google	https://www.citibank.com/tts/insights/articles/article191.html	NO	NO	NO	Yes	NO	NO						
Google	https://www.resbank.co.za/content/dam/sarb/quick-links/fintech/SARB_ProjectKhokha_20180605.pdf	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	noexp.pdf	Yes	Yes	Yes	Yes	NO	maybe						
Google	blueprint	NO	NO	NO	Yes	NO	NO						
Google	https://www.aimspress.com/article/doi/10.3934/QFE.2021003?viewType=HTML	NO	NO	NO	Yes	NO	NO						
Google	%20Rev%201.pdf	NO	NO	NO	Yes	NO	NO						
Google	dlt-and-digital-currencies-to-advance-financial-inclusion.pdf	NO	NO	NO	Yes	NO	NO						
Google	https://link.springer.com/chapter/10.1007/978-981-16-7830-1_6	Yes	Yes	Yes	Yes	Yes	NO	Not GL	2	2	2	2	8
Google	https://academic.oup.com/book/35207/chapter/299662559	NO	NO	NO	Yes	NO	NO						
Google	markets-perspective-full-report-feb-2022-final.pdf	Yes	Yes	Yes	Yes	NO	maybe						
Google	https://www.suerf.org/policynotes/12575/overview-of-central-bank-digital-currency-state-of-play	Yes	Yes	Yes	Yes	NO	NO						
Google	https://www.rbnz.govt.nz/-/media/d85959f29bb0473488004fb569d80613.ashx	Yes	Yes	Yes	Yes	NO	NO		2	2	2	2	8
Google	assets-asia.pdf	NO	NO	NO	Yes	NO	NO						
Google	https://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID3612009_code2519140.pdf?abstractid=3612009	NO	Yes	Yes	Yes	Yes	NO						0
Google	ledger-technologies.pdf	NO	NO	NO	Yes	NO	NO						
Google	debt/	NO	NO	NO	Yes	NO	NO						
Google	tech/en/articles/2022/02/cbdc-and-dlt-in-debt-capital-markets--why-the-banque-de-france-s.html	NO	NO	NO	Yes	NO	NO						
Google	https://www.scielo.br/j/ecos/a/NFnZwKXNRvcvz8g65qFzWKG/	NO	NO	NO	Yes	NO	NO						
Google	https://www.irsg.co.uk/assets/Reports/IRSG-The-Use-of-CBDCs-in-Wholesale-Markets.pdf	Yes	Yes	Yes	Yes	NO	maybe						
Google	https://www.darrellduffie.com/uploads/policy/duffiedigitalpaymentsmay2019.pdf	NO	NO	NO	Yes	NO	NO						
Google	n_Central_Bank_of_Brazil.pdf	Yes	Yes	Yes	Yes	Yes	Yes		2	2	2	2	8
Google	https://www.gemini.com/cryptopedia/central-bank-digital-currencies-cbdc	Yes	Yes	NO	Yes	Yes	NO						
Google	considerations-rationales-and-implications.html	Yes	Yes	Yes	Yes	Yes	NO						0
Google	ce=1	NO	NO	NO	Yes	NO	NO						
Google	santander-to-execute-first-cross-chain-pilot-debt-transaction-on-public-ethereum-and-fnality-payment-	NO	NO	NO	Yes	NO	NO						
Google	https://www.dnb.nl/media/ji0pza2a/working_paper_no-_718.pdf	NO	NO	NO	Yes	NO	NO						
Google	https://www.fsb.org/wp-content/uploads/P310519.pdf	NO	NO	NO	Yes	NO	NO						

Table 5. 6 Snapshot of the results of applying the quality assessment checklist

Following the selection process, formal literature and grey literature were merged into distinct files in the final pools.

Below are the results of the evaluation and the number of sources retrieved:

- ***Academic Sources:***

Step 1: Applying search strings on data bases:
Scopus (n = 40)

Web of science (n = 3)

Step 2: Applying Inclusion and exclusion criteria:

Removed (n = 36)

Step 3: Removing duplicates:

Less (n = 1)

Step 4: Final considered.

(n = 6)

- ***Grey Literature sources***

Applying search string on database

Step 1: Google: (n = 6860)

Step 2: Reviewed top ten pages (n =100)

Step 3: Removed 2 duplicates left with (n = 98 papers**)**

Step 4: Snowballing (n = 8)

Applied inclusion and exclusion criteria at the same time – Removed (n = 85)

Final (n = 21)

iii) Data extraction

The approach adopted for the data extraction was a multi-stage approach. In the first stage, a data extraction form, in the form of a spreadsheet hosted on Google sheet, was created to extract bibliometric data, deduce specific DLT applications in central bank payment system functions and DLT platforms used. Table 5.7 presents the online database (a spreadsheet hosted on Google Docs). The bibliometric data allowed the development of the descriptive section and the analysis of the thematic distribution of published work, which is applied to indicate the research trend in DLT applications in central stem functions.

No	Source	New GL Sources Included in the MLR	Link of the GL Source	In- Text Citation	Citation	Year	citation count	Type	Outlet Type	Research Type
1	Google	DISTRIBUTED LEDGER TECHNOLOGY	https://www.imf.org/-	(Shabsigh et al., 2020)	Shabsigh, G., Khiaonarong,	2020		Report	2nd tier	validation research
2	Google	Central Banks and Distributed Ledger Technology:	https://www3.weforum.org/d	(Central Banks and	World Economic Forum.	2019		White Paper	1st tier	validation research
3	Google	STELLA - a joint research project of the European	https://www.ecb.europa.eu/pub/p	(STELLA - a joint	European Central Bank	2017		White Paper	1st tier	Solution proposa
4	Google	Blockchain and Financial Services	https://thecommonwealth.org/sit	(Blockchain and	Common Wealth Finte	n/d		Report	2nd tier	validation research
5	Google	WHOLESALE CENTRAL BANK DIGITAL	https://www.banque-	(WHOLESALE CENTRAL	Banque de France. (20	2021		White Paper	1st tier	Solution proposa
6	Google	Realizing Programmability in Payment and	https://www.boj.or.jp/en/researc	(Masashi & Junichiro, 2022)	Masashi, H. O. J. O., &	2022		Report	2nd tier	validation research
7	Google	Wholesale financial markets and digital currencies:	https://www.bde.es/f/webbde/GA	(Gorjón, 2022)	Gorjón, S. (2022).	2022		White Paper	1st tier	validation research
8	Google	Cross-border settlement using wholesale CBDC	https://www.snb.ch/en/mmr/refe	(Project Jura: Cross-	Banque de France, Bank	2021		White Paper	2nd tier	Solution proposa
9	Google	Distributed ledger technology in payments,	https://www.federalreserve.g	(Mills et al., 2016)	Mills, D., Wang, K.,	2016		Report	2nd tier	validation research
10	Google	Central Bank Digital Currencies and Distributed	https://www.bbvaresearch.com/w	(Lis & Sebastián, 2019)	Lis, S. F. de, & Sebastián,	2019		Report	2nd tier	opinion studies
11	Google	Project Aber	https://www.sama.gov.sa/en-	(Project Aber: Joint	The Saudi Central Bank	2019		White Paper	1st tier	Solution proposa
12	Google	PROJECT KHOKHA Exploring the use of	https://www.resbank.co.za/conte	(PROJECT KHOKHA	South African Reserve	2018		White Paper	1st tier	Solution proposa
13	Google	Distributed ledger technical research in Central	https://www.bcb.gov.br/content/	(Burgos et al., 2017)	Burgos, A. de V., Filho, J.	2017		White Paper	1st tier	Solution proposa
14	Google	Inthanon - LionRock tomBridge Building a multi	https://www.hkma.gov.hk/media/	(Inthanon - LionRock	BIS Innovation Hub Hong	2021		White Paper	1st tier	Solution proposa
15	Snowballing	Project Jasper: Are Distributed Wholesale	https://www.bankofcanada.c	(Garratt et al., 2017)	Garratt, J. C. R., McCo	2017		White Paper	1st tier	Solution proposa
16	Snowballing	Project Jasper	https://payments.ca/sites/def	(McCormack et al., 2022)	(McCormack et al., 202	2022		White Paper	1st tier	Solution proposa
17	Snowballing	The future is here Project Ubin: SGD on	https://www.mas.gov.sg/-	(The future is here	Deloitte & Monetary A	2016		White Paper	1st tier	Solution proposa
18	Snowballing	PROJECT UBIN PHASE 2 Re-imagining	https://www.mas.gov.sg/-	(PROJECT UBIN PHASE	The Association of bar	2017		White Paper	1st tier	Solution proposa
19	Snowballing	INTHANON Phase I An application of	https://www.bot.or.th/Thai/P	(INTHANON Phase I An	Bank of Thailand . (201	2018		White Paper	1st tier	Solution proposa
20	Snowballing	CROSS-BORDER INTERBANK PAYMENTS	https://www.mas.gov.sg/-	(CROSS-BORDER	Bank of Canada, Bank	2018		White Paper	1st tier	Solution proposa
21	Snowballing	Synchronised cross-border payments	https://www.ecb.europa.eu/p	(STELLA – joint research	European Central Bank	2019		White Paper	1st tier	Solution proposa
22	Snowballing	Project Jasper (Phase 4)—Project Ubin (Phase 4)	https://www.mas.gov.sg/-	(Jasper–Ubin Design Pap	The Bank of Canada (B	2019		White Paper	2nd tier	Solution proposa
23	Snowballing	European Central Bank and Bank of Japan:	https://www.ecb.europa.eu/p	(Project Stella Synchronis	European Central Bank	2019		White Paper	2nd tier	Solution proposa
24	Snowballing	Project Inthanon-LionRock	https://www.hkma.gov.hk/me	(Inthanon-LionRock Leve	Bank of Thailand and H	2019		White Paper	2nd tier	Solution proposa

No	RQ1 What are the applications of DLT in Central Banks payment systems	moved from proposing the conceptual/insigh	RQ1 What is the motivation/Value proposition behind adopting DLT in the	What DLT platform was used ?	What consensus protocol was used?	associated with DLT use in the specific application?	RQ2 What are the challenges and risks associated with DLT use in the specific use case?	RQ5 What are existing solution suggestions to the DLT-related challenges in the use case?
1	1.Payment system	N/A	1. Large -value payment				1. Large -value payment system infrastructure - 1.1 DLT is, at least to	
2	1. wCBDC 2. CBDC	N/A	1.The	N/A	N/A		Large -value payment system infrastructure - A final set has not yet	
3	1.Payment system	POC	Payment system- This	Hyperledger Fabric version 0.6.1,	Practical Byzantine		1.DLT-based solutions could meet the performance needs of a Real-Time	
4	1.Payment system	N/A	Large -value	N/A	N/A		Large -value payment system infrastructure- The number of nodes on	
5	wCBDC							
6	1.Payment system	N/A	Payment system -					
7	1. wCBDC 2.	N/A						
8	1.wCBDC 2. Cross -	POC		corda				
9	Central Bank Digital	N/A	Payment systems - The				Payment systems - Although there is much optimism regarding the promise	
10	1. wCBDC 2.	N/A	Payment systems- Main				RTGS- In the case of wholesale payment systems it is unclear to what extent	
11	1. wCBDC 2. CBDC	Pilot	The project sought to	Hyperledger Fabric			One of the key mandates was to design a solution that is decentralized to the	
12	Payment system							
13	Payment system							
14	1.wCBDC 2. Cross -							
15	Payment system							
16	Payment system							
17	Payment system							
18	Payment system							
19	Payment system							
20	1.Payments between							
21	1.Payments between							
22	Cross -border	Prototype		Quoroum and Corda				
23	Cross -border	Prototype		Interledger.js42 and Hyperledger				
24	Cross -border	POC		Phase 1: corda Phase 2: Project				

Table 5. 7 Data extraction form

iv) Thematic Analysis

Subsequently, we employed a thematic analysis to qualitatively analyze the gathered data. According to Braun and Clarke (2006), thematic analysis is aimed at "identifying, analyzing, and reporting patterns" that frequently appear within a dataset. Alternatively, it can provide a more comprehensive and in-depth examination of a particular theme or group of themes within the data in relation to a specific question or area of interest referred to a semantic approach (Braun and Clarke., 2006). In this context, thematic analysis was utilized to achieve the latter objective of providing a more comprehensive and in-depth exploration of a particular theme or group of themes within the dataset (Braun and Clarke., 2006). The thematic analysis was guided by the research question focusing on the motivation/value proposition (i.e., the driving force of implementing DLT in that specific use case).

We followed the iterative process guidelines of thematic analysis described in Braun and Clarke's (2006). Each step is discussed in the following section within the context of our research.

The initial step of thematic analysis involves the researcher becoming acquainted with the data, with the purpose of providing the researcher with an initial understanding of it. This initial step can reveal wide ranging insights that consistently recur across the data and respond to the research question. To undertake the stage of data familiarization, the researcher reviewed each of the 27 documents included in the final dataset and began to annotate relevant ideas for coding purposes. This initial step facilitated the creation of a provisional coding frame, which was established based on the identified applications of DLT in central bank payment system functions. Furthermore, during this stage, we commenced the process of populating data related to the DLT platforms employed and the consensus algorithms utilized in the proof of concepts, pilots, and projects considered in the dataset in the google form. This data was subsequently cross-referenced in latter stages and was employed to respond to the two- sub research questions.

The second step of the thematic analysis involved generating initial codes, which were guided by the research question regarding the motivation/value proposition driving the implementation of DLT in the specific use case, as well as the applications facets identified in the previous data familiarization stage, which formed the initial coding frame. The coding process was carried out using NVivo software, where relevant text excerpts were tagged to their corresponding codes. The approach used for coding was a semantic approach, which underpins the process of coding to the data and the specific research question.

In the third step, the researcher searched for themes by grouping the codes into meaningful clusters after completing the coding process. The emerging themes were identified in accordance with the motivation/value proposition driving the implementation of DLT in the specific use case being studied. For instance, the efficiency components, such as improved settlement speed, reduced complexity especially in multi-party and cross-border transactions, more efficient collateral management, potential cost savings, and reduced back-office costs by automating various settlement processes, were grouped into the theme of improving payment system efficiency.

In the fourth step, the researcher should review and refine the identified themes by checking whether they accurately capture the essence of the data. The researcher should also ensure that the themes are distinct from each other and that there is no overlap. In this step we read the tagged extracts on NVivo corresponding to each theme which resulted in the collapse of some themes into others. In this step we also classified the applications identified in the first stage into three overarching first- order themes based on central bank payment system functions

In the last step of the analysis, the researcher should name the themes descriptively and meaningfully to convey the main idea behind each one and further expound on their significance. This involves going beyond a basic label and aiming to capture the essence of the theme in a way that clearly conveys its main idea. In this stage, the researcher reviewed and renamed the themes to better reflect the research questions. For example, the "resilience" theme was renamed to "improved resilience" to better capture the theme in the context of motivation for adoption of DLT- based RTGS systems. The findings are presented in a descriptive manner, and NVivo code extracts and tables are used to summarize the data and highlight some key findings.

5.4 Results and Discussions

The section begins with a quantitative analysis of the literature to identify the current state of research and development of DLT applications in central banks payment systems functions. This is done through a bibliometric analysis of the MLR's data source to review and identify the state-of-the-art research on DLT application in central banks payment systems functions to answer research question RQ.4. The section then provides discussions on the application of DLT in the payment systems functions of central banks to address RQ.5. and all subset questions. The discussions focus on each use case, including the motivation, DLT platform, and consensus algorithm (where applicable) to answer practical questions about when and where DLT will be most beneficial and when implementations will offer only marginal benefits in comparison to conventional centralized systems. The section aims to provide a comprehensive and practical overview of the current state of research and development of DLT applications in central banks payment systems functions.

(RQ4): What is the current state of the art of research and development of DLT applications in central bank payment system functions?

To answer RQ4, a bibliographic analysis was conducted to examine the distribution of publications on DLT applications in central banks payment systems functions over time and literature types.

5.4.1 Distribution of publications over time and literature types

There are 21 grey literature sources and 6 academic literature sources included in the final MLR source pool. All the academic literature included was published in journals. Figure 5.3 illustrates the publication years for the publications identified between 2016 and 2022. The color difference conveys the sort of literature included in the final MLR source pool, distinguished as academic literature or grey literature.

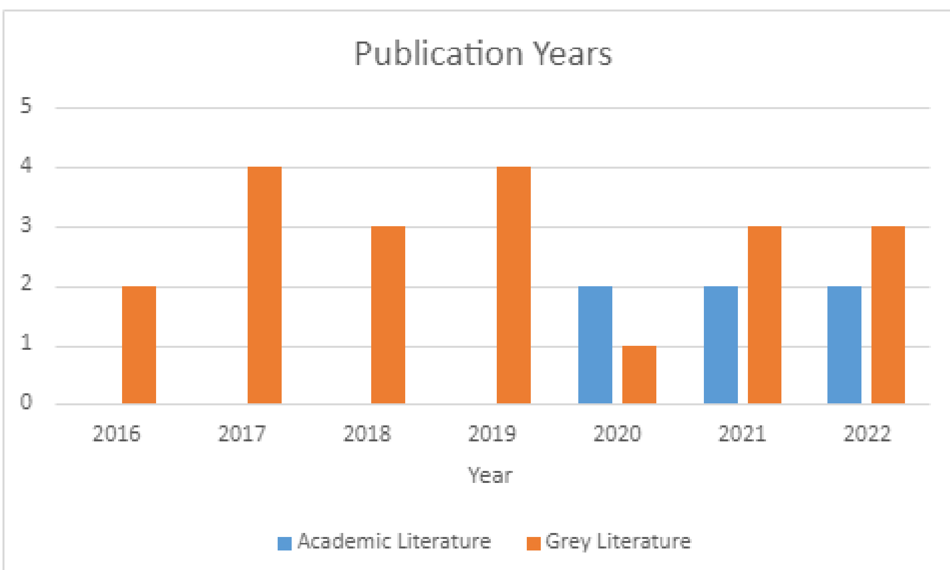


Figure 5. 3 The Publication years of the sources included.

The search string *(Distributed Ledger Technology OR DLT OR Blockchain) AND ("Payment Systems" OR Payment Clearing and Settlement OR Interbank) AND "CENTRAL BANKS")* for academic literature in broad-coverage abstract databases (i.e., Scopus and Web of Science) resulted in only forty and three publications, respectively. Following an abstract screening for relevance and quality assessment only six of these academic publications are included in the final MLR source pool. Furthermore, the search is not year bound but the first article included in the MLR source pool appears in 2020, despite the introduction of blockchain by Satoshi Nakamoto in 2008. This demonstrates that the study of DLT, application in central banks payment systems functions is a novel and an unexplored field of inquiry relative to other DLT research topics in the financial services sector that have demonstrated growing interest from the academic community according to (Ali et al., 2020). The lack of data and production-scale DLT pilots in central bank payment system functions limits the availability of empirical research, making it difficult to draw definitive conclusions about the benefits of DLT in this context.

Out of the 27 data sources included, only six articles (representing 22% of the sample), were scholarly academic articles indicating that most of the research was informed by grey literature. This trend reveals that industry practitioners as opposed to academic researchers are taking the lead in investigating the application of DLT within the payment systems function of central banks. The lack of or the inadequate scholarly rigor has led to an imbalanced homogenous research output that is skewed heavily towards the technical dimension, leaving out critical social, economic, policy and philosophical considerations that are key to exploring impact and predicting the possibility of social-technical transition towards DLT payment systems. Cross-disciplinary research bridging the gap between academic research and industry application is, therefore, necessary to foster a deeper understanding of the phenomenon, also further justifying the choice of a MLR research methodology.

The distribution of the listed scholarly papers is uniform between 2020 and 2022. Notably, despite central banks testing and investigating DLT pilots, there is a dearth of pilots implemented on a production scale, hence empirical research is limited due to lack of data. It is therefore likely that industry practitioners will continue to direct research in the area.

5.4.2 Publishing avenues for the academic literature

Figure 5.4 illustrates the frequencies of academic literature included in the final MLR source pool across different publishing avenues. The small sample size of academic publications limits the ability to make meaningful inferences about the most targeted journal for research in DLT application in central banks payment systems functions. However, based on both the pre-screened academic pool and final MLR source pool, the Institute of Electrical and Electronics Engineers (IEEE) ranks the highest, which suggests that DLT research is heavily focused on the technical perspective. Another study by Dashkevich et al. (2020) on the applications of blockchain (not focusing on payment systems by central banks) also found that IEEE and Elsevier BV were the most used publishers, with IEEE focusing on conference proceedings and Elsevier BV on academic publications.

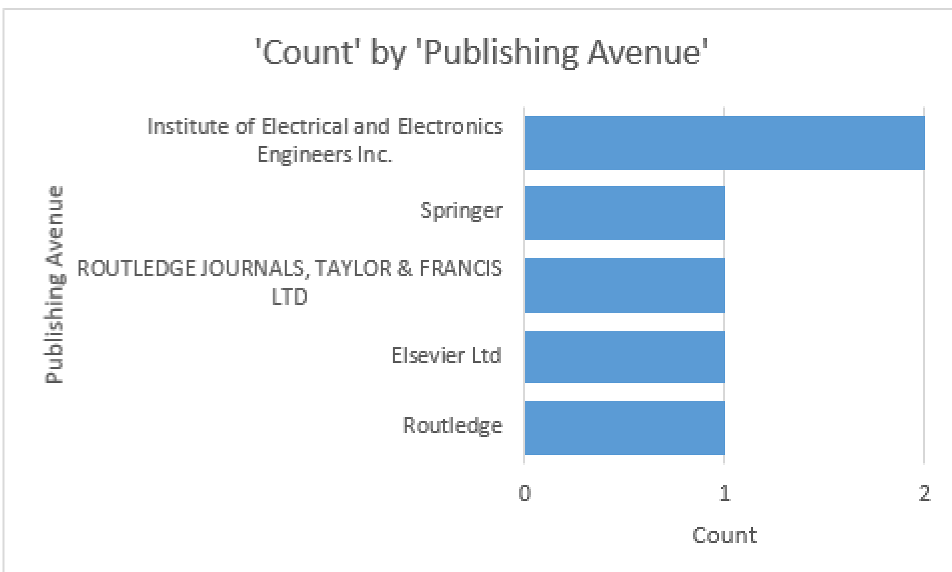


Figure 5. 4 The frequencies of the academic literature publishing avenue

5.4.3 Research type and contribution

This study utilized the framework proposed by Garousi et al. (2019) for categorizing research types. The framework prescribes seven research categories including: 1) solution proposal-research that proposes an approach or method to address a challenge, 2) validation research (or weak empirical study) that attempts to validate or refute prior conclusions but utilizes weak empirical evidence, 3) evaluation research (or strong empirical study) that evaluates a new or existing strategy or method based on substantial empirical evidence, such as experiments or case studies, 4) experience studies research that investigates the experience learnt from adopting an approach in practice, 5) philosophical studies research that investigates the rationale, principles, and values behind an approach, 6) opinion studies research studies that aim to gather people's opinions, beliefs, and attitudes towards a particular subject, 7) Other research that do not fall into any of the previously mentioned categories and can encompass a wide range of research approaches and methods.

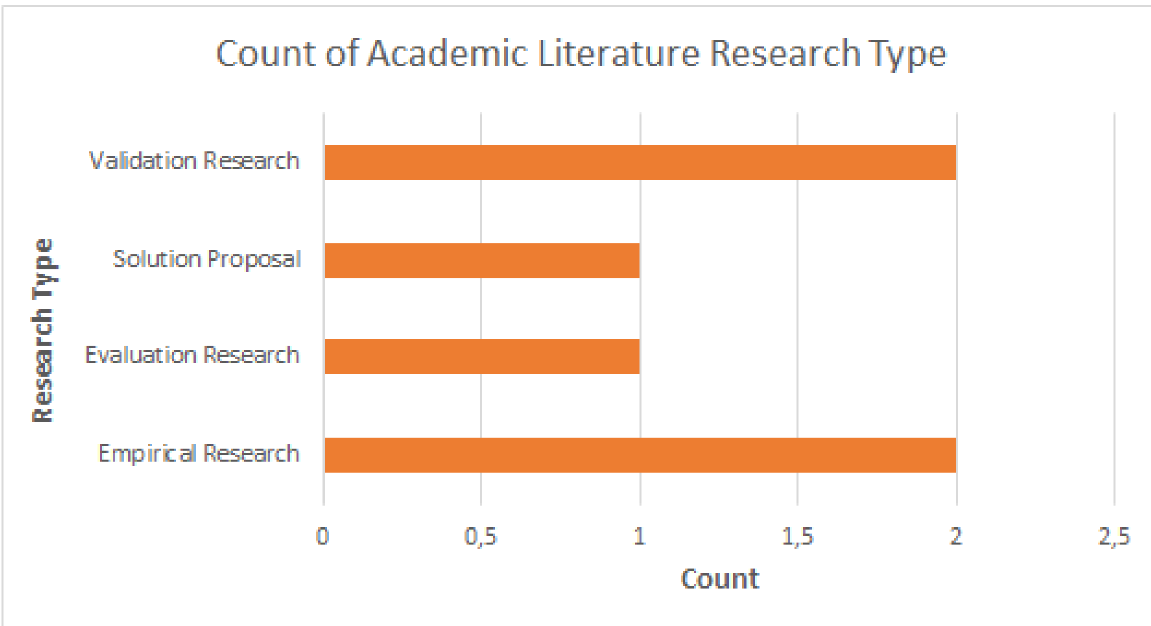


Figure 5. 5 illustrates the distribution of academic literature by research type.

The final pool distribution of academic research is evenly split between empirical research and validation research. It also applies to evaluation and solution research. However, the number of articles in the final pool is insufficient to draw any meaningful conclusions. The few empirical articles may be attributed to the lack of empirical data due to few or no live implementations of DLT applications in central bank payment systems functions. It is important to consider these findings in the context of the research questions and objectives of the MLR to assess the implications for the review's conclusions and recommendations.

The distribution of grey literature by research type is illustrated in Figure 5.6. Grey literature has more solution proposal research types than other research types. The high number of solution proposal research in grey literature could be attributed to the fact that grey literature is more likely to contain industry reports, technical whitepapers, and other documents focusing on practical applications of technology rather than theoretical or empirical research. Furthermore, because grey literature is not subjected to the same peer-review process as academic literature, it may contain less rigorously evaluated solution proposals.

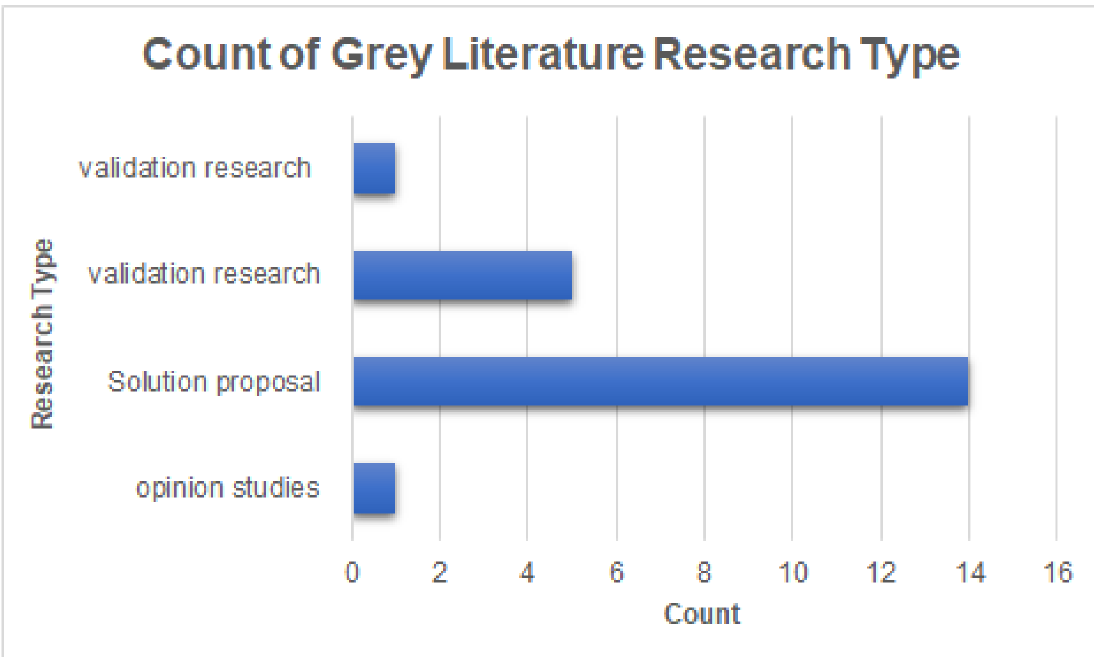


Figure 5. 6 illustration of the distribution of grey literature by research type.

5.4.4 Thematic distribution of the literature

For the thematic distribution of the published work on DLT applications in central bank payment systems functions, MLR identified three first-order themes corresponding to the three central banks' functions in payment systems. These include operational responsibilities in payment and settlement systems, issuance of central bank digital money, and regulatory oversight/supervisory functions and other ancillary operational management functions. The second-order applications correspond to the high-level DLT applications in central bank payment systems functions and are divided into six third-order applications, which provide more detailed information on the specific application of DLT in the central bank payment systems functions. The theme of operational responsibilities in payment and settlement systems, which encompass the application of DLT as financial market infrastructure operated by central banks to facilitate funds-only transfers between or among participating agents, appears to be the most researched and reported DLT application in central bank payment systems functions, with 18 papers (or 66% of the total sample) examining it (see Table 5.5). The prevalence of research on this theme could be attributed to the fact that the potential benefits of application of DLT in this area may be more immediately apparent to researchers and industry participants as compared to the other use cases. It could also be because of the overlap of studies on application of DLT as infrastructure for central bank digital currencies (CBDC), a widely researched use-case that is often underpinned and cast on the application of DLT-based interbank payment rails operated by central banks. Research on CBDC may, therefore, have contributed to the increase in the number of papers on operational responsibilities in payment and settlement systems.

The second most extensively researched theme in the final literature pool on DLT applications in central bank payment systems functions is the use of DLT as an infrastructure for CBDCs. Despite having the most academic articles compared to other DLT applications in central bank payment systems, more than half of the research on this topic is derived from grey literature sources [AL3 GL9]. This might suggest that the interest in CBDCs is not limited to only one group, instead the academic community, industry practitioners and policymakers are also actively exploring this area. The reason for the high level of interest in CBDCs is due to its potential to transform the way central banks issue and distribute money, which is immediately apparent to researchers and industry participants. While academic research is more rigorous and empirically validated, grey literature sources, such as white papers, provide up-to-date information and practical insights into CBDC implementation and use in real-world scenarios.

In the final literature pool on DLT applications in central bank payments systems, the theme of regulatory oversight and ancillary operational management functions has received minimal coverage [AL1 GL5]. This lack of attention may be attributed to the fact that this theme is less well-defined compared to other themes, such as CBDCs or operational responsibilities in payment and settlement systems. Furthermore, regulatory oversight and ancillary management functions may not be the primary focus of DLT applications in central bank payment systems, but rather a secondary use case that stems from the applications of DLT-based interbank payment rails and DLT as an infrastructure for CBDCs. Thus, this could explain the limited amount of attention that this theme has received in the studied literature.

In conclusion, the analysis of published works on DLT applications in central bank payment systems functions suggests a high level of interest in utilizing DLT, particularly amongst industry players. However, the identified themes also reveal the challenges and limitations that must be addressed when applying DLT in this context. For example, the limited coverage of all these applications in academic literature implies a need for additional research in this area to better understand the applications, potential benefits, challenges, and risks of implementation. Considering the findings from the MLR, there is a need for sustained research and development efforts aimed at investigating the applications, potential benefits, challenges, and risks of DLT in central bank payment system functions. Such efforts should involve not only scholars but also stakeholders from the industry, who stand to benefit from the insights generated by academic inquiry.

Identified themes.

First order theme/ Central banks Functions in payment systems	Second order themes	Third order themes	Number of papers	References	
				Grey Literature	Academic Literature
Operational responsibilities in payment and settlement systems	DLT–based Interbank payment rails operated by central banks	DLT- based domestic RTGS systems	18 (AL 17, GL - 1)	1. (Mills et al., 2016)	18. (Dashkevich et al., 2020)
				2. (Gorjón, 2022)	
				3. (Lis & Sebastián, 2019)	
				4. (Burgos et al., 2017)	
				5. (STELLA – joint research project of the European Central Bank and the Bank of Japan June 2019 Synchronised cross-border payments 2019)	
				6. (STELLA - a joint research project of the European Central Bank and the Bank of Japan Payment systems: liquidity saving mechanisms in a distributed ledger environment 2017)	
				7. (Garratt et al., 2017)	
				8. (Shabsigh et al., 2020)	
				9. (Jasper–Ubin Design Paper Enabling Cross-Border High Value Transfer Using Distributed Ledger Technologies 2019)	
				10. (McCormack et al., 2022)	
				11. (The future is here Project Ubin: SGD on Distributed Ledger 2016)	
				12. (PROJECT UBIN PHASE 2 Re-imagining Interbank Real-Time Gross Settlement System Using Distributed Ledger Technologies 2017)	
				13. (Project Aber: Joint Digital Currency and Distributed Ledger proof of concept Project. 2019)	
				14. (Project Jura: Cross-border settlement using wholesale CBDC 2021)	
				15. (Inthanon-LionRock Leveraging Distributed Ledger Technology to Increase Efficiency in Cross-Border Payments 2019)	
				16. (PROJECT KHOKHA Exploring the use of distributed ledger technology for interbank payments settlement in South Africa 2018)	
				17. (Central Banks and Distributed Ledger Technology: How are Central Banks Exploring Blockchain Today? 2019)	
		DLT- based cross-border interbank payment and settlement arrangements	9 (AL - 8, GL - 1)	19. (Mills et al., 2016)	27. (Zetzsche et al., 2021)
				20. (Gorjón, 2022)	
				21. (STELLA – joint research project of the European Central Bank and the Bank of Japan June 2019 Synchronised cross-border payments 2019)	
				22. (Shabsigh et al., 2020)	
				23. (Jasper–Ubin Design Paper Enabling Cross-Border High Value Transfer Using Distributed Ledger Technologies 2019)	
				24. (Project Aber: Joint Digital Currency and Distributed Ledger proof of concept Project. 2019)	
				25. (Project Jura: Cross-border settlement using wholesale CBDC 2021)	
				26. (Inthanon-LionRock Leveraging Distributed Ledger Technology to Increase Efficiency in Cross-Border Payments 2019)	

		DLT- based cross-border interbank payment and settlement arrangements	9 (AL - 8, GL - 1)	19. (Mills et al., 2016)	27. (Zetzsche et al., 2021)
				20. (Gorjón, 2022)	
				21. (STELLA – joint research project of the European Central Bank and the Bank of Japan June 2019 Synchronised cross-border payments 2019)	
				22. (Shabsigh et al., 2020)	
				23. (Jasper–Ubin Design Paper Enabling Cross-Border High Value Transfer Using Distributed Ledger Technologies 2019)	
				24. (Project Aber: Joint Digital Currency and Distributed Ledger proof of concept Project. 2019)	
				25. (Project Jura: Cross-border settlement using wholesale CBDC 2021)	
				26. (Inthanon-LionRock Leveraging Distributed Ledger Technology to Increase Efficiency in Cross-Border Payments 2019)	
Issuance of central bank digital money	DLT as infrastructure for CBDCs	DLT based-Wholesale CBDCs	4 (AL - 2, GL - 2)	28. (Gorjón, 2022)	37. (Wang et al., 2022)
				29. (Lis & Sebastián, 2019)	38. (Opare & Kim, 2020)
		DLT-based Retail CBDCs	8 (AL - 7, GL - 1)	30. (Blockchain and Financial Services)	39. (Chorzempa, 2021)
				31. (Inthanon - LionRock tomBridge Building a multi CBDC platform for international payment, 2021)	
				32. (Project Aber: Joint Digital Currency and Distributed Ledger proof of concept Project. 2019)	
				33. (Project Jura: Cross-border settlement using wholesale CBDC 2021)	
				34. (WHOLESALE CENTRAL BANK DIGITAL CURRENCY EXPERIMENTS WITH THE BANQUE DE FRANCE 2021)	
				35. (Lloyd, 2022)	
				36. (Central Banks and Distributed Ledger Technology: How are Central Banks Exploring Blockchain Today? 2019)	
Regulatory oversight /supervisory functions and other ancillary operational management functions		Information registry and data sharing	4 (AL - 4, GL - 0)	40. (Blockchain and Financial Services)	
				41. (Central Banks and Distributed Ledger Technology: How are Central Banks Exploring Blockchain Today? 2019)	
		Digital KYC/AML processes	2 (AL - 2, GL - 0)	42. (Opare & Kim, 2020)	
				43. (Blockchain and Financial Services)	
				44. (Inthanon - LionRock tomBridge Building a multi CBDC platform for international payment, 2021)	
				45. (WHOLESALE CENTRAL BANK DIGITAL CURRENCY EXPERIMENTS WITH THE BANQUE DE FRANCE 2021)	

Table 5. 8 Thematic distribution of published work

RQ2: DLT application in Central Bank Payment Functions

This section discusses the findings of the research to address (RQ5): What are the specific applications of DLT in central bank payment system functions? and the subset research questions for each application including (RQ5.1): What is the motivation behind adopting DLT in the specific use case? And (RQ5.2): What DLT platforms are used, and what algorithm consensus are implemented in the proof of concepts, pilots, and projects considered in the literature pool?

This question seeks to understand the specific applications of DLT in central bank payment systems functions and whether research has moved from conceptual propositions to practical development and testing in real-world scenarios.

5.4.4.1 DLT–based Interbank payment rails operated by central banks.

This theme pertains to the application of DLT as the financial market infrastructure (FMI) operated by central banks to facilitate funds-only transfer between participating agents. The theme is widely discussed across grey literature and has been cited in one academic literature in the final pool [25GL and 2AL]. The theme encompasses two identified applications: *DLT-based domestic Real-Time Gross Settlement (RTGS) systems* and *DLT-based cross-border interbank payment and settlement arrangements.*

The following section provides a narrative synthesis of themes for each identified application of DLT-based Interbank payment rails operated by central banks. For each use case, the section examines the motivation, the role of the central bank in the DLT arrangement, and the DLT platform and consensus algorithm, where applicable. It also provides insight into where the applications offer significant benefits and where they only offer marginal or no benefits relative to the conventional and centralized systems used by central banks for their payment systems functions. Each section begins with an overview of the conventional systems currently used by central banks in the use case. By offering a comprehensive analysis of the use of DLT in the financial market infrastructure, this section aims to provide insight on where the applications offer significant benefits and where implementations only offer marginal or no benefits relative to centralized and conventional systems used by central banks for their payment system functions.

5.4.4.1.1 DLT-based domestic Real-Time Gross Settlement (RTGS) systems.

i) ***RTGS system without DLT***

According to the Committee on Payment and Settlement Systems, a large-value payment system (LVPS) is typically used for processing high-priority and large-value payments (The Bank for International Settlements, 2015). Such payment systems are categorized as systemic, given that a failure in the system can result in disruptions in the financial system. Consequently, most central banks assume the crucial responsibility of overseeing and operating LVPS to ensure safety, efficiency, and stability in the financial system (Ahiabenu, 2022).

According to M. Khan and Roberds (2001), a real-time gross settlement system is “a type of payment system where all transactions involve the transfer of central bank funds from the paying bank's account to the receiving bank's account.” Large-value payment systems can take different forms, and two common examples are deferred net settlement systems and RTGS systems. In recent years, many central banks have shifted away from deferred net settlement systems, which settle transactions on a net basis at the end of a predefined cycle (Priem, 2018) and moved towards RTGS systems. These systems allow for immediate or near-immediate settlement of funds and assets between financial institutions on an individual gross basis and are more efficient and secure (Mañalac et al.). The rapid expansion of volumes and values processed by large value payment systems has been a significant factor driving the transition from deferred net settlement systems to RTGS systems (Bech et al., 2008). The adoption of an RTGS system is preferred because it mitigates settlement risk that could lead to contagion effects in the financial system if deferred net settlement systems were used instead. In addition, the RTGS model eliminates the interbank settlement risk that could arise from participant defaults, thus ensuring financial stability (Bech et al., 2008).

In a standard RTGS system for funds-only transfers, banks interact with one another through the central bank, which acts as a central hub. The central bank is responsible for maintaining settlement accounts, issuing settlement instruments, and has significant flexibility in determining the terms and conditions under which banking system reserves are made available, providing it with a potent mechanism for implementing monetary policy. This arrangement places the central bank at the center of the payment system (Mills et al., 2016).

Wang et al. (2018) highlight that typical RTGS systems include three essential capabilities: gross settlement, instruction queues, and gridlock resolution. The gross settlement feature of the RTGS ensures that transactions are settled in real-time or near real-time, provided the corresponding paying bank has sufficient liquidity. The instruction queue function on the other hand involves the transfer of pending orders to an outgoing queue if the paying bank has insufficient liquidity. This capability ensures that the counterparty receiving bank obtains real-time or near real-time settlement, even when the corresponding paying bank does not have sufficient liquidity to meet its obligations. Lastly, the gridlock resolution refers to the ability to resolve a situation in which failure of some transfer instructions prevents the settlement of many other instructions. In this scenario, the RTGS system employs a liquidity-saving mechanism (LSM) to unlock the stalled payments and restore the smooth flow of settlements. Figure 5.7 presents a simplified diagram depicting the relationships and connections among the principal actors in an RTGS system where a single intermediary, typically the central bank, serves as the settlement entity. Despite this simplified model, payment systems often involve more complex arrangements within and between payment tiers, involving commercial banks, other non-bank payment service providers, and clearing houses (Committee on Payment and Settlement Systems, 2003).

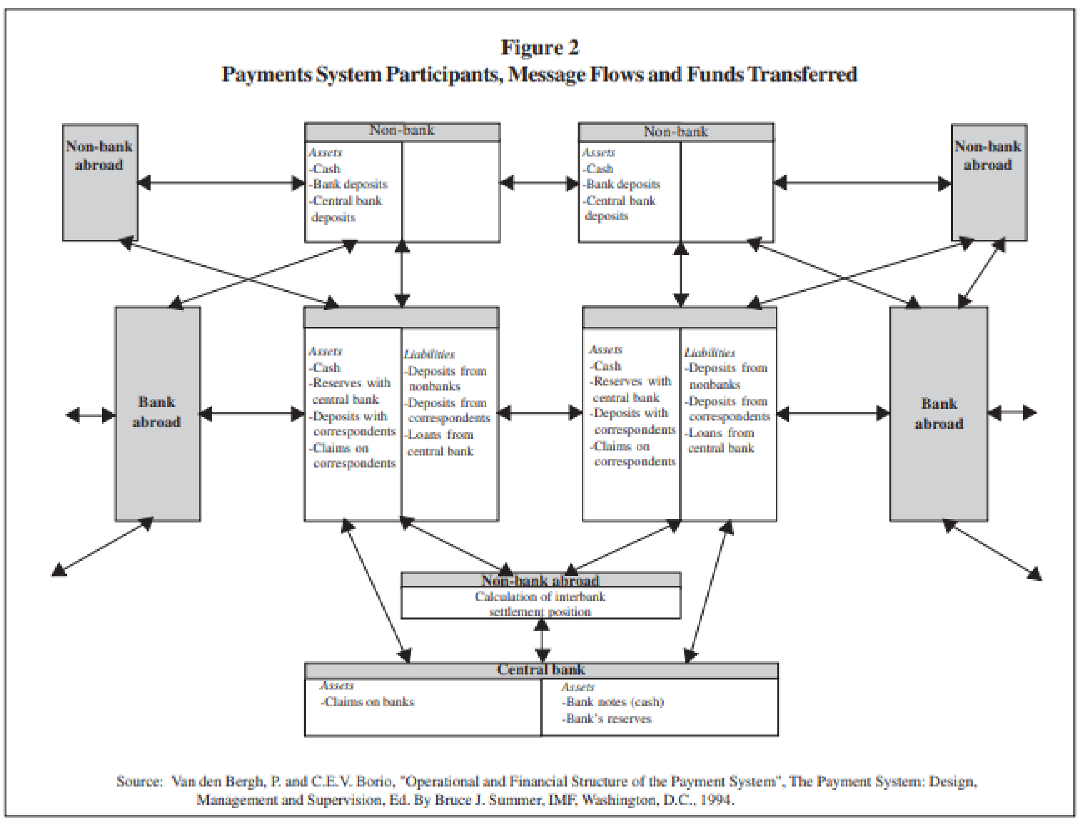


Figure 5. 7 relationships and linkages among the key players in an RTGS system

In this stylized RTGS system, participating agents such as banks interact with each other through the central bank, which acts as the central hub. While each participating agent maintains its own ledger, the central hub maintains the authoritative record of all transactions settled through the central bank. In a settlement transaction, the paying bank's account is debited, while the receiving bank's account is credited at the central bank (Committee on Payment and Settlement Systems, 2003).The centralized role of central banks in conventional payment systems is emphasized in the RTGS system arrangement, as the central bank maintains settlement accounts (Khiaonarong & Liebenau, 2009), issues settlement instruments, and has considerable leeway in determining the terms and conditions under which it makes banking system reserves available, giving it a powerful tool for implementing monetary policy and stabilizing the interbank money market in times of stress (Mañalac et al., n.d.). In contrast, in a DLT-based domestic RTGS system, reserve accounts are replaced with reserve "wallets," and the central bank is transformed from being the sole intermediary to one of the nodes in the network (Shabsigh et al., 2020).

ii) ***DLT-based domestic Real-Time Gross Settlement (RTGS) systems.***

This section provides an overview of four select proofs of concept and pilots for DLT-based domestic Real-Time Gross Settlement (RTGS) systems, drawn from reports and white papers in the final literature pool before discussing the themes corresponding to the research questions.

Garratt et al. (2017) report describes a proof-of-concept project, named Project Jasper Phase 1&2, which was developed collaboratively by Payments Canada, Bank of Canada, R3 and Canadian commercial banks. The project aimed to investigate the feasibility of using DLT for domestic RTGS systems and evaluate whether such a system could fulfill the key requirements of a financial market infrastructure, as set out in the Principles of Financial Market Infrastructure (PFMI). The platform was built on the Ethereum protocol, and the central bank's role in the system was to issue digital depository receipts that could be used for exchange and settlement by participating financial institutions. Phase 1 of the project successfully demonstrated the transfer of value between participants, but it failed to provide the required settlement finality for a core settlement system. Furthermore, as per the report's findings, the adoption of previous versions of public permissionless DLT systems did not yield a net advantage compared to the present centralized systems. To address the probabilistic settlement challenge, the project moved to Phase 2, which employed an alternative consensus model on the Corda platform that assigned the central bank a "notary node" function. Phase 2 also introduced a liquidity savings mechanism (LSM) similar to what is in conventional RTGS systems to reduce liquidity requirements for participating financial institutions.The project's conclusion was that additional improvements in technology capabilities are necessary to meet the PFMIs for any wholesale interbank payment settlement system. As of 2022, the project is not yet in the production stage (McCormack et al., 2022).

In the white paper PROJECT KHOKHA published in 2018, a collaborative proof of concept project utilizing distributed ledger technology (DLT) for interbank payments settlement in South Africa was described. The project was developed and tested in a production environment with the aim of building a DLT-based RTGS system, followed by a data-driven simulation exercise to assess its performance in terms of privacy and scalability in a realistic environment. The platform was built on Quorum, a private permissioned Ethereum blockchain. The central bank played a role in issuing the tokenized South African Rand used for settlement between participating financial institutions and provided oversight but did not have operational involvement in validating transactions. The project successfully demonstrated the technical feasibility of conducting wholesale payments between participating agents while maintaining regulatory monitoring by the central bank. The performance of the system was compared against the current South African interbank settlement system.

Project Stella is a joint research project of the European Central Bank and the Bank of Japan Payment systems. It is about liquidity saving mechanisms in a distributed ledger environment (2017) and the white paper describes Project Stella as a collaborative research project. The proof-of-concept was designed to test whether the capabilities that encompass a typical RTGS system would operate effectively on DLT systems. The study's findings indicated that a domestic RTGS system based on DLT could satisfy the performance standards of present high-value payment systems.

In another project, the Project Ubin Singapore Dollar (SGD) on Distributed Ledger (2016) report, the authors investigated the potential use of DLT for RTGS features. The main aim of the project was to assess the practicability and consequences of employing a tokenized variant of the Singapore dollar on a DLT system, along with recognizing the essential elements for forthcoming enhancements. The experiment was conducted using a private Ethereum DLT protocol, and the Monetary Authority of Singapore issued tokenized Singapore dollars on the DLT network. According to the report's findings, the pilot study showed the potential to eliminate a central infrastructure operator in a DLT-based RTGS system.

5.4.4.1.1.1 Motivations for Adopting DLT-Based Domestic RTGS Systems (RQ5.1)

This section aims to respond to the research questions related to the adoption of DLT-based domestic Real-Time Gross Settlement (RTGS) systems. The research questions focus on the motivation behind adopting DLT-based RTGS systems and the DLT platforms and consensus algorithms applied to the projects identified in the final literature pool.

The MLR resulted in 16 papers (or 59% of the total pool) which mention or explore the potential benefits of a DLT-based domestic RTGS system over the conventional RTGS systems.At the outset, it is worth mentioning that a key finding of the MLR is that the motivations for investigating DLT-based domestic RTGS systems across different proof-of-concept projects are very consistent and the projects have several shared commonalities.

The research findings indicate that a recurring theme in the motivation for adopting DLT-based domestic RTGS systems is the potential efficiency benefits of such systems. DLT-based domestic RTGS systems can eliminate operational and financial inefficiencies and frictions inherent in traditional RTGS systems. Researchers have identified various benefits of DLT-based domestic RTGS systems, including improved settlement speed (Mills et al., 2016), reduced complexity (especially in multiparty, cross-border transactions) (Mills et al., 2016), decreased need for reconciliation across multiple recordkeeping infrastructures (Mills et al., 2016; Dashkevich et al., 2020), improved service and overall operational efficiency (Dashkevich et al., 2020), more efficient collateral management and potential cost savings (Lis & Sebastián, 2019), elimination of the need for centrally maintained back-up systems (Dashkevich et al., 2020), reduced back-office costs by automating various settlement processes (Garratt et al., 2017), reduced likelihood of costly errors and disputes between participating financial institutions , improved automation through the use of smart contracts (The Bank of Canada & Monetary Authority of Singapore , 2019), and increased liquidity efficiency (Monetary Authority of Singapore & The Association of Banks in Singapore, 2017).Although the documents widely recognizes the potential for DLT-based domestic RTGS systems to enhance efficiency over conventional RTGS, Lis & Sebastián (2019) notes that it is uncertain to what extent DLT can improve the efficiency of present RTGS systems in wholesale payment systems. Additionally, (McCormack et al., 2022) notes that it is challenging to evaluate the capabilities of a DLT solution to reduce operating expenses associated with exception processing without implementation in a production environment.

The research identified improved resilience and security as the second most frequent theme on the potential benefits of DLT-based domestic RTGS systems over traditional RTGS systems. All sixteen articles on DLT-based RTGS domestic systems included in the final pool mention or explore the advantages of enhanced resilience and security, alongside improved efficiency, as a key motivation for adopting DLT-based RTGS systems. The documents discuss the benefits of enhanced resilience and security from four perspectives. First, using DLT as a backup to the domestic interbank payment system can enhance the organizational resilience of payment infrastructure (Burgos et al., 2017). Second, the decentralized architecture of DLT can enhance the architectural resilience of payment system infrastructure, as the failure of a single node does not affect the system's operational continuity (Burgos et al., 2017), (STELLA, 2017). Third, DLT can improve security, as the technology is fundamentally different from other technologies and cannot be attacked using the same attack vectors used to corrupt traditional systems (Mills et al., 2016). Lastly, DLT can offer improved network resiliency through distributed data management (Mills et al., 2016).

Some articles also discuss the potential benefits of regulatory efficiency improvement that could result from the adoption of DLT-based domestic RTGS systems. They highlight that DLT could enable more efficient real-time monitoring of transactions, which would allow regulators to perform their oversight functions more effectively (Dashkevich et al., 2020). Furthermore, the transaction audit trail enabled by DLT-based RTGS systems could enhance efficiency in resolving false positives tied to sanctions screening (Garratt et al., 2017). While regulatory efficiency improvement is considered a potential benefit of DLT-based domestic RTGS systems, it is not as frequently discussed as efficiency and resilience in the reviewed literature. The overall frequency of discussions related to regulatory efficiency improvement is low, compared to the other three themes.

In addition to the more commonly discussed themes of efficiency and resilience, other potential drivers for the adoption of DLT-based domestic RTGS systems have been identified in the document pool. These include the motivation by central banks to adapt financial market infrastructures (Gorjón, 2022;Dashkevich et al., 2020), the potential for broader access to payment systems by non-bank financial intermediaries (Lis & Sebastián, 2019; Dashkevich et al., 2020; South African Reserve Bank, 2018), extended operating hours through continuous operations (Lis & Sebastián, 2019), and improved risk management (Dashkevich et al., 2020; Deloitte, 2017). However, these motivations are not as frequently discussed in the documents as the themes of efficiency and resilience.

In conclusion, the research findings indicate that the potential benefits of DLT-based domestic RTGS systems are consistent across different proof-of-concept projects, with improved efficiency and enhanced resilience and security being the most frequently discussed themes. While other potential drivers for adoption, such as regulatory efficiency improvement and broader access to payment systems, have been identified, they are not as commonly discussed in the literature. Despite the potential benefits, it is still uncertain to what extent DLT can improve the efficiency of present RTGS systems in wholesale payment systems. Moreover, evaluating the capabilities of DLT solutions to reduce operating expenses requires implementation in a production environment.

Figure 5. 8 Themes on motivations for adopting DLT-Based Domestic RTGS Systems (NVivo extract)

(RQ5.2): What DLT platforms are used, and what algorithm consensus are implemented in the proof of concepts, pilots, and projects considered in the literature pool?

Table 5.9, below, indicates that there is a recurrent trend across the DLT-based domestic RTGS systems proof-of-concept and prototype projects included in the final pool to develop on permissioned DLT systems with access limited to a predetermined set of participating financial institutions (i.e., permissioned DLT system). This indicates that there is an acknowledgement of the necessity for central banks managing both the system and its participants, which could be attributed to apprehensions about security, privacy requirements, adhering to regulations, and ensuring effective governance of DLT-based domestic RTGS systems. The research findings also reveal that the use proof-of-work consensus algorithm is not suitable for DLT-based domestic RTGS systems due to the requirements of processing capacity and privacy. Instead, all the prototypes utilized DLT consensus protocols that used fewer processing resources and provided greater privacy. It was observed that only the initial stages and genesis pilots trialed permissionless networks. The findings suggest that the focus is on DLT-based domestic RTGS systems that can effectively handle large-value payments while maintaining privacy and security. Furthermore, the MLR findings indicate that central banks have a significant role in the governance and supervision of the DLT-based RTGS systems. This is demonstrated through their maintenance of a notary node across most pilots and projects considered, enabling them to perform their operational responsibilities in payment systems functions.

PROJECT	DLT PLATFORM
Project STELLA	Hyperledger Fabric V Version 0.6.1
Project ABER	Hyperledger Fabric
Project KHOKHA	Quorum
Distributed Ledger technical research in Central Bank of Brazil	Corda
Project JASPER	Corda
Project Ubin: SDG on Distributed Ledger	Quorum
Project Ubin phase 2	Quorum
Project INTHANON phase 1	Corda

Table 5. 9 DLT platforms used for DLT-based domestic Real-Time Gross Settlement (RTGS) systems.

The findings on DLT-based domestic RTGS systems indicates that the research has progressed beyond conceptual and insight-level proposals to actual development and testing in relevant environments. However, despite this progress, no live implementations of DLT-based domestic RTGS systems at the production level were identified. This may suggest that there are significant challenges in implementing these systems in real-world settings, potentially due to regulatory compliance, security concerns, or technological limitations. Further research is necessary to explore the underlying reasons for the absence of live implementations and to identify potential solutions to address these challenges.

5.4.4.1.2 DLT-based cross-border settlements arrangements.

This section discusses the second-order application under DLT–based interbank payment rails operated by central banks which is DLT-based cross-border settlement arrangements. It first presents an overview of the conventional cross-border settlement arrangements to set context, followed by a discussion of DLT-based cross-border settlements arrangements.

(a) Current designs of cross-border settlement arrangements

Cross-border settlement is defined as the process by which financial institutions domiciled in different countries exchange assets or currencies (Bank for International Settlements, n.d.). Cross border settlement arrangements can be classified into various types based on their operational and technical characteristics, including correspondent banking, closed-loop, infrastructure, and peer-to-peer models (Financial Action Task Force, 2016).

According to Financial Action Task Force, (2016), the correspondent banking model is the prevailing method for cross-border settlement compared to the other models. This arrangement facilitates the provision of payment services by payment service providers such as banks and fintech firms to their clients across different jurisdictions, without necessarily having a physical presence in those countries. In this model, a network of international financial institutions forms bilateral relationships by opening accounts with each other. Specifically, the respondent bank opens a Nostro account with the correspondent bank, which in turn opens a corresponding vostro account in the respondent bank's domestic currency. The terms "nostro" and "vostro" are used interchangeably and refer to the same account.

The correspondent banking arrangement is further categorised into three operational designs, including, nested correspondent banking, payable-through or pass-through accounts and the traditional correspondent banking model (Financial Action Task Force, 2016). Nested correspondent banking allows foreign financial institutions, or nested banks, to indirectly access a correspondent bank's services through a third party, which is the direct respondent bank (Committee on Payments and Market Infrastructures, 2016). The payable-through or pass-through accounts model, on the other hand, is characterised by accounts that are "maintained by a correspondent institution but can be operated directly by the customer of the respondent institution (Law Insider, 2021)". This model is different from the traditional correspondent banking and nested correspondent banking arrangements as it allows customers of the respondent bank to directly initiate transactions and have direct access to the correspondent bank's services. Finally, in the traditional correspondent banking model, the respondent bank maintains a deposit account with the correspondent bank, and the correspondent bank handles payment execution and/or processing on behalf of the respondent bank. This method does not allow customers of the respondent bank to directly access the correspondent banking account (Committee on Payments and Market Infrastructures, 2016). Payment requests are initiated by the bank client and then processed by the respondent bank, which determines the appropriate amount to debit from the customer's account or the cash payment to receive. The correspondent bank then executes the payment to the payee from the nostro account it maintains with the correspondent bank in the payee's country. Bilateral instructions to receive or pay funds are sent via the SWIFT (Society for Worldwide Interbank Financial Telecommunication) international messaging network, which uses pre-defined series codes that contain identifying data such as a bank/non-bank payment service provider code, a country code, a location code, and a branch code (Qiu et al., 2019). These payments are processed, cleared, and settled using payment processing, clearing, and settlement systems such as Automated Clearing House (ACH) and central banks. (Qiu et al., 2019).

In nested correspondent banking, the correspondent bank acts as an intermediary, whereby the respondent bank's account is opened with a respondent bank of the correspondent bank. In payable-through or pass-through accounts, the correspondent bank allows the respondent bank's customers to transact using the correspondent bank's own account. In the traditional correspondent banking design, the correspondent bank and respondent bank have a direct relationship. The respondent bank maintains a deposit account with the correspondent bank. When a bank client requests a cross-border payment of X amount, the respondent bank determines the amount to debit from the customer's account or the cash payment to receive and instructs its correspondent bank to execute and/or process the payment to the payee from the nostro account it maintains with the correspondent bank in the payee's country. The bilateral instructions to receive or pay funds between the respondent and the correspondent bank are sent via the SWIFT international messaging network. The SWIFT system employs pre-defined series codes, which include several identifying data characters such as a bank/non-bank payment service provider code, a country code, a location code, and a branch code (Qiu et al., 2019). A swift code format can be represented as AAAA BB CC in the example below. AAAA is the bank code, BB is the location of the PSP (payment service provider), CC is the head office of the PSP, and CC is the specific branch. Payments are processed, cleared, and settled after payment instructions are delivered via modern payment processing, clearing, and settlement systems such as Automated Clearing House (ACH) and central banks (Qiu et al., 2019).

Figure 5.9, adopted from Zetzsche et al (2014), illustrates a stylised flow of cross-border payments in a traditional correspondent banking arrangement.

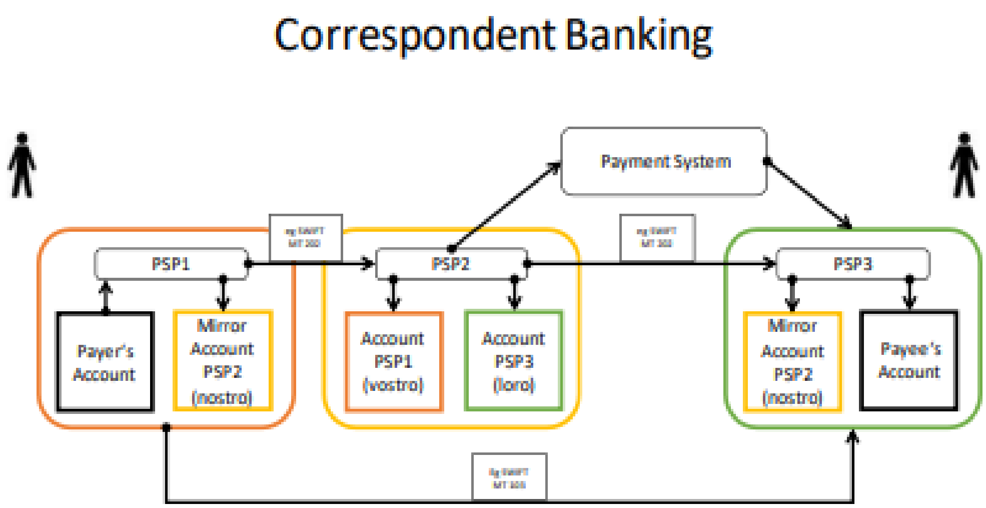


Figure 5. 9 Flow of cross-border payments in a traditional correspondent banking arrangement. Source: (Zetzsche et al., 2021)

In addition to the traditional correspondent banking model, there are other emerging alternatives for cross-border payments such as the cross-border expansion of "closed loop" proprietary systems, interconnecting domestic payment infrastructures and peer-to-peer" mechanisms based on DLT (Bank for International Settlements, 2018). The closed loop model involves direct connection between the payer and payee through the same payment operator, such as Western Union and MoneyGram. Non-bank payment providers like PayPal, Alipay, and WeChat also use a closed loop model for domestic payments. These alternatives are still in their infancy and experience inherent cross-border messaging, clearing, and settlement complexities (Bank for International Settlements, 2018).

The interconnecting domestic payment infrastructures model, on the other hand, involves cooperation between central banks to create a cross-border payment system (Zetzsche et al., 2021). Directo a México is an example of such a model, which enables the transfer of funds between US and Mexican bank accounts. However, the development and linking of payment infrastructure across borders requires significant investment and policy guidance. The CPMI highlights that the development and linking of payment infrastructure across borders in principle requires significant investment and significant policy guidance (Bank for International Settlements, 2018).

(b) DLT- based cross-border settlements arrangements.

This section provides an overview of DLT-based cross-border settlements arrangements and presents four select proofs of concept and pilots for DLT-based cross-border settlements arrangements, drawn from reports and white papers in the final literature pool before discussing the themes corresponding to the research questions.

Central banks have conducted assessments of DLT as a potential means of facilitating cross-border settlement, a function that has not traditionally been within their purview, given that most central banks exclusively offer settlement to financial institutions based in their respective countries (Zetzsche et al., 2021). The attributes and inherent DLT properties of decentralized synchronized ledger, immutability, interoperability, and smart contracts render DLT particularly suitable for enabling cross-border settlement arrangements between various financial institutions by facilitating the secure and efficient transfer of value across borders, without relying on intermediaries or third parties. Various experiments for DLT-based cross-border settlements have been primarily explored and trialed by both public and private sector initiatives, including central banks and private sector entities, with the use of CBDCs and stable coins as settlement currencies.

According to Bank for International Settlements, (2021), "a group of private sector firms, along with the Banque de France, the BIS Innovation Hub, and the Swiss National Bank, collaborated to investigate the potential of using wholesale central bank digital currencies (wCBDCs) to facilitate cross-border settlements between commercial banks in France and Switzerland. "This was conducted on a DLT platform that was operated by a third-party. The experiment successfully demonstrates the technical feasibility of utilizing wCBDCs for cross-border settlements.

The Bank of Canada and Monetary Authority of Singapore, on the other hand, conducted an experiment to build a proof-of-concept solution that enables "cross-border, cross-currency, and cross-platform atomic transactions based on a smart contract". They interlinked their individual experimental DLT-based domestic interbank payment systems, namely Project Jasper and Project Ubin for this purpose (Bank of Canada & Monetary Authority of Singapore, 2019). The project utilized an intermediary approach, assuming that the two countries' respective DLT RTGS systems would run on different DLT. The project demonstrated that atomic transactions can be conducted between different countries, currencies, and platforms without the need for a central authority, demonstrating the technical feasibility of this approach.

Project Stella Phase 3 aimed to explore how the use of DLT, HTLC smart contracts, and an interledger protocol could enhance cross-border payments by eliminating credit risk in payment processes (ECB, 2019). Safety was a primary focus of the project, and the prototype showed the feasibility of using HTLC to synchronize settlement between several types of ledgers, including centralized ledgers.

In 2019, the Hong Kong Monetary Authority and the Bank of Thailand collaborated on Project Inthanon-Lion Rock (Hong Kong Monetary Authority & Bank of Thailand, 2019). The project aimed to investigate "real-time cross-border transfers and atomic Payment-versus-Payment (PvP) settlements on distributed ledger technology (DLT)". The project also demonstrated the viability of using a common central bank digital currency (CBDC) platform to enable cross border settlement between the two countries.

5.4.4.1.2.1 Motivations for Adopting DLT- based Cross-Border Settlements Arrangements (RQ 5.1)

This section aims to respond to the research questions related to the adoption of DLT- based cross-border settlements arrangements: The research question RQ5.1 focuses on the motivation behind adopting DLT-based cross-border settlements arrangements and the DLT platforms and consensus algorithms applied to the projects identified in the final literature pool.

The final literature pool was analyzed to explore the motivations for adopting DLT-based cross-border settlements arrangements. A key finding is that most proof-of-concept and prototype projects analyzed in the final grey literature pool share motivations for exploring and testing DLT-based cross-border settlement arrangements. Specifically, these projects aim to address existing frictions in current cross-border settlement arrangements.

The analyzed documents consistently suggests that central banks and financial institutions seek to improve process efficiency and reduce costs when exploring DLT-based cross-border settlement arrangements. This theme is a prevalent and recurrent factor across projects included in the final grey literature pool, underscoring the importance of process efficiency and cost-effectiveness as key drivers in the adoption of DLT-based cross-border settlement systems. The primary components of efficiency encompass real-time gross settlement of cross-border funds transfers, payment versus payment of FX settlement, enhanced liquidity efficiency through multi-currency liquidity saving mechanisms, and transaction atomicity. Moreover, automated interfaces in DLT-based cross-border settlements arrangements lead to a reduction in compliance costs and costs of reconciliation, thereby contributing to increased efficiency. For participating financial institutions, reducing nostro-vostro liquidity costs is another aspect that is considered in terms of efficiency gain. Mills et al. (2016) and Hong Kong Monetary Authority & Bank of Thailand, (2019) are among the sources that reaffirm these findings.

The findings indicate that risk mitigation is the second most common theme regarding the potential benefits of DLT-based cross-border settlement arrangements. The analyzed central bank proof of concept projects and prototypes included in the final grey literature pool consistently explores ways to leverage the capabilities of DLT to mitigate various types of risks, such as liquidity, credit, transaction delay, settlement finality, counterparty, and operational risks associated with cross-border payments. To mitigate such risks, some projects propose the deployment of various mechanisms such as HTLC smart contracts that automate and synchronize settlement (Saudi Arabian Monetary Authority & Central Bank of the United Arab Emirates, 2019), on-ledger and third-party escrows, and conditional payment channels that lock fund's purpose (Bank of Canada & Monetary Authority of Singapore, 2019). The safety of cross-border payments is also postulated to improve by using DLT-based systems which provide a decentralized and distributed ledger that lowers the risk of a single point of failure and increases the architectural resilience of the system (Mills et al. 2016). The proof of concept and prototypes included in the final grey literature pool demonstrate that the risks associated with cross-border payments could potentially be mitigated, and safety could be improved by leveraging DLT capabilities and deploying payment and enforcement mechanisms that synchronize payments and lock funds. These findings are consistent across sources, including Bank of Canada & Monetary Authority of Singapore, (2019), Saudi Arabian Monetary Authority & Central Bank of the United Arab Emirates, (2019), and Bank for International Settlements, (2021).

Interoperability is another emerging theme, albeit less frequent, highlighting the potential benefits of DLT-based cross-border settlements arrangements. Interoperability refers to "the ability of systems to communicate and coordinate seamlessly with other systems (Heckel & Waldenberger, 2022)", including centralized payment systems, other central bank digital currencies, and digital assets. Select prototypes in the final grey literature pool place emphasis on interoperability of designed DLT-based cross-border settlement arrangements due to the heterogeneity of DLT platforms in the future. Bank for International Settlements, (2021), Saudi Arabian Monetary Authority & Central Bank of the United Arab Emirates, (2019) and Bank of Canada & Monetary Authority of Singapore, (2019) are among the sources that underscore the importance of interoperability in DLT-based cross-border settlement arrangements.

The findings indicate that, beyond the widely discussed themes of process efficiency, cost reduction, risk mitigation, and interoperability, there are additional drivers for exploring DLT-based cross-border settlement arrangements. The literature has identified motivations such as central banks' desire to implement a more efficient private cross-border system with extended operational hours (Shabsigh et al., 2020) and the potential for improved compliance with local regulations. However, these factors are not as commonly discussed in the literature as the previously mentioned themes. The findings highlight the need to consider a range of potential drivers for the adoption of DLT-based settlement systems, and the importance of exploring these factors in future research on the topic.

In addition to the more commonly discussed themes of enhanced process efficiency and reduced costs, risk mitigation and interoperability, other potential drivers for the exploration of DLT- based cross-border settlements arrangements have been identified. These include the potential benefits of a new private cross-border system that could offer greater efficiency and longer operational hours compared to existing RTGS systems (Shabsigh et al., 2020) and improved compliance with local regulations (Bank for International Settlements, 2021). However, these motivations are not as frequently discussed in the literature as the other themes.

In conclusion, the findings reveals that the adoption of DLT-based cross-border settlement arrangements is motivated by the need to address frictions in current cross-border settlement systems, primarily process inefficiency and high costs. The analyzed literature consistently suggests that central banks and financial institutions seek to improve process efficiency and reduce costs when exploring DLT-based cross-border settlement arrangements. Risk mitigation is another key theme, with DLT-based systems seen to mitigate various types of risks associated with cross-border payments. Interoperability is an emerging theme, highlighting the potential benefits of DLT-based cross-border settlement arrangements.

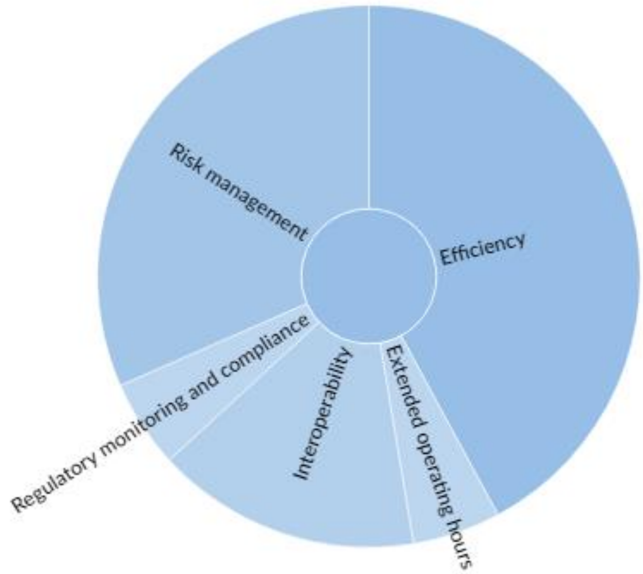


Figure 5. 10 Themes on motivations for adopting DLT- based cross-border settlements arrangements (NVivo extract)

(RQ5.2): What DLT platforms are used, and what algorithm consensus are implemented in the proof of concepts, pilots, and projects considered in the literature pool?

This section aims to respond to the research questions related to the adoption of DLT- based cross-border settlements arrangements:

Figure 5.11 illustrates that several DLT platforms were utilized in the proof-of-concept and prototype projects for DLT-based cross-border settlement arrangements that were considered in the final grey literature pool. The examination showed that Hyperledger Fabric was the most employed platform out of the seven prototypes that were analyzed. It should be noted that some projects, such as Project Stella developed by the European Central Bank and the Bank of Japan, compare different platforms for the same use case. The extensive usage of Hyperledger Fabric in DLT-based cross-border settlement arrangements may suggest that the platform is a popular and dependable choice for such applications. The comparison of various platforms for the same use case in other projects implies a growing interest in optimizing platform selection and enhancing the efficiency and effectiveness of DLT-based cross-border settlement arrangements.

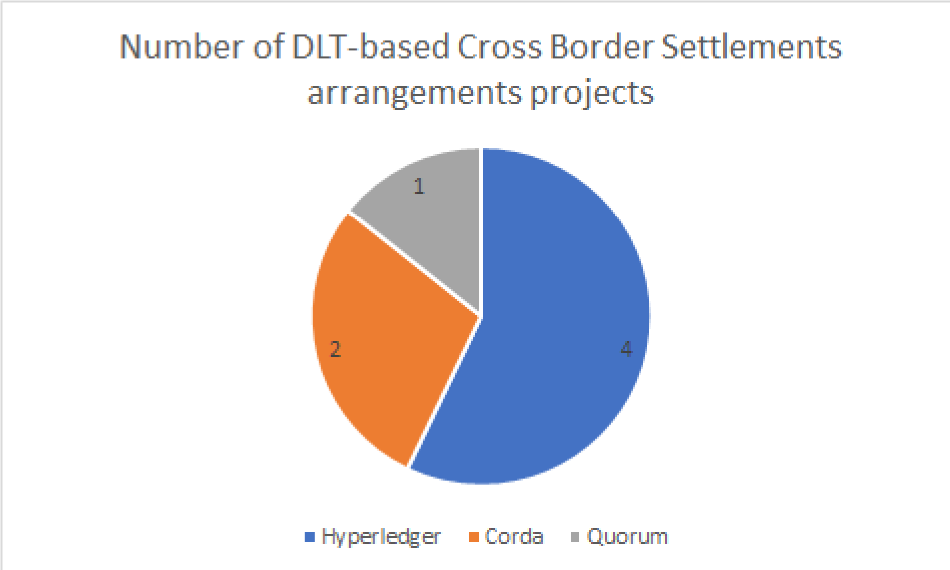


Figure 5. 11 DLT platforms used for DLT- based cross-border settlements arrangements.

In addition, the findings reveal that several consensus algorithms were implemented in the reviewed projects, including Byzantine fault tolerance and proof of stake. The selection of consensus algorithm was typically influenced by the specific needs of the use case and the chosen DLT platform. Notably, the design of proof-of-work and the open transaction ledger utilized in Bitcoin protocols were found to be inadequate for DLT-based cross-border settlement arrangements, as well as domestic RTGS proof-of-concept and prototype projects, due to concerns over processing capacity and confidentiality.

The findings also reveal the significant role of central banks in DLT-based cross-border settlement arrangements. Central banks played multiple crucial roles in the reviewed projects, including the initiator, coordinator, and regulator. All projects examined from the final grey literature pool were initiated by a central bank. Central banks also facilitated coordination among various stakeholders involved in the project, including financial institutions and technology providers.

The findings suggest that research on DLT-based cross-border settlement arrangements has progressed from conceptual and theoretical proposals to actual development and testing in real-world environments. The inclusion of proof-of-concept and prototype projects in the final grey literature pool is evidence of this progress. However, it is important to note that most of the reviewed projects are still in their pilot stages of development and have not been fully implemented. As such, future research should focus on addressing the challenges that arise during the implementation phase and evaluating the actual impact of DLT-based cross-border settlement arrangements on the financial system.

5.4.4.2 Issuance of Central Bank digital money

This theme pertains to the use of DLT by central banks to issue CBDCs. This topic is widely discussed across the grey literature and has also received the most attention in academic literature, as evidenced by the documents in the final pool [9 GL and 3 AL]. This theme includes one second order application, which is DLT as infrastructure for CBDCs, and it is further subdivided into two third-order specific applications: DLT-based wholesale CBDCs and DLT-based retail CBDCs. The following section presents a narrative synthesis of the various themes within the use of DLT as infrastructure for CBDCs that emerge from the literature. The section begins with a description of the central banks' role in issuing central bank money and the different CBDCs designs.

DLT-based CBDCs

In addition to operating and supervising payment and settlement systems, central banks are responsible for issuing and circulating central bank money. In most monetary systems, banknotes and commercial bank reserves are the fundamental types of central bank money (Dashkevich et al., 2020). In a payment system context, bank notes issued by central banks can serve as a means of payment for individuals and businesses, while commercial bank reserves refer to funds held in central bank accounts by commercial banks to satisfy legal reserve requirements and enable interbank payment settlements. The issuance and circulation of central bank money is critical to promoting the seamless operation of the payment system and ensuring financial stability. However, the competition in the fintech space from private startups and Big Tech firms, in the development of digital currencies, could challenge the conventional monetary system and the role of central banks. In response, central banks have been exploring the issuance of digital currencies in the form of CBDCs as a sustainable and innovative complement to cash to retain control over monetary and financial stability. For example, as the usage of cash declines, the Swedish central bank has been exploring the possibility of creating a DLT-based "e-krona" as an alternative form of physical money issued by the central bank (Sveriges Riksbank, 2017). In the face of a future financial market with distributed infrastructure, it is essential for central banks to enable access to their currency on DLT systems to ensure the stability of financial systems through neutral and risk-free monetary assets for settlements. The fundamental question remains on the role that central bank money should play in an economy that is rapidly shifting towards digitalization.

According to Barrdear and Kumhof (2020), CBDCs are a digital representation of a country's fiat currency that is issued by the central bank and can be used as a means of payment and a store of value. "The

Money Flower: A Taxonomy of Money" presented below presents a taxonomy of money, categorizing different forms of money including CBDCs according to their key characteristics.

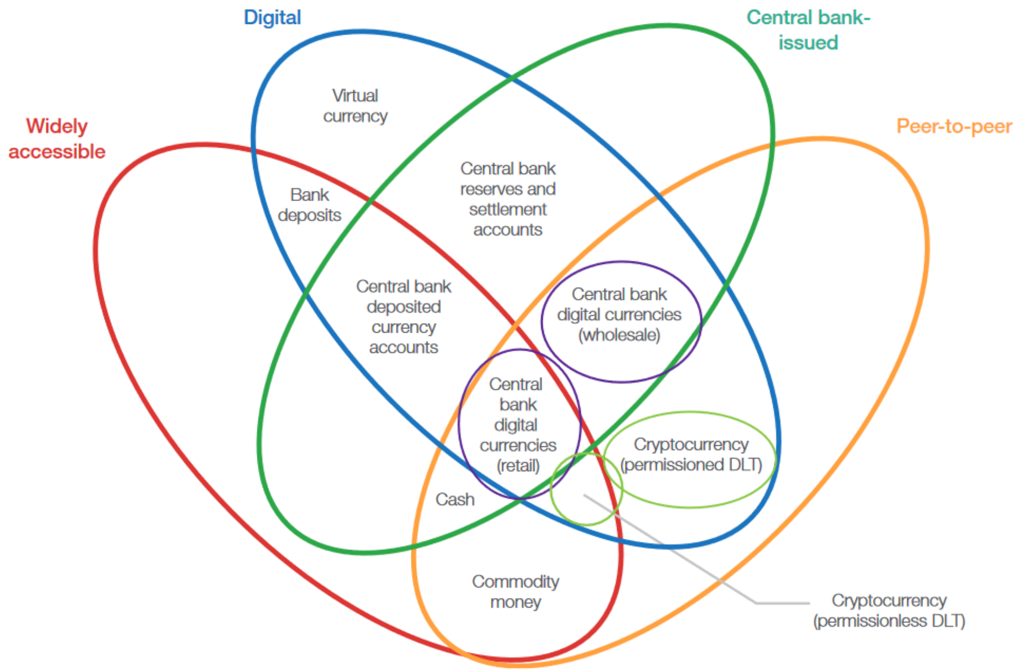


Figure 5. 12 The money flower: a taxonomy of money. Sources: M Bech and R Garratt, "Central bank cryptocurrencies," BIS Quarterly Review, September 2017; As seen in "Cryptocurrencies: looking beyond the hype", BIS Annual Economic Report 2018.

Lis and Sebastián (2019) highlight that CBDCs can be deployed on DLT, centralized systems, or a combination of both. The selection of DLT versus non-DLT infrastructure for CBDC implementation depends on a range of factors including the central bank's specific goals, the intended audience, regulatory considerations, and the current state of technology. However, in all the CBDC pilots examined in the final literature pool, the participating central banks issued digital tokens using DLT infrastructure. Guo et al. (2022) suggest that among the technical options available for CBDCs, DLT has the greatest potential to drive a fundamental transformation of the financial system rather than simply a reconfiguration.

In the reviewed literature, CBDCs are classified as **wholesale** and **retail** CBDCs. Wholesale CBDCs are limited to settlement scheme participants, such as commercial banks and clearing houses, and function within the two-tier banking system where the central bank maintains reserves and provides liquidity to commercial banks, which subsequently use them to settle interbank transactions (Guo et al., 2022). The Banque De France's (2021) report on Wholesale Central Bank Digital Currency Experiments delineates several variants of wholesale CBDCs. These include reserve-based wholesale CBDCs, which are similar to the electronic reserves that commercial banks already hold with central banks and token-based wholesale CBDCs which have unique characteristics as they are represented through digital tokens and are exchanged on DLT platforms. Two proofs of concept and pilots of wholesale DLT based CBDCs, selected from the white papers and reports contained in the final grey literature pool Is described below.

Bank of Canada & Monetary Authority of Singapore, (2019) report discusses the wholesale CBDCs experiment conducted by the Bank of Canada and the Monetary Authority of Singapore (MAS) in collaboration with JP Morgan and Accenture. The purpose of the project was to explore the feasibility of cross-border payments across different blockchain platforms using cross-currency CBDCs (Canadian Dollar, CAD - Singapore Dollar, SGD). The prototype employed cross-chain atomic swaps enabled by Hash and Time Locked Contracts (HTLCs), which synchronize all actions through smart contracts, allowing for the secure and efficient exchange of value across different blockchain networks. In the Jasper-Ubin proof of concept, Bank A in Singapore ran its own node on the Quorum DLT platform while Bank B in Canada ran a node on the Corda DLT platform. An intermediary bank, Intermediary A, was appointed to facilitate the payment process on both DLT platforms. The experimental setup successfully demonstrated the technical feasibility of a cross-border interledger high-value transfer using wholesale CBDCs.

Bank for International Settlements, (2021) report discusses Project Inthanon-LionRock, which is a wholesale CBDC experiment between the Hong Kong Monetary Authority (HKMA) and the Bank of Thailand (BOT) aimed at exploring the use of CBDCs to facilitate cross-border HKD-THB payments versus payments (PvP) between banks in Hong Kong and Thailand. To achieve this, a cross-border corridor network on R3 blockchain was designed, which enabled participating banks to perform cross-border payments and foreign exchange on a peer-to-peer basis. Each participating bank runs a node on its domestic DLT platform and the corridor network, while the respective central banks also run nodes on the corridor network. The prototype demonstrated the feasibility of using wholesale CBDCs for cross-border payments.

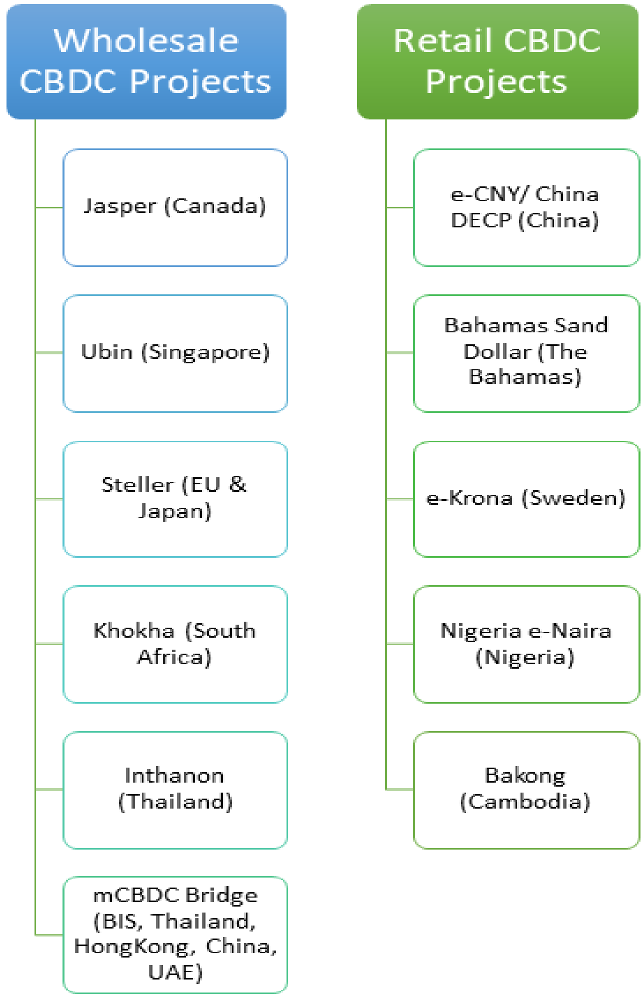


Figure 5. 13 some prominent CBDC projects. Adopted from Blockchain application for CBDC, (Sethaput & Innet 2023)

The following section describes Retail CBDCs and a pilot of retail DLT based CBDCs, selected from the white papers and reports contained in the final grey literature pool.

The e-CNY project is an example of a retail CBDC (Bank for International Settlements, 2021). The project was initiated by the People's Bank of China (PBC) in 2017 and the first pilot began in 2020. Its objective is to enhance the efficiency and security of payment and settlement systems and increase access to financial services for the public. The e-CNY is not intended to replace the existing payment system, but rather to complement it. The e-CNY is issued by the PBC to commercial banks, which distribute them to the public in a two-tier system. The e-CNY system is a hybrid of identified (account-based) and anonymous (token-based) models. The e-CNY prototype was successfully built, demonstrating the technical feasibility and basic functionalities of a CBDC. The rolling pilots across various cities illustrate the PBC's desire to test the functional and non-functional impact of retail CBDCs.

5.4.4.2.1 What is the motivation/Value proposition behind adopting DLT based CBDCs? (RQ 5.1)

This section aims to respond to the research questions related to the adoption of DLT based CBDCs. The research questions focus on the motivation behind adopting DLT based CBDCs and the DLT platforms and consensus algorithms applied to the projects identified in the final literature pool. A key finding of the research is that despite central banks of different countries having varying reasons for researching and experimenting with CBDCs, the review identifies common themes emerging from both academic and grey literature included in the final pool. Hence, it can be inferred that there is a consensus among researchers and experts regarding the benefits and value of CBDCs, which drives the central banks to explore this technology.

The research has identified a primary and recurrent theme among central banks' motivation for researching and experimenting with DLT based CBDCs, which is to improve the efficiency of the payment system. This theme is echoed across all the 12 papers included in the final pool that discusses or explores the implementation of DLT based CBDCs. This can infer consensus among industry participants and researchers about the potential benefits of DLT based CBDCs in enhancing payment system efficiency. The payment efficiency goals of central banks on either consumer or interbank levels are reflected in the choice of design of the CBDC, whether retail or wholesale models. The literature consistently identifies the primary motivation for wholesale CBDCs as the improvement of cross-border interbank payments through the elimination of inefficiencies inherent in conventional correspondent banking models, or to enhance domestic financial market infrastructure by improving the efficiency of linked functions, such as liquidity management, securities trading, and settlement between banks (Gorjón, 2022;Opare & Kim, 2020; FCA's 2017; Bank for International Settlements, 2021). Retail CBDCs, on the other hand, are expected to drive efficiency by saving the cost of issuing, handling, and distributing physical banknotes are expected to enhance efficiency by reducing the cost of issuing, handling, and distributing physical banknotes (Lloyd, 2022; Bank for International Settlements, 2021). While some projects in the final grey literature pool have reported achieving their intended payment efficiency goals, it is vital to conduct further research and evaluations to determine the scope and constraints of implementing CBDCs at a production level. This highlights the importance of more thorough testing and evaluation to ensure the secure and effective implementation of CBDCs. Although CBDCs can improve payment efficiency, it is necessary to carry out more research and evaluation to ensure their feasibility, particularly in real-world production environments.

The research identifies the preservation of monetary sovereignty and the maintenance of the relevance of the monetary system in an increasingly digital economy as the second most common theme among the motivations of central banks in exploring and experimenting with CBDCs. This finding is supported by evidence from several papers included in the review (Wang et al., 2022), (Opare & Kim, 2020), (Lis & Sebastián, 2019), (Bank for International Settlements, 2021), (Lloyd, 2022), and (Chorzempa, 2021).

A primary motivation for central banks to issue wholesale CBDCs is to offer financial institutions a risk-free and neutral monetary asset for settling interbank payments. This allows central banks to directly manage and regulate the creation and distribution of digital central bank money, thereby supporting their control over monetary policy and supply (Bank for International Settlements, 2021). In addition, wholesale CBDCs and retail CBDCs function as digital replacements for privately issued money and cryptocurrencies, which central banks consider threats to their monetary sovereignty due to their distinct unit of account and potential to encourage capital flight (Wang et al., 2022). This finding underscores the importance of exploring CBDCs as a tool to ensure that central banks can effectively regulate and maintain their control over monetary policy and supply in an increasingly digital economy.

The research also identifies the potential of DLT based CBDCs to promote financial inclusion as a common theme among the motivations of central banks in exploring and experimenting with CBDCs. This finding is supported by several papers included in the final pool (Wang et al., 2022), (Opare & Kim, 2020), (Blockchain and Financial Services), (Bank for International Settlements, 2021), (Lloyd, 2022), (Chorzempa, 2021). The analyzed documents indicate that DLT-based CBDCs can promote financial inclusion, particularly in emerging economies that have underdeveloped financial infrastructure. Retail CBDCs can enable unbanked individuals to access central bank money, thus reducing their dependence on cash and increasing their use of digital payments (Chorzempa, 2021). This, in turn, can have broader implications for financial inclusion by increasing access to other financial services. These are among the reasons why emerging market countries have been at the forefront of advocating for retail CBDCs (Boston Consulting Group, 2020).

Figure 5. 14 Emerging Markets are embracing CBDC development. Source: Central Banks report, BCG analysis 2020

The analyzed documents also frequently discusses the issuance of DLT-based CBDCs as a substitute for cash, which is experiencing a decline in some countries (Opare & Kim, 2020; Lis & Sebastián, 2019;), Saudi Arabian Monetary Authority & Central Bank of the United Arab Emirates, (2019); Lloyd, 2022.This trend of declining cash usage is observed in many economies, and central banks are exploring DLT-based CBDCs as a feasible alternative (Lis & Sebastián, 2019). The literature discusses this in the context of countries with modern developed monetary systems. This finding suggests that CBDCs may play a vital role in the future of the monetary system as cash loses its popularity among consumers and businesses. Consequently, central banks are motivated to explore and experiment with CBDCs to remain abreast of changing trends in the economy and provide a digital replacement for conventional currency.

Other less frequent themes on central banks' motivations for researching and experimenting with DLT-based CBDCs encompass DLT-based CBDCs as a “digital and efficient economic tool, and CBDC as a means to address economic fluctuation and stagnation caused by emergencies (Wang et al., 2022)”. Furthermore, central banks aim to modernize financial market infrastructures in response to the requirements of the digital economy by introducing CBDCs (Gorjón, 2022).

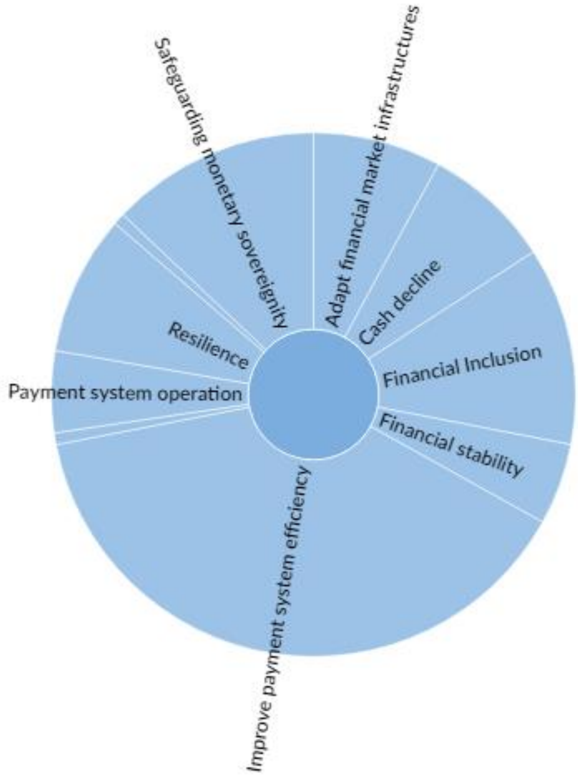


Figure 5. 15 Themes on motivations for the motivation/Value proposition behind adopting DLT based CBDCs (NVivo extract)

(RQ5.2): What DLT platforms are used, and what algorithm consensus are implemented in the proof of concepts, pilots, and projects considered in the literature pool?

Consistent with other applications of DLT-based interbank payment rails, several DLT platforms and consensus algorithms have been employed in pilot projects for DLT-based CBDCs, including Corda, Hyperledger Fabric, and Ethereum, as indicated by DLT-based CBDCs pilots included in the final grey literature pool. This indicates that central banks are investigating various DLT platforms to assess their potential in facilitating CBDCs, reflecting a range of technological solutions to address diverse needs. Nonetheless, further research is necessary to identify which platforms can provide the necessary scalability, security, and confidentiality to support the widespread adoption of CBDCs.

According to the findings based on the grey literature reviewed, it is evident that central banks have a pivotal role in the development, issuance, and regulation of DLT-based CBDCs. The documents emphasize the significance of central banks in supervising the CBDC design, setting up the necessary infrastructure for issuance, and managing the underlying technology.

The analyzed documents suggests that research on DLT-based CBDCs has progressed from conceptual and theoretical proposals to actual development and testing in relevant environments. The numerous pilot projects and experiments conducted by central banks and other stakeholders demonstrate a growing interest and commitment to exploring the potential of DLT-based CBDCs. However, the research also highlights the need for further research, particularly in areas such as scalability, security, and regulatory frameworks.

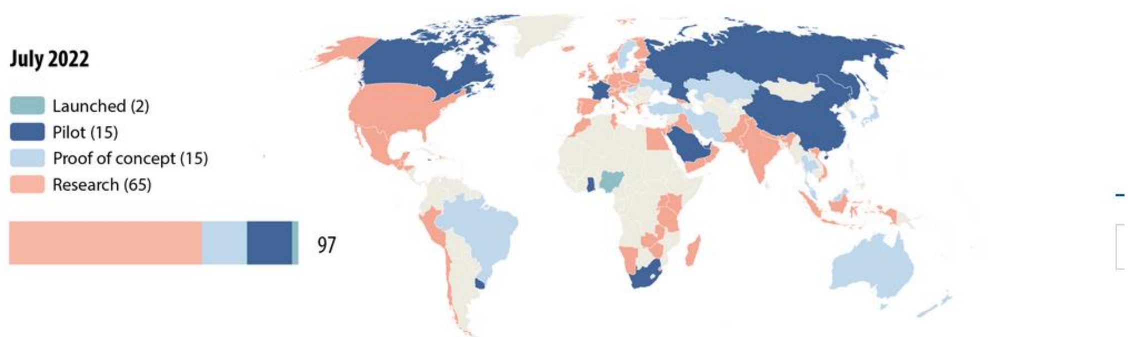


Figure 5. 16 Status of most advanced stage of development in each country for both retail and wholesale CBDC. Source: CBDC Tracker (cbdctracker.org), 2022

5.4.4.3 Regulatory oversight, supervisory functions, and other ancillary operational management functions

This theme pertains to the supervisory and regulatory tasks, along with other operational management functions, that central banks may perform as part of their payment system duties. The theme is the least discussed across grey literature and has been cited in one academic literature in the final pool [25GL and 2AL]. The theme encompasses two identified applications: i) Information registry and data sharing and ii) Digital KYC/AML processes.

The infrequent discussion of the supervisory and regulatory function theme in the reviewed grey literature suggests that there is limited attention being given to this aspect of central bank payment system functions in the context of DLT applications in central bank payment systems functions. However, the two identified applications under this theme, namely information registry and data sharing, and digital KYC/AML processes, highlight the potential for central banks to leverage DLT technology to enhance their supervisory, regulatory tasks, and other operational management functions.

i) **Information registry and data sharing**

The application of DLT in information registry and data sharing is discussed in a limited number of papers, with only one academic literature source being identified in the final pool (Opare & Kim, 2020) and two grey literature sources (Blockchain and Financial Services, (FCA's 2017); Central Banks and Distributed Ledger Technology: How are Central Banks Exploring Blockchain Today? 2019).

This application utilizes the inherent distributed database feature of DLT to store both transactional and non-transactional information, creating an alternative system for information and data sharing among financial institutions, regulatory bodies, supervisory institutions, and private sector organizations. According to Mills et al. (2016) the management of distributed data is widely recognized as one of the most compelling use cases of DLT across various domains. Unlike a centralized ledger system governed and operated by a single entity, DLT systems enable a unified, sequenced, and cryptographically secured log of records to be disseminated and processed by a network of diverse participants, promoting coordination in distributed systems. Although cross-organizational coordination has not yet achieved full interoperability between participants in payment systems, Project MADRE (cited in World Economic Forum, (2019), and Opare & Kim, (2020) is an illustrative example of a successful implementation of cross-organizational data sharing. Launched by Banque de France in 2017, Project MADRE explored the feasibility of using a DLT-based infrastructure to improve the efficiency of the interbank system by enabling "cross-organizational exchange of Single Euro Payments Area (SEPA) creditor identifiers between SEPA Direct Debit (SDD) scheme participants (European Payments Council, n.d.)." The SEPA creditor identifier register was previously centralized and managed by Banque de France. Further research may be needed to explore the practical implementation of such systems and to address any regulatory and supervisory challenges that may arise.

5.4.4.3.1 What is the motivation/Value proposition behind adopting DLT in Information registry and data sharing? (RQ 5.1)

The primary motivation for central banks' research and experimentation with DLT-based information exchange and data sharing is to improve the efficiency and automation of the processes involved in information exchange and data sharing processes. This is echoed across one academic literature (Opare & Kim, 2020) and three grey literature sources (Blockchain and Financial Services), (World Economic Forum, 2019) and (Mills et al., 2016) that discusses or explores the implementation of DLT application in information registry and data sharing across central banks. Mills et al. (2016) notes that despite the technology's potential to revolutionize the storage, record, and transfer of digital assets, most payment system market participants are focused on exploring ways to incorporate technology into already-established systems most of which involve data sharing among multiple network participants. The shared database model functionality that enables Information exchange and data sharing is, however, not unique to DLT systems. Other forms of distributed database management systems (DDBMS) would enable information exchange and sharing across financial institutions. However, DLT is proposed to offer greater efficiency and security benefits relative to the conventional distributed database management systems (DDBMS) (FCA's 2017).

The findings also identify central banks' research and experimentation with DLT-based information exchange and data sharing applications is also driven with the aim to improve regulatory oversight and compliance through real-time data access (World Economic Forum, 2019) and (Bank for International Settlements, 2021). Real-time data access, enabled through DLT-based interbank payment rails operated by central banks, and DLT as infrastructure for CBDCs applications can allow central banks to act as notary nodes that could validate transactions and have centralized views of transaction data between participating financial institutions. This heightened oversight could contribute to enhanced regulatory oversight. For instance, in Project Ubin, the central bank acts as a notary node to record and validate transactions. As a result, it gains a centralized and real-time view of the transaction data between participating financial institutions, leading to improved regulatory oversight. Furthermore, in DLT-based retail CBDCs applications, a notary node operated can provide the central bank with real-time visibility into the retail CBDC ecosystem, enabling the detection and prevention of financial crime and compliance monitoring (although this is often not a primary function of central banks).

Other motivations that are not unique to DLT based systems and are already provisioned for by conventional DDBMS are enhanced security and transparency of data sharing (Mills et al., 2016), (World Economic Forum, 2019) and increased data accuracy and completeness (World Economic Forum, 2019).

In conclusion, the findings reveals that central banks are motivated to research and experiment with DLT-based information exchange and data sharing to improve the efficiency and automation of the processes involved in information exchange and data sharing processes, as well as enhancing regulatory oversight and compliance. While some potential benefits considered are not unique to DLT systems, DLT is proposed to offer greater efficiency and security benefits relative to conventional distributed database management systems. This presents opportunities for future research to compare DLT-based information exchange and data sharing applications to conventional distributed database management systems in achieving efficiency and enhanced regulatory oversight and compliance objectives. Additionally, research could investigate the implementation challenges, costs, and risks of implementing DLT-based information exchange and data sharing applications.

ii) **DLT based-digital Know Your Customer (KYC) and Anti-Money-Laundering applications.**

The application of DLT for digital KYC/AML processes pertains to its application as a service support infra- structure that leverages DLT to track and share customers payment and identification information across financial institutions hence circumventing inefficiencies in the current KYC identity management applications that are used by financial institutions to prevent money laundering and other illegal activities (Malhotra et al., 2021) (Central Bank of Brazil, 2017), (World Economic Forum,2019). This application is less frequent in the publications compared to other use cases and has mostly been included as an addendum in conceptual papers and reports as opposed to implementation-based papers or any specific proof of concepts in the included white papers. These conceptual papers discuss the ideas, benefits, and adoption challenges of DLT-based KYC systems but do not provide implementation details or frameworks. For instance, FCA's (2017) discussion paper suggests that banks in a shared network can benefit from more effective transaction monitoring by assigning customers an identity and verifying their status using DLT. This verified identity can be shared between institutions, reducing data collection and verification effort duplication. Similarly, the Central Bank of Brazil (2017) discusses the use of DLT for KYC/AML processes to provide a unified view of users' digital identities and to give users control over data that can be shared with multiple banks, thereby optimizing costs incurred by firms in KYC/ AML processes. The report by Deloitte and the Monetary Authority of Singapore (2017) also acknowledges the possibility of establishing a verifiable repository for identities that can be utilized by various firms within a network, leading to a simplification of KYC compliance.

5.4.4.3.2 What is the motivation/Value proposition behind adopting DLT for Digital KYC/AML processes?

The research has identified a primary motivation among central banks for researching and experimenting DLT-based digital KYC/AML applications is to enhance efficiency and minimize duplication of effort in KYC compliance processes within a network of financial institutions (Central Bank of Brazil, 2017), (Deloitte and the Monetary Authority of Singapore 2017) (FCA's 2017). By leveraging DLT, customer payment and identification information can be tracked and shared across financial institutions, reducing duplication of data collection and verification efforts (Deloitte and the Monetary Authority of Singapore 2017).

Another motivation is enhancing transaction monitoring by assigning customers a verified digital identity that can be shared between institutions, reducing illicit activities (Blockchain and Financial Services) (FCA's 2017). Central banks also recognize the value of DLT in giving users control over their data, which can be shared with multiple banks, optimizing costs incurred in KYC and AML processes. Furthermore, the digitalization of unique government identity systems in DLT is seen as a potential driver of financial inclusion (Central Bank of Brazil, 2017). Despite the recognition of the benefits of DLT-based KYC/AML systems, there is a lack of implementation-based papers or specific proof of concepts included in the grey literature sources, indicating that more research is needed to evaluate the feasibility and implications of DLT-based KYC/AML systems.

5.5 Conclusion

The findings presented in this chapter aimed to provide a systematic approach for identifying DLT applications in central bank payment systems functions by analyzing both peer-reviewed academic publications and grey literature document sources. The research is focused on identifying the different applications, the research trends, and the sources of the research for each use case. The particular emphasis was on identifying the motivation behind adopting DLT in that particular use case, as well as the DLT platform, consensus algorithm and the role of the central bank for applicable use cases based on the available literature.

One of the key contributions of the study is the identification and categorization of DLT applications in central bank payment systems functions. The study identified a range of use cases related to DLT-based applications in central bank payment system functions including: DLT-Based Domestic RTGS Systems, DLT-based cross-border settlements arrangements, DLT as infrastructure for CBDCs, information registry and data sharing and DLT based -digital KYC/AML applications. This systematic approach can serve as a starting point for further research and development of DLT applications in the payment system functions of central banks.

Additionally, the study provides valuable insights into the current state of research on DLT applications in central bank payment systems functions. While most of these use cases were identified and discussed in both academic and grey literature sources, the practical implementation of DLT-based applications in central bank payment systems was mostly discussed in grey literature sources. This emphasizes the significance of considering both academic and grey literature sources when investigating DLT applications in central bank payment systems functions, as they can provide complementary perspectives on the practical and theoretical aspects of the use cases.

Another significant contribution of this study is the identification of the motivation for adoption DLT in central bank payment system functions. A primary and recurrent theme on motivation across the different use cases is to improve efficiency compared to conventional systems or ways of performing the payment system function. This finding can provide valuable insights for policymakers and researchers in understanding the potential benefits of DLT and inform their decision-making processes.

In addition to identifying the key motivations behind the adoption of DLT in central bank payment system functions, this study also identified the different DLT platforms and consensus algorithms used for each use case, and the role of the central bank in implementing DLT-based applications. The range of DLT platforms and consensus algorithms that have been identified indicates that there is no universal solution that can be applied in all cases. Policymakers and practitioners must carefully consider the unique needs of their use case and choose the appropriate DLT platform and consensus algorithm to maximize the potential benefits. Moreover, the role of the central bank in implementing DLT-based applications varied across applications, with some use cases such as DLT based interbank payment rails and DLT as infrastructure for CBDCs requiring a more active role from the central banks. This highlights the importance of understanding the specific needs of each use case when implementing DLT-based applications in central bank payments systems.

In conclusion, the research has demonstrated the potential of DLT-based applications in central bank payment systems, highlighting the need for continued research and experimentation in this field. The study has contributed to the existing literature by identifying the different use cases, research trends, and sources of research, and key motivations behind the adoption of DLT in central bank payment systems functions. The research has provided a foundation for future research in this area and can inform policymakers and central banks on the potential use of DLT-based applications in central bank payments systems.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

This concluding chapter of the thesis discusses the contributions to knowledge in methodology, knowledge, and practice. The limitations of the research are also acknowledged, and recommendations for further research are provided. Lastly, the chapter discusses the broader impact of the research on the practical application of DLT (Distributed Ledger Technology) in payment, clearing and settlement systems.

6.1 Summary on the research topic

Before presenting the main findings and conclusions, this section serves as a recap of the research area and objectives. The focus of this PhD research is on payment, clearing and settlement systems, which are critical components of financial markets that allow for the transfer of funds and assets to meet financial obligations. Despite significant advancements in payment system technology, centralized payment systems have continued to be the dominant architecture for payment systems. DLT is being investigated as a possible platform for the upcoming generation of payment systems, owing to its potential benefits, including operational streamlining, regulatory efficiency, and risk mitigation. The technology is however still in its infancy, and its widespread adoption and implementation are hindered by various barriers. While there is a substantial amount of non-peer-reviewed literature on the use of DLT in the broader financial services industry, there is a scarcity of academic research on the current state of DLT applications, their benefits, and challenges, within specific payment, clearing and settlement contexts. Furthermore, there is still a lack of in-depth understanding of its potential use cases within the specific context of central bank payment system functions.

The overarching aim of this thesis was to assess the barriers to adoption and implementation of blockchain-based payment systems, and to conduct a comprehensive analysis of the current state-of-the-art and practice of DLT applications in central bank payment system functions, with a focus on specific applications. With a goal to expand existing empirical research and contribute to bridging the knowledge gap on this emerging subject.

6.2 Summary of Key Findings and Conclusions for each research objective

The descriptive chapters on payment, clearing, and settlement systems; and DLT in payment, clearing, and settlement systems form the background of this thesis. These chapters are based on comprehensive review of relevant academic and grey literature sources, aiming to identify and synthesize the relevant information on the conventional payment, clearing and settlement systems and DLT. The resulting insights offer a foundational understanding of the context in which DLT innovation is taking place and provide a basis for the subsequent analysis presented in the empirical chapters of the thesis.

The first empirical chapter research objective was to identify the socio-technical barriers to adoption and diffusion of blockchain-based payment systems and the proposed solutions to address them. Three research questions were formulated to achieve this objective. The following section presents the main findings corresponding to each research question.

(RQ1): The first research question seeks to investigate the current state of research on the barriers of blockchain-based payment systems.

The SLR found that academic interest in blockchain technology beyond cryptocurrencies started to emerge after 2017, as all the extracted papers that met the predefined inclusion criteria were published after 2017, despite performing a systematic search for papers that date back to 2009. Additionally, the upward trend in the number of academic publications on blockchain payment systems since 2017 suggests that there is a growing interest in exploring the potential of blockchain beyond cryptocurrencies, and this is likely to lead to more innovative applications of the technology in the future.

(RQ2) and (RQ3): The second research question was focused on identifying the barriers to adoption and implementation of blockchain-based payment systems, while the third research question aimed to explore the solutions proposed by the literature to address those barriers.

The SLR identified barriers across each of the five dimensions of a social-technical system: technological, infrastructure, institutions, cultural, and markets/user preferences dimensions. Barriers within the technological dimension received the most coverage in the reviewed literature on blockchain-based payment systems. Several barriers were identified within the immature technological designs theme in this dimension including scalability, inefficiency of public blockchain in processing micropayments, security threats and vulnerabilities, and volatility of cryptocurrencies. There are corresponding solutions proposed and evaluated for each barrier, indicating that researchers and practitioners are actively working towards overcoming these challenges. However, there is still need for further empirical research to evaluate the effectiveness of these proposed solutions and to explore other barriers within the various dimensions.

In the infrastructure dimension, network connectivity requirements were identified as a barrier, and the proposed solution to address this include the employment of the intermediary node mechanisms and offline transaction mechanisms. The SLR also identifies barriers within the institutions dimension including, lack of adequate regulatory frameworks, requirements for regulatory compliance and lack of clear governing structure as barriers to the adoption and diffusion of blockchain-based payment systems and the associated blockchain-based cryptocurrencies. A potential solution to overcoming regulatory barriers is a decentralized payment system that is both anonymous and secure, while also ensuring that privacy is maintained to a reasonable degree.

The SLR further reveals a research gap in coverage of barriers within the informal rules and norms, and power structures components of the institution's dimensions. Cultural factors such as societal norms and beliefs were also identified as potential barriers to the adoption and diffusion of blockchain-based payment systems and the associated blockchain-based cryptocurrencies, and further empirical research is necessary to explore their impact on the adoption and diffusion of blockchain-based cryptocurrencies in different contexts. Within the markets/user preferences dimension several barriers were identified, including rigidity of user preferences and routines, negative perceptions of the usefulness and ease of use of blockchain-based cryptocurrencies, lack of trust, and lack of knowledge and awareness. Further empirical research is necessary to evaluate these barriers in specific contexts and understand their interplay with other dimensions.

The second empirical chapter's overarching research objective is to provide a systematic analysis of DLT applications in central bank payment systems functions. The article has two main research questions.

(RQ4): The fourth question aims to explore the current state of research and development of DLT applications in central bank payment systems functions.

The finding suggests that most of the research on DLT applications in central bank payment systems functions is informed by grey literature sources, with only a small percentage (22%) being scholarly academic articles. This indicates that industry practitioners are leading the investigation into the application of DLT in this area. Regarding the research's thematic distribution, the findings identified three first-order themes and six third-order applications of DLT applications in central bank payment systems functions. The most widely investigated theme was operational responsibilities in payment and settlement systems, which includes the application of DLT-based interbank payment rails operated by central banks. The Issuance of central bank digital money which includes the application of DLT as an infrastructure for central bank digital currencies (CBDCs) was the second most extensively researched theme, with the highest level of interest on the academic literature included in the final pool. The theme of regulatory oversight and ancillary operational management functions including applications for information registry and data sharing and digital KYC/AML processes received minimal coverage, likely due to it being a secondary use case.

(RQ5): The fifth research question focuses on identifying specific applications of DLT in central bank payment systems functions. Additionally, there are two subset research questions, RQ5.1 and RQ5.2, that aim to identify the motivations behind adopting DLT in specific use cases and investigate the DLT platforms and consensus algorithms used in the literature pool, respectively.

The findings identified several use cases, including DLT-based domestic RTGS systems and DLT-based cross-border settlements arrangements, DLT -based CBDCs, information registry and data sharing, and DLT based - digital KYC/AML applications. The analysis also highlighted the variety of DLT platforms and consensus algorithms used, and the need to carefully consider the specific needs of each use case to maximize potential benefits. Additionally, the role of the central bank varied across applications, highlighting the importance of understanding the specific needs of each use case when implementing DLT-based applications in central bank payment systems.

6.3 Contributions

The area of DLT applications in payment, clearing, and settlement systems is still in its nascent stage of applications development, and there is a dearth of scholarly literature and empirical research available on this topic. In terms of our first overarching aim of identifying and evaluating social- technical barriers to blockchain-based payments, previous studies such as Trivedi et al. (2021), Ali et al. (2020), and Saheb & Mamaghani (2021) have mainly explored the potential of blockchain technology in the financial services sector without specifically focusing on blockchain-based payment systems and proposed solutions in the literature. Regarding the second overarching objective, which aims to analyze and categorize the various applications of DLT in central bank payment system functions, including insights into the motivations, DLT platforms used, and consensus algorithms for applicable use cases, the studies that are most closely related to this are Dashkevich et al. (2020) and Del Río (2017). The contributions outlined in this section are based on the research of these main authors and previously identified research gaps in this area as discussed in previous chapters.

First contribution

The first contribution to knowledge is made by discussing the existing payment and settlement systems. The literature on DLT frequently concentrates on the potential of DLT to revolutionize present payment and settlement systems; however, there is limited discussion about the current payment systems. This thesis provides a comprehensive and up-to-date review of the literature and industry reports sources in this area and synthesizes them to provide a detailed understanding of the context in which DLT innovation is taking place and identifying potential areas where DLT can address existing challenges. Furthermore, the chapter draws upon identified literature to draw the institutional and economic factors that impact innovation and competitiveness in payment and settlement systems. We illustrate all these using the UK payment system ecosystem case. This provides preliminary insights into the subject matter, which is presently scarce and not updated in the academic pool. By doing so, this thesis fills a gap in the existing literature and provides a valuable resource for scholars and practitioners interested in payment and settlement systems. Furthermore, the analysis and evaluation of the current systems provide a foundation for the subsequent chapters in which DLT applications in payment, clearing and settlement are analyzed.

Second contribution

The second contribution to knowledge is made through the provision of foundational knowledge and a systematic approach to comprehending the potential implementation of DLT in payment, clearing, and settlement systems. This discussion has primarily been limited to industry reports and discourse, as we did not come across any academic articles that explore the application of DLT in payment, clearing, and settlement systems in the depth and scope covered by this research. By synthesizing findings from a wide range of published and grey literature, this study provides a comprehensive overview of DLT applications in payment, clearing, and settlement systems. It discusses the technological components of DLT systems, potential configurations of DLT systems, and their implications for various stakeholders. This information can be valuable to both researchers and industry practitioners seeking to gain knowledge and insights into DLT applications in payment, clearing and settlement systems.

Third Contribution

The third contribution to knowledge is made through the application of socio-technical systems theory to the blockchain context in assessing the barriers of blockchain-based payment systems. To the best of our knowledge, the social-technical systems perspective has not been applied in any previous studies to evaluate the barriers of blockchain-based payment systems. It is therefore a novel contribution to the literature, as it provides a new lens through which to evaluate the barriers of blockchain-based payment systems, which can also be replicated across other blockchain applications.

The study's findings indicate that the application of the social-technical systems perspective is applicable to the blockchain context, and it offers a valuable approach for considering and identifying barriers that may not be apparent on a surface level. Furthermore, the social-technical systems theory recognizes the interdependence of social and technical factors in influencing the adoption and diffusion of innovations, thus offering a more intricate comprehension of the barriers to adoption in the context of blockchain-based payment systems.

In the context of blockchain-based payment systems, industry stakeholders have placed significant emphasis to the development of diverse types of blockchain systems, applications, and solutions to address the limitations of existing blockchain-based payment systems. For instance, alternative consensus protocols to the initial proof of work have been explored to address scalability and energy efficiency challenge. However, by employing the social- technical systems perspective the study's findings suggest there are other significant and latent barriers that require attention beyond the technical aspect. The socio-technical perspective also underscores the importance of recognizing the interrelatedness of barriers across multiple dimensions. The research findings reveal instances where the factors within the technical and social dimensions of blockchain-based payment systems do not function optimally together, creating barriers to adoption of blockchain-based payment systems. For instance, a key property of public blockchain systems is the immutability of data. This could conflict with requirements for regulatory compliance, for example the GDPR’s “Right to be Forgotten (RtbF)” provision that gives individuals the right to erasure of their personal data. This highlights the need for an integrated approach to identifying and addressing barriers in blockchain-based payment systems that recognizes the interplay between technical and social factors, in line with sociotechnical system theory's principle.

Conversely, the study also contributes to social-technical systems research by demonstrating its applicability in the context of blockchain-based payment systems. It provides evidence of how this perspective can be applied to assess the barriers to adoption and implementation of blockchain-based payment systems. This approach could serve as a model for future research that examines the barriers to adoption and implementation of blockchain applications in various contexts beyond payment systems.

Fourth Contribution

The fourth contribution to knowledge is made through the identification of unique barriers to adoption and implementation of blockchain-based payment systems, which were not identified in previously considered reviews. By specifically analyzing blockchain-based payment systems and limiting the data sources to "blockchain-based payment systems literature" through the constructed search string: this study draws targeted insights that are specific to this context, as opposed to broader reviews on financial services or banking industry that do not delve deeply into this specific context. To the best of the researcher's knowledge, this is the first study to adopt a narrow focus on blockchain- based payment systems. Other SLRs take a broad approach to blockchain adoption in the financial services industry or cryptocurrency. This has led to the identification of barriers that are unique to this context. One such barrier is the inefficiency of public blockchain in processing micropayments, which has not been previously highlighted in SLRs focusing on the adoption of blockchain in the broader financial services industry.

The identification of barriers to blockchain adoption across multiple dimensions including (technological, infrastructure, institutional, cultural, and market/user preferences) is also a contribution to literature as, no other study has considered these exact dimensions in-depth for this context. While previous studies have identified barriers in some of these dimensions, the present study provides a more comprehensive description of the barriers in a payment systems context and aggregates them in a matrix hence provides a more nuanced understanding of the challenges faced by the industry in adopting blockchain-based payment systems. This has led to the identification and discussion of existence of other barriers that have either not been thoroughly discussed in earlier research or have been underestimated in their impact on blockchain adoption. For instance, within the technology dimension, while previous studies have identified the immaturity of technological designs as a barrier, the present study has recognized the importance of the supporting infrastructure required for implementation. The absence of a robust physical infrastructure can cause network latency, system downtime, and slow processing times, which can make it less attractive to potential users. Similarly, the lack of supportive financial infrastructure can make it difficult to transfer funds seamlessly, limiting adoption and implementation. Moreover, the availability of a comprehensive knowledge infrastructure is crucial in ensuring that users have the skills to operate and maintain the system effectively, yet this aspect has not received any coverage in the literature pool considered. In the infrastructure dimension, the study has identified network connectivity requirements as a barrier, particularly in areas with unreliable and intermittent network connectivity. In the institution dimension, the study has identified the lack of clear governing structure as a barrier to the widespread adoption and utilization of blockchain-based payment systems. The identification of these unique barriers by considering these dimensions further reinforces the novelty of this study, as it provides new insights into latent barriers that need to be considered and must be addressed to achieve widespread adoption and implementation of blockchain-based payment systems.

Fifth Contribution

In addition to identifying barriers, the research also presents contribution to knowledge by considering proposed solutions for each barrier. In the current academic literature, proposed solutions for blockchain-based payment systems are dispersed across various sources and there has been no study that aggregates them. This study explores the solutions proposed in existing literature as countermeasures for the barriers to blockchain-based payment systems corresponding them to the identified barrier where applicable. This approach sets the study apart as the first SLR on blockchain-based payment systems that considers corresponding solutions proposed for each barrier.

This contribution is important because exploring potential solutions to overcome the identified barriers to the adoption and implementation of blockchain-based payment systems is equally important alongside the identification of the barriers which has been the focus of most studies. By considering proposed solutions for applicable barriers, the study provides a more comprehensive understanding of the extent of the barriers and potential solutions and their effectiveness. This is particularly valuable to practitioners seeking to implement blockchain-based payment systems while encountering various obstacles, as well as policymakers interested in understanding how these concerns can be addressed. Additionally, this contribution is crucial for researchers who seek to further advance the knowledge base on blockchain-based payment systems. By exploring proposed solutions for each barrier, the study can help researchers identify gaps in the literature and develop new and innovative solutions to overcome these barriers. Furthermore, the study's approach of considering proposed solutions can serve as a basis for future research on the effectiveness and feasibility of these solutions in practice.

Sixth Contribution

Regarding methodological contribution, the thesis applies a unique systematic approach to selecting central bank white papers, policy documents and industry reports on DLT applications in central bank payment systems functions. The multivocal literature review (MLR) approach employed to identify and select the sources highlights its potential application in emerging research areas, such as DLT in central bank payment systems, where diverse opinions and viewpoints exist, and academic literature lags industry development. The absence of prior research on DLT application in central bank payment systems function adopting this specific approach of document selection, as revealed by the researcher's thorough review of the existing literature, serves to underscore the novelty of the study. The use of official publications, such as white papers, enhanced the reliability and credibility of the research, as these publications undergo review and approval by the central bank's management before publication. Furthermore, the use of thematic analysis with software support in NVivo is a notable methodological contribution to academic literature on DLT. This approach provides a more systematic and rigorous way to analyze the vast amounts of data available on DLT applications in central bank payment system functions. It allows for a more in-depth and comprehensive analysis of the data, leading to a better understanding of the topic. While thematic analysis has been used in other research contexts, its application to DLT applications in central bank payment system functions is relatively new. As such, this chapter makes a notable contribution to the existing literature by presenting a fresh perspective on this topic and offering practical guidelines on how thematic analysis can be effectively applied in this area of study.

Seventh Contribution

The seventh contribution to knowledge is through the comprehensive analysis and synthesis of a wide range of sources, including official publications from central banks and proof of concept and pilot projects, to provide insights on DLT applications in central bank payment systems functions. This research fills a gap in the existing literature, as there is no academic study that specifically focuses on the application of DLT in central bank payment systems functions to the best of our knowledge.

First, the research identifies and classifies the various applications of DLT in central bank payment systems functions, presenting a consolidated view of the field. This approach provides a more comprehensive and nuanced understanding of how DLT is being used in this context, which can be valuable for policymakers and practitioners who are interested in implementing DLT-based solutions in central bank payment systems. By understanding the different ways in which DLT can be used, they can make more informed decisions about which applications to prioritize and how to address the potential benefits and challenges associated with each one.

The classification of DLT applications in central bank payment system functions into operational responsibilities, issuance of central bank digital money, regulatory oversight/supervisory functions, and other ancillary operational management functions is also a novel way of categorizing DLT applications in central bank payment system functions. By identifying the distinct categories and analyzing them, this study contributes to a better understanding of the potential applications of DLT in central bank payment systems. This categorization can also serve as a useful framework for future research and implementation of DLT in central bank payment systems. By utilizing this classification matrix, researchers and industry practitioners can gain a better understanding of how these developments are emerging in the context of central banks' payment system responsibilities.

The analysis of the motivations, DLT platforms, and consensus algorithms for applicable use cases in central bank payment systems is also a relatively new area of research. By compiling evidence from various sources and presenting a ranking of the most common motivation, DLT platforms and consensus algorithms employed, this study can be useful for researchers and industry practitioners seeking to understand the current trends and make informed decisions regarding implementing DLT applications.

The study's categorization and discussion of DLT-based interbank payment rails operated by central banks into two distinct categories, DLT-based domestic RTGS (Real Time Gross Settlement) systems and DLT-based cross-border interbank payment and settlement arrangements, is another contribution to the literature as these tend to be aggregated in industry discourse on DLT and blockchain. This distinction allows researchers and industry practitioners to gain a better understanding of the distinct opportunities associated with each approach, enabling them to make more informed decisions regarding DLT adoption. Furthermore, by highlighting resilience as a primary driver for DLT-based domestic RTGS systems, the study offers a preliminary guide for evaluating the potential benefits of these systems. This finding suggests that there may be benefits to implementing DLT-based systems in addition to, or instead of, traditional domestic RTGS systems which are in most countries already considered efficient. Further research would be necessary to fully assess the benefits of implementing DLT-based systems for domestic RTGS. Similarly, the finding that efficiency is the primary driver for DLT-based cross-border interbank payment and settlement arrangements is also an important contribution to the literature. This insight echoes the inefficiency in current cross-border payments arrangements and suggests that DLT-based cross border arrangements may offer unique advantages in this context. This finding provides a valuable starting point for further research into the potential benefits of DLT-based cross-border interbank payment and settlement arrangements. Lastly, by identifying gaps in the existing literature and outlining potential areas for future research, the chapter could help drive further innovation and development in DLT and central bank payment systems.

6.4 Study Limitations

Although this research has contributed to the literature on blockchain-based payment systems and DLT applications in central bank functions, it is important to acknowledge its limitations.

First, the research relied on secondary sources of data. The use of secondary sources of data has certain inherent limitations since the accuracy and completeness of the information is dependent on the quality and the interpretation of the original sources. Furthermore, focusing solely on academic literature and document analysis may have missed updated practitioners' perspectives. To address these constraints, future study should draw on a broader range of sources, such as interviews or focus groups with industry practitioners.

Second, the study aimed to identify the applications and motivations of DLT in central bank payment systems and the barriers and solutions proposed of blockchain-based payment systems in the literature. However, it did not provide an empirical analysis of the actual implementation and adoption of these systems, as most are still in the production stage without live implementations. The real-world challenges and opportunities may differ from what is presented in literature and documents, and there may be barriers that arise during the implementation process. To gain a deeper understanding of the actual adoption and implementation of DLT in payment, clearing and settlement processes, further empirical research such as case studies would be necessary when the projects are in live implementation.

Finally, while the study aimed to provide an exhaustive identification and classification of existing DLT applications in central bank payment system functions, we acknowledge that DLT applications are constantly evolving, and new use cases are likely to emerge. It is therefore crucial that the research remains adaptable to these changes in the future.

Despite these limitations, the study provides a valuable contribution to the literature on blockchain-based payment systems and DLT applications in central bank functions.

6.5 Future Research Directions

This research presents opportunities for further exploration, indicating that there remains a considerable scope for future research. The study identified a broad range of barriers for blockchain-based payment systems within each of the dimensions of the social-technical systems lens. Each barrier should be investigated further to understand their overall impact on the effectiveness and consequent adoption and widespread diffusion of these systems.

Within the technological dimensions, further research could be undertaken to: (1) Compare the effectiveness of on-chain solutions versus off-chain solutions and evaluate the effectiveness of currently proposed solutions in resolving scalability challenges; (2) To explore the solutions for scaling blockchain-based payment systems without comprising the inherent security of these systems; (3) To explore how low performance devices can participate as nodes in blockchain-based payment systems; (4) Evaluate the effectiveness of proposed more efficient mining hardware and other energy sources in mitigating the undesirable environmental effects of public blockchain-based payment systems such as the bitcoin network.

In the infrastructure dimension, future research could be undertaken to: (1) identify the barriers related to knowledge infrastructures that facilitate the transfer of knowledge and expertise, such as national university systems (Weber and Rohracher, 2012),and investigate financial infrastructures, which involve the technical systems used for the flow of money (Edler et al., 2020) , within the broader social-technical systems context of blockchain-based payment systems.

In regards the institutional dimension, future research could broaden its scope beyond formal rules informal rules and norms, to include governance structures, and power dynamics. Moreover, to provide a more comprehensive understanding of the obstacles to widespread adoption and use of blockchain-based payment systems, it is necessary to investigate the interplay between the institution and technology dimensions. This could involve research that considers the complex relationship between the technological limitations of DLT systems and how this impact how it is regulated. By incorporating these elements, future research can provide a more integrated perspective on the barriers to adoption and utilization of blockchain-based payment systems.

Based on the SLR findings, there are barriers within the markets and user preferences dimension that can hinder the widespread adoption and utilization of blockchain-based payments and cryptocurrencies. However, the literature reviewed within this dimension may not be applicable to all contexts. Therefore, future research should explore context-specific barriers within the markets and user preferences dimension. This could involve investigating the factors that influence consumer attitudes and behaviors towards blockchain-based payments and cryptocurrencies, as well as the regulatory and legal frameworks that govern their use in different regions and industries.

Additionally, building upon the chapter on 'DLT niches and experimentation in Central Banks payment system functions' the researcher endeavors to keep track and update emerging applications and maturation of the implementations that progress to live productions. The current research primarily relies on secondary data sources, such as official publications by central banks on pilot and proof of concept projects. This underscores the importance of tracking the transition from pilot phases to live implementations, particularly focusing on the application of DLT–based Interbank payment rails operated by central banks and DLT as infrastructure for CBDCs.

Given the dynamic nature of these applications, the researcher plans to keep track of the motivations driving the exploration, DLT platforms employed and the consensus algorithms of these applications when implemented in live production. Future research will seek to compare whether the actual benefits derived from live implementation of these projects align with the initial motivations for their exploration and if not, how they pivot over time.

Notably, the researcher is now affiliated with the UK Financial Conduct Authority which collaborates with the Bank of England. This provides an opportunity to access data on the implementation of DLT by the Bank of England. This access to data positions the researcher in a plausible position to stay abreast of the latest developments, and to update the findings of the research to ensure they remain current and relevant.

6.6 Implications to Practice

The following key implications for practice are offered by this research, to contribute to the development of more efficient, secure, and transparent payment systems.

The study's findings suggest that Central Banks are exploring functions beyond their existing operational and oversight roles by exploring the application of DLT to perform new functions or functions that were conventionally carried out by financial institutions such as commercial banks in the tiered banking arrangements. For example, central banks are exploring the use of DLT as infrastructure to issue retail CBDCs either directly to consumers or through commercial banks. In the conventional monetary systems, central bank money is exclusively issued to commercial banks, who then distribute it among households and businesses. Additionally, central banks are exploring the use of DLT for cross-border settlement arrangements. In the conventional financial systems central banks only offer settlement services to domestic participants. Moreover, central banks are exploring the use of DLT for digital KYC and AML, which were traditionally conducted by commercial banks for their customers. Such functions represent a significant shift in the traditional roles of central and commercial banks, highlighting the need for financial institutions and industry practitioners to adapt to these changes and explore opportunities for collaboration with central banks. Financial institutions and regulators should stay informed and adapt to the changing landscape by exploring partnerships with central banks or adopting similar technologies to remain competitive.

The research also reveals that research and development of DLT applications in payment, clearing and settlement has shifted from conceptual propositions to live implementations. The technical feasibility of DLT applications has been demonstrated through various proof of concepts and pilot projects, with some central banks already planning real-world experimentation. One example is the e-CNY pilot program launched by the central bank of China. As more central banks experiment with DLT, a growing number of real-world use cases are anticipated to emerge in the coming years. Therefore, financial institutions and industry practitioners need to stay up to date with these developments and explore opportunities for collaboration and adoption to remain competitive in the market.

Lastly, the study's finding that technical barriers to DLT adoption have been largely addressed through proposed solutions in literature has significant implications for practice. For example, the scalability challenge has been prevalent in industry discourse but the proposed on-chain and off- chain solutions, proposed to scale transactions on DLT platforms like blockchains have already demonstrated effectiveness. The focus in the industry discourse should therefore now shifts to incorporate other social and regulatory barriers, such as regulatory and legal frameworks, and governance structures. Furthermore, practitioners should stay up to date with proposed solutions and engage in dialogue with regulators and other stakeholders to shape the necessary regulatory and governance frameworks. Collaboration among stakeholders will be key to ensure the successful adoption of DLT-based solutions in payment, clearing, and settlement processes. As such, industry practitioners should continue to monitor the developments in the field and actively contribute to shaping the future of DLT in payment systems.

APPENDICES

Appendix A: Code book extract

Name	Files	References
DLT as an infrastructure for CBDs'	12	158
Drivers	12	139
Adapt financial market infrastructures	7	11
Cash decline	9	11
Financial Inclusion	7	17
Financial stability	5	7
Improve payment system efficiency	12	54
Others	1	1
Payment system operation	3	7
Resilience	6	12
Risk management	1	1
Safeguarding monetary sovereignty	9	18
DLT-based payment rails operated by central banks	19	198
Wholesale payment systems	19	198
Cross border cross-border interbank payment arrangements	8	75
Drivers	8	69
Efficiency	8	42
Extended operating hours	1	1
Regulatory monitoring and compliance	1	7
Risk management	6	16
Domestic DLT- based RTGS systems	16	123
Drivers	16	104

	Adapt financial market infrastructure	3	3
	Broader Access	4	4
	Efficiency	14	50
	Extended Operating Hours	2	2
	Improved resilience and security	13	27
	Regulatory monitoring and compliance efficiency	5	11
	Risk management	4	7

Appendix B: Snapshot of Gray Literature

Source	Source Link	*Quality Assessment Questions				Quality Score
		Q1. Methodology - Does the source have a clearly stated aim?	Q2. Date - Does the item have a clearly stated date?	Q3. Authority of the source - Is the publishing organization reputable?	Q4. Novelty- Does it enrich or add something unique to the research	
Google	Care.pdf	2	1	2		5
Google	https://www.imf.org/-/media/Files/Publications/FTN063/2020/English/FTNEA2020001.ashx	2	2	2	2	8
Google	https://www.bis.org/publ/work1015.pdf	1	2	2	2	7
Google	https://www.bis.org/speeches/sp190207.htm					
Google	money-successfully-tested-861444					
Google	https://www.accenture.com/bg-en/services/blockchain/rtgs					
Google	https://www3.weforum.org/docs/WEF_Central_Bank_Activity_in_Blockchain_DLT.pdf	1	2	2	2	7
Google	https://www.redalyc.org/jatsRepo/5722/572261717001/html/index.html	2	2	0	2	6
Google	https://www.r3.com/blog/blockchains-and-central-banks-what-have-we-learnt/					
Google	https://www.bankofcanada.ca/research/digital-currencies-and-fintech/projects/					
Google	blockchain-based-payments					
Google	https://www.nthexception.com/2021/07/dlt-in-payments-and-settlements.html					
Google	fnality.html					
Google	https://www.ecb.europa.eu/pub/pdf/other/ecb.stella_project_report_september_2017.pdf	2	2	2	2	8
Google	72/gs-16-1-distributed-ledger-technology.pdf					
Google	https://thecommonwealth.org/sites/default/files/inline/CFT%20Chapter%203.pdf	2	2	2	2	8
Google	https://www.banque-france.fr/sites/default/files/media/2021/11/09/rapport_mnbc_0.pdf	2	2	2	2	8
Google	https://www.fnality.org/fnality-global-payments-insights					
Google	https://www.boj.or.jp/en/research/wps_rev/rev_2022/data/rev22e08.pdf	1	2	2	2	7
Google	idadFinanciera/22/4_FSR42_Divisas.pdf	1	2	2	2	7
Google	T/focusgroups/dfc/Documents/FGDFC_RA%20WG_Reference%20Architecture%20and%20Use%20	1	2	2	2	7
Google	Ledger-Technology-and-Blockchain-Fintech-Notes.pdf	2	0	2	2	6
Google	https://www.bankofengland.co.uk/financial-stability-in-focus/2022/march-2022					
Google	payments.pdf					
Google	https://www.icmagroup.org/assets/ICMA-DLT-and-blockchain-in-bond-markets-FAQ-220922.pdf					
Google	digital-currency-20220203.html	1	2	2	2	7
Google	system-f98f9a6de013					
Google	https://www.degruyter.com/document/doi/10.1515/ael-2019-0095/html?lang=en	2	2	2	2	8
Google	https://www.snb.ch/en/mmr/reference/project_jura_report/source/project_jura_report.en.pdf	2	2	2	2	8
Google	Clearing_and_Settlement	2	2	2	2	8
Google	https://www.bbvaresearch.com/wp-content/uploads/2019/11/Banking-Lab-DLT-CBDCs_edi.pdf	2	2	2	2	8
Google	https://consensys.net/blockchain-use-cases/finance/project-khokha/					
Google	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8751668/					
Google	https://www.iosco.org/library/pubdocs/pdf/IOSCOPD685.pdf					
Google	april-2021.pdf					
Google	https://www.sama.gov.sa/en-US/News/Documents/Project_Aber_report-EN.pdf	2	2	2	2	8
Google	istituzionali/2021-010/N.10-MISP.pdf	2	2	2	2	8
Google	https://www.citibank.com/tts/insights/articles/article191.html					

Appendix C: Data Extraction Snapshot

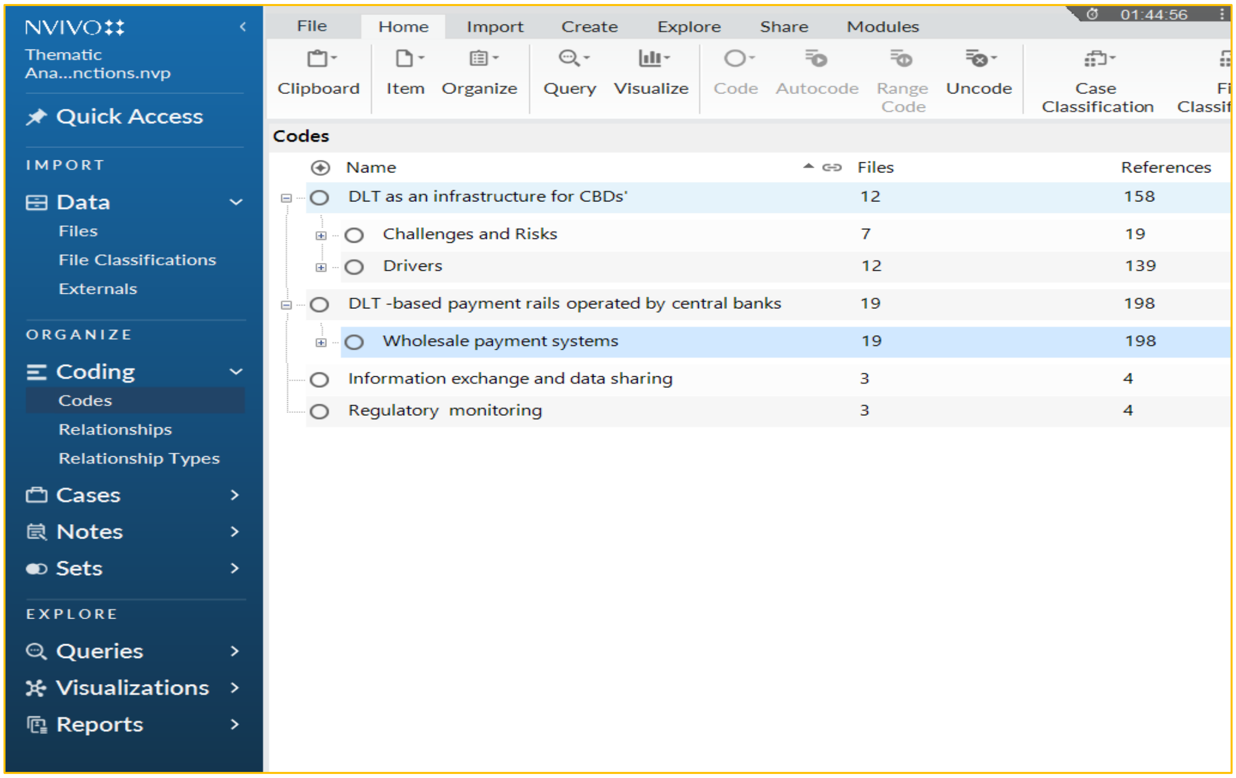
Designated Number	Reference	Bibliography	Title	Journal Title	Publisher	Time- period covered	Country(s)	Level of Analysis	Sample size	Data	Product	Data type (Panel, time series or c	Methodology	Overall summary of findings
A	(Zhang & Yang, 2021)	Zhang, Y., & Yang, D. (202	Robust Payment Routing With Approximation Guarantee in Blockchain-Based Payment Channel Networks	IEEE/ACM Transactions o	IEEE	2021	N/A	N/A	N/A	N/A	RobustPay	N/A	Proposed solut	scalability issue- large overhead of global consensus and
B	(Hu et al., 2019)	Hu, Y., Manzoor, A., Ekpa	Demo: A Delay-Tolerant Payment Scheme on the Ethereum Blockchain	IEEE Access	IEEE	2019	N/A	N/A	N/A	N/A	blockchain-ba	N/A	Proposed solution	
C	(Zhang et al., 2021)	Zhang, Y., Deng, R., Liu, X	Outsourcing Service Fair Payment Based on Blockchain and Its Applications in Cloud Computing	IEEE TRANSACTIONS ON S	IEEE	2021	N/A	N/A	N/A	N/A	BPay	N/A	Proposed solution	
D	(Lin et al., 2020)	Lin, C., He, D., Huang, X.,	DCAP: A Secure and Efficient Decentralized Conditional Anonymous Payment System Based on Blockchain	IEEE Transactions on Info	IEEE	2020	N/A	N/A	N/A	N/A	DCAP	N/A	Proposed solution	
E	(Lin et al., 2021)	Lin, C., He, D., Huang, X.,	optimized blockchain-based fair payment (OBFP) system model,	IEEE TRANSACTIONS ON II	IEEE	2021	N/A	N/A	N/A	N/A	OBFP	N/A	Proposed solution	
F (NO)	(Ray et al., 2021)	Ray, P., Kumar, N., & Dasl	BLWN: Blockchain-Based Lightweight Simplified Payment Verification in IoT-Assisted e-Healthcare	IEEE Systems Journal	IEEE	2020	N/A	N/A	N/A	N/A	BLWN	N/A	Proposed solution	
G	(Politou et al., 2021)	Politou, E., Casino, F., Ale	Blockchain Mutability: Challenges and Proposed Solutions	IEEE Transactions on Eme	IEEE	2021	N/A	N/A	N/A	N/A		N/A	Review	
H	(Ryu et al., 2020)	Ryu, K., Kim, W., & Lee, E.	payGo: Incentive-Comparable Payment Routing Based on Contract Theory	IEEE Access	IEEE	2020	N/A	N/A	N/A	N/A	payGo	N/A	Proposed solution	
I	(Conoscenti et al., 2019)	Conoscenti, M., Vetro, A.,	Hubs, Rebalancing and Service Providers in the Lightning Network	IEEE Access	IEEE	2019	N/A	N/A	N/A	N/A	CLoTH,	N/A	Proposed solution	
J	(Ye et al., 2021)	Ye, Y., Ren, Z., Luo, X., Zha	Garou: An Efficient and Secure Off-Blockchain Multi-Party Payment Hub	IEEE Transactions on Netw	IEEE	2021	N/A	N/A	N/A	N/A	Garou	N/A	Proposed solution	
K	(Jia et al., 2022)	Jia, Y., Sun, S., Zhang, Y., Z	PBT: A New Privacy-Preserving Payment Protocol for Blockchain Transactions	IEEE TRANSACTIONS ON D	IEEE	2022	N/A	N/A	N/A	N/A	PBT	N/A	Proposed solution	
L	(Zhang et al., 2020)	Zhang, D., Le, J., Mu, N., &	An Anonymous Off-Blockchain Micropayments Scheme for Cryptocurrencies in the Real World	IEEE Transactions on Syst	IEEE	2018	N/A	N/A	N/A	N/A	AOM	N/A	Proposed solution	
M	(Varma & Maguluri, 202	Varma, S., & Maguluri, S.	Throughput Optimal Routing in Blockchain-Based Payment Systems	IEEE Transactions on Con	IEEE	2021	N/A	N/A	N/A	N/A		N/A	Proposed solution	
N	(Dai et al., 2018)	Dai, M., Zhang, S., Wang,	A Low Storage Room Requirement Framework for Distributed Ledger in Blockchain	IEEE Access	IEEE	2018	N/A	N/A	N/A	N/A	NC-DS framew	N/A	Proposed solution	
O	(Podgorelec et al., 2020)	Podgorelec, B., Herieko, N	State Channel as a Service Based on a Distributed and Decentralized Web	IEEE Access	IEEE	2020	N/A	N/A	N/A	N/A		N/A	Proposed solution	
P	(Dai et al., 2018)	Dai, W., Deng, J., Wang, C	SBLWT: A Secure Blockchain Lightweight Wallet Based on Trustzone	IEEE Access	IEEE	2018	N/A	N/A	N/A	N/A		N/A		
Q	(Rezaeibagha & Mu, 201	Rezaeibagha, F., & Mu, Y.	Efficient Micropayment of Cryptocurrency from Blockchains	The Computer Journal	IEEE	2018	N/A	N/A	N/A	N/A		N/A	Proposed solution	
R (NO)	(Li et al., 2021)	Li, L., Chang, X., Liu, J., Liu	Bit2CV: A Novel Bitcoin Anti-Fraud Deposit Scheme for Connected Vehicles	IEEE Transactions on Intel	IEEE	2021	N/A	N/A	N/A	N/A	Bit2CV	N/A	Proposed solution	
S	(Siris et al., 2019)	Siris, V., Nikander, P., Vou	Interledger Approaches	IEEE Access	IEEE	2019	N/A	N/A	N/A	N/A		N/A	Descriptive	
T	(Yan et al., 2020)	Yan, G., Wang, S., Yang, Z.	Dynamic Game Model for Ranking Bitcoin Transactions Under GSP Mechanism	IEEE Access	IEEE	2020	N/A	N/A	N/A	N/A		N/A		
U	(Rahouti et al., 2018)	Rahouti, M., Xiong, K., &	Bitcoin Concepts, Threats, and Machine-Learning Security Solutions	IEEE Access	IEEE	2018	N/A	N/A	N/A	N/A	N/A	N/A	Survey	
V	(Kus Khalilov & Levi, 201	Kus Khalilov, M., & Levi, A	A Survey on Anonymity and Privacy in Bitcoin-Like Digital Cash Systems	IEEE Communications Sur	IEEE	2018	N/A	N/A	N/A	N/A	N/A	N/A	Survey	
W (N0)	(Kim, 2018)	Kim, S. (2018). A Novel B	A Novel Bitcoin Mining Scheme Based on the Multi-Leader Multi-Follower Stackelberg Game Model	IEEE Access	IEEE	2018	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
X	(Alqassem et al., 2020)	Alqassem, I., Rahwan, I., &	The Anti-Social System Properties: Bitcoin Network Data Analysis	IEEE Transactions on Syst	IEEE	2020	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
Y	(Viriyasitavat et al., 2021	Viriyasitavat, W., Hoonso	Augmenting cryptocurrency in smart supply chain	Journal of Industrial Infor	Elsevier	2021	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
Z	(Igboanusi et al., 2021)	Igboanusi, I., Dirgantoro,	Blockchain side implementation of Pure Wallet (PW): An offline transaction architecture	ICT Express	Elsevier	2021	N/A	N/A	N/A	N/A	Pure Wallet	N/A	Proposed solution	
A1	(Salcedo & Gupta, 2021)	Salcedo, E., & Gupta, M. (	The effects of individual-level espoused national cultural values on the willingness to use Bitcoin-like blockchain currencies	International Journal of Ir	Elsevier	2021	N/A	N/A	N/A	N/A	N/A	survey	Empirical study	
B1	(Wang et al., 2021)	Wang, X., Chen, Y., & Zha	Incentivizing cooperative relay in UTXO-based blockchain network	Computer Networks	Elsevier	2021	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
C1	(Li et al., 2021)	Li, Y., Jiang, S., Shi, J., & W	Pricing strategies for blockchain payment service under customer heterogeneity	International Journal of P	Elsevier	2022	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
D1	(van Dam & Abdul Kadir,	van Dam, G., & Abdul Kad	Hiding payments in lightning network with approximate differentially private payment channels	Computers & Securit	Elsevier	2022	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
E1	(Erdin et al., 2021)	Erdin, E., Cebe, M., Akkay	A scalable private Bitcoin payment channel network with privacy guarantees	Journal of Network and C	Elsevier	2021	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
F1	(Mercan et al., 2021)	Mercan, S., Erdin, E., & Ak	Improving transaction success rate in cryptocurrency payment channel networks	Computer Communicatio	Elsevier	2021	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
G1	(Lin et al., 2020)	Lin, C., Ma, N., Wang, X., &	Rapido: Scaling blockchain with multi-path payment channels	Neurocomputing	Elsevier	2020	N/A	N/A	N/A	N/A	Rapido	N/A	Proposed solution	
H1	(Zhong et al., 2019)	Zhong, L., Wu, Q., Xie, J., (	A secure large-scale instant payment system based on blockchain	Computers & Security	Elsevier	2019	N/A	N/A	N/A	N/A	(SLIP	N/A	Proposed solution	
I1	(Konashevych & Khovay	Konashevych, O., & Khov	Randpay: The technology for blockchain micropayments and transactions which require recipient's consent	Computers & Security	Elsevier	2020	i	N/A	N/A	N/A	Randpay proto	N/A	Proposed solution	
J1	(Mohanty & Tripathy, 20	Mohanty, S., & Tripathy,	n-HTLC: Neo hashed time-Lock commitment to defend against wormhole attack in payment channel networks	Computers & Security	Elsevier	2021	N/A	N/A	N/A	N/A	n-HTLC	N/A	Proposed solution	
k1	(Zhong et al., 2019)	Zhong, L., Wu, Q., Xie, J.,	A secure versatile light payment system based on blockchain	Future Generation Compu	Elsevier	2019	N/A	N/A	N/A	N/A	SVLP) scheme	N/A	Proposed solution	
L1	(Robert et al., 2020)	Robert, J., Kubler, S., & Gl	Enhanced Lightning Network (off-chain)-based micropayment in IoT ecosystems	Future Generation Compu	Elsevier	2020	N/A	N/A	N/A	N/A	N/A	N/A	Empirical	
M1	(Szumski, 2020)	Szumski, O. (2020). Digita	Digital payment methods within Polish students – leading decision	Procedia Computer Scien	Elsevier	2020	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
N1	(Saito & Iwamura, 2019)	Saito, K., & Iwamura, M. (	characteristics	Future Generation Compu	Elsevier	2019	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
O1	(Zachariadis et al., 2019)	Zachariadis, M., Hileman,	Governance and control in distributed ledgers: Understanding the challenges facing blockchain technology in financial services	Information and Organiza	Elsevier	2019	N/A	N/A	N/A	N/A	N/A	N/A	Survey	
P1	(Li et al., 2021)	Li, C., Tian, Y., Chen, X., &	An efficient anti-quantum lattice-based blind signature for blockchain-enabled systems		Elsevier	2021	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
Q1	(Erdin et al., 2020)	Erdin, E., Cebe, M., Akkay	A Bitcoin payment network with reduced transaction fees and confirmation times	Computer Networks	Elsevier	2020							Proposed solution	
R1	(Nerurkar et al., 2021)	Nerurkar, P., Patel, D., Bu	Dissecting bitcoin blockchain: Empirical analysis of bitcoin network (2009–2020)	Journal of Network and C	Elsevier		N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
S1	(Presthus & O'Malley, 20	Presthus, W., & O'Malley,	Motivations and Barriers for End-User Adoption of Bitcoin as Digital Currency	Procedia Computer Scien	Elsevier	2017							Empirical study	
T1	(Wang et al., 2020)	Wang, H., He, D., & Ji, Y. (	Designated-verifier proof of assets for bitcoin exchange using elliptic curve cryptography	Future Generation Compu	Elsevier	2020	N/A	N/A	N/A	N/A	N/A	N/A		
U1	(Biryukov & Tikhomirov,	Biryukov, A., & Tikhomiro	Security and privacy of mobile wallet users in Bitcoin, Dash, Monero, and Zcash	Pervasive and Mobile Cor	Elsevier	2019	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
V1	(Jawaheri et al., 2020)	Jawaheri, H., Sabah, M., B	Deanonymizing Tor hidden service users through Bitcoin transactions analysis	Computers & Security	Elsevier	2020	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
W1	(Ziegeldorf et al., 2018)	Ziegeldorf, J., Matzutt, R.,	Secure and anonymous decentralized Bitcoin mixing	Future Generation Compu	Elsevier	2018	N/A	N/A	N/A	N/A	CoinParty	N/A	Proposed solution	
	(Nikbakht et al., 2019)	Nikbakht, E., Shahrokhi, M	Blockchain & distributed financial data	Managerial Finance	Emerald	2019	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
	(Yoo, 2017)	Yoo, S. (2017). Blockchai	Blockchain based financial case analysis and its implications	Asia Pacific Journal of Inn	Emerald	2017	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
	(Nadeem et al., 2020)	Nadeem, M., Liu, Z., Pitafi	Investigating the repurchase intention of Bitcoin: empirical evidence from China	Data Technologies and Ap	Emerald	2020	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
	(Huberman et al., 2017)	Huberman, G., Leshno, J.,	Monopoly Without a Monopolist: An Economic Analysis of the Bitcoin Payment System	SSRN Electronic Journal	Elsevier	2017	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
	(Paquet-Clouston et al., :	Paquet-Clouston, M., Has	Ransomware payments in the Bitcoin ecosystem	Journal of Cybersecurity	Oxford Universi	2019	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
	(Rezaeibagha & Mu, 201	Rezaeibagha, F., & Mu, Y.	Efficient Micropayment of Cryptocurrency from Blockchains	The Computer Journal	Oxford Universi	2018	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
	(Ferrari, 2020)	Ferrari, V. (2020). The reg	The regulation of crypto-assets in the EU – investment and payment tokens under the radar	Maastricht Journal of Eur	SAGE Publicatic	2020	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
	(Fernandez-Vazquez et a	Fernandez-Vazquez, S., Ro	A comparative study of blockchain's largest permissionless networks	Technology Analysis & St	Informa UK Lim	2021	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
	(Malherbe et al., 2019)	Malherbe, L., Montalban,	Cryptocurrencies and Blockchain: Opportunities and Limits of a New Monetary Regime	International Journal of P	Informa UK Lim	2019	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
	(Ziolkowski et al., 2020)	Ziolkowski, R., Miscione,	Decision Problems in Blockchain Governance: Old Wine in New Bottles or Walking in Someone Else's Shoes?	Journal of Management I	Informa UK Lim	2020	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
	(Papadaki & Karamitsos,	Papadaki, M., & Karamits	Blockchain technology in the Middle East and North Africa region		Information Tec	2021	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study	
	(Ying et al., 2021)	Ying, Z., Zhengyuan, H., Li	LOPE: A Low-Overhead Payment Verification Method for Blockchains	Chinese Journal of Electr	Institution of Er	2021	N/A	N/A	N/A	N/A	N/A	N/A	Proposed solution	
	(Kewell & Michael Ward,	Kewell, B., & Michael Wa	Blockchain Futures: With or Without Bitcoin?	Strategic Change	Wiley	2017	N/A	N/A	N/A	N/A	N/A	N/A	Empiricalstudy	

Appendix D: Snapshot of Articles & Methodology used.

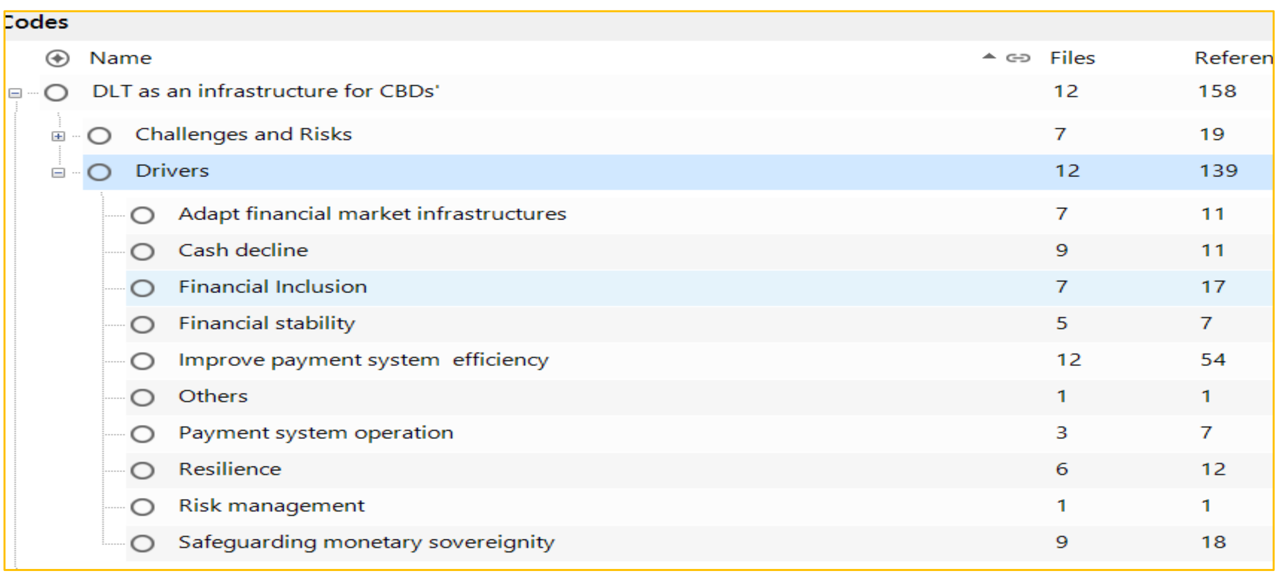
Designated	Reference	Bibliography	Title	Journal Titl	Publisher	Time- peric	Country(s)	Level of Analys	Sample size	Data	Product	Data type (Panel	Methodology used
A	(Zhang & Yang, 2021)	Zhang, Y., & Yang, D. (2021). Robu:	Robust Payment Routing With Approximation Guarantee in Blockchain-Based Pa	IEEE/ACM Tran	IEEE	2021	N/A	N/A	N/A	N/A	RobustPay	N/A	technical paper
B	(Hu et al., 2019)	Hu, Y., Manzoor, A., Ekparinya, P., L	Demo: A Delay-Tolerant Payment Scheme on the Ethereum Blockchain	IEEE Access	IEEE	2019	N/A	N/A	N/A	N/A	blockchain-based digital	N/A	technical paper
C	(Zhang et al., 2021)	Zhang, Y., Deng, R., Liu, X., & Zheng	Outsourcing Service Fair Payment Based on Blockchain and Its Applications in Clo	IEEE TRANSACT	IEEE	2021	N/A	N/A	N/A	N/A	BPay	N/A	technical paper
D	(Lin et al., 2020)	Lin, C., He, D., Huang, X., Khan, M.,	DCAP: A Secure and Efficient Decentralized Conditional Anonymous Payment Sys	IEEE Transactio	IEEE	2020	N/A	N/A	N/A	N/A	DCAP	N/A	technical paper
E	(Lin et al., 2021)	Lin, C., He, D., Huang, X., & Choo, K	optimized blockchain-based fair payment (OBFP) system model,	IEEE TRANSACT	IEEE	2021	N/A	N/A	N/A	N/A	OBFP	N/A	technical paper
G	(Politou et al., 2021)	Politou, E., Casino, F., Alepis, E., & I	Blockchain Mutability: Challenges and Proposed Solutions	IEEE Transactio	IEEE	2021	N/A	N/A	N/A	N/A		N/A	Review paper
H	(Ryu et al., 2020)	Ryu, K., Kim, W., & Lee, E. (2020). p	payGo: Incentive-Comparable Payment Routing Based on Contract Theory	IEEE Access	IEEE	2020	N/A	N/A	N/A	N/A	payGo	N/A	technical paper
I	(Conoscenti et al., 2019)	Conoscenti, M., Vetro, A., & De Ma	Hubs, Rebalancing and Service Providers in the Lightning Network	IEEE Access	IEEE	2019	N/A	N/A	N/A	N/A	CLoTH,	N/A	technical paper
J	(Ye et al., 2021)	Ye, Y., Ren, Z., Luo, X., Zhang, J., & \	Garou: An Efficient and Secure Off-Blockchain Multi-Party Payment Hub	IEEE Transactio	IEEE	2021	N/A	N/A	N/A	N/A	Garou	N/A	technical paper
K	(Jia et al., 2022)	Jia, Y., Sun, S., Zhang, Y., Zhang, Q.,	PBT: A New Privacy-Preserving Payment Protocol for Blockchain Transactions	IEEE TRANSACT	IEEE	2022	N/A	N/A	N/A	N/A	PBT	N/A	technical paper
L	(Zhang et al., 2020)	Zhang, D., Le, J., Mu, N., & Liao, X. (	An Anonymous Off-Blockchain Micropayments Scheme for Cryptocurrencies in tl	IEEE Transactio	IEEE	2018	N/A	N/A	N/A	N/A	AOM	N/A	technical paper
M	(Varma & Maguluri, 2021)	Varma, S., & Maguluri, S. (2021). Tl	Throughput Optimal Routing in Blockchain-Based Payment Systems	IEEE Transactio	IEEE	2021	N/A	N/A	N/A	N/A		N/A	technical paper
N	(Dai et al., 2018)	Dai, M., Zhang, S., Wang, H., & Jin,	A Low Storage Room Requirement Framework for Distributed Ledger in Blockchai	IEEE Access	IEEE	2018	N/A	N/A	N/A	N/A	NC-DS framework	N/A	technical paper
O	(Podgorelec et al., 2020)	Podgorelec, B., Herieko, M., & Turk	State Channel as a Service Based on a Distributed and Decentralized Web	IEEE Access	IEEE	2020	N/A	N/A	N/A	N/A		N/A	technical paper
P	(Dai et al., 2018)	Dai, W., Deng, J., Wang, Q., Cui, C.,	SBLWT: A Secure Blockchain Lightweight Wallet Based on Trustzone	IEEE Access	IEEE	2018	N/A	N/A	N/A	N/A		N/A	technical paper
Q	(Rezaeibagha & Mu, 2018)	Rezaeibagha, F., & Mu, Y. (2018). E	Efficient Micropayment of Cryptocurrency from Blockchains	The Computer	IEEE	2018	N/A	N/A	N/A	N/A		N/A	technical paper
T	(Yan et al., 2020)	Yan, G., Wang, S., Yang, Z., & Zhou,	Dynamic Game Model for Ranking Bitcoin Transactions Under GSP Mechanism	IEEE Access	IEEE	2020	N/A	N/A	N/A	N/A		N/A	technical paper
U	(Rahouti et al., 2018)	Rahouti, M., Xiong, K., & Ghani, N.	Bitcoin Concepts, Threats, and Machine-Learning Security Solutions	IEEE Access	IEEE	2018	N/A	N/A	N/A	N/A	N/A	N/A	Survey paper
V	(Kus Khalilov & Levi, 2018)	Kus Khalilov, M., & Levi, A. (2018).	A Survey on Anonymity and Privacy in Bitcoin-Like Digital Cash Systems	IEEE Communi	IEEE	2018	N/A	N/A	N/A	N/A	N/A	N/A	Survey paper
X	(Alqassem et al., 2020)	Alqassem, I., Rahwan, I., & Svetinov	The Anti-Social System Properties: Bitcoin Network Data Analysis	IEEE Transactio	IEEE	2020	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study
Z	(Igboanusi et al., 2021)	Igboanusi, I., Dirgantoro, K., Lee, J.,	Blockchain side implementation of Pure Wallet (PW): An offline transaction archi	ICT Express	Elsevier	2021	N/A	N/A	N/A	N/A	Pure Wallet	N/A	technical paper
A1	(Salcedo & Gupta, 2021)	Salcedo, E., & Gupta, M. (2021). Tr	The effects of individual-level espoused national cultural values on the willingnes	International Jo	Elsevier	2021	N/A	N/A	N/A	N/A	N/A	survey	Empirical study
B1	(Wang et al., 2021)	Wang, X., Chen, Y., & Zhang, Q. (20	Incentivizing cooperative relay in UTXO-based blockchain network	Computer Netv	Elsevier	2021	N/A	N/A	N/A	N/A	N/A	N/A	technical paper
D1	(van Dam & Abdul Kadir, 2022)	van Dam, G., & Abdul Kadir, R. (202	Hiding payments in lightning network with approximate differentially private payr	Computers &a	Elsevier	2022	N/A	N/A	N/A	N/A	N/A	N/A	technical paper
E1	(Erdin et al., 2021)	Erdin, E., Cebe, M., Akkaya, K., Bulu	A scalable private Bitcoin payment channel network with privacy guarantees	Journal of Netv	Elsevier	2021	N/A	N/A	N/A	N/A	N/A	N/A	technical paper
F1	(Mercan et al., 2021)	Mercan, S., Erdin, E., & Akkaya, K. (	Improving transaction success rate in cryptocurrency payment channel networks	Computer Com	Elsevier	2021	N/A	N/A	N/A	N/A	N/A	N/A	technical paper
G1	(Lin et al., 2020)	Lin, C., Ma, N., Wang, X., & Chen, J.	Rapido: Scaling blockchain with multi-path payment channels	Neurocomputi	Elsevier	2020	N/A	N/A	N/A	N/A	Rapido	N/A	technical paper
H1	(Zhong et al., 2019)	Zhong, L., Wu, Q., Xie, J., Guan, Z., &	A secure large-scale instant payment system based on blockchain	Computers & S	Elsevier	2019	N/A	N/A	N/A	N/A	(SLIP	N/A	technical paper
I1	(Konashevych & Khovayko, 2020)	Konashevych, O., & Khovayko, O. (	Randpay: The technology for blockchain micropayments and transactions which	Computers & S	Elsevier	2020	i	N/A	N/A	N/A	Randpay protocol	N/A	technical paper
J1	(Mohanty & Tripathy, 2021)	Mohanty, S., & Tripathy, S. (2021).	n-HTLC: Neo hashed time-Lock commitment to defend against wormhole attack ir	Computers & S	Elsevier	2021	N/A	N/A	N/A	N/A	n-HTLC	N/A	technical paper
k1	(Zhong et al., 2019)	Zhong, L., Wu, Q., Xie, J., Li, J., & Qi	A secure versatile light payment system based on blockchain	Future Generat	Elsevier	2019	N/A	N/A	N/A	N/A	SVLP) scheme	N/A	technical paper
L1	(Robert et al., 2020)	Robert, J., Kubler, S., & Ghatpande,	Enhanced Lightning Network (off-chain)-based micropayment in IoT ecosystems	Future Generat	Elsevier	2020	N/A	N/A	N/A	N/A	N/A	N/A	technical paper
M1	(Szumski, 2020)	Szumski, O. (2020). Digital paymen	Digital payment methods within Polish students – leading decision	Procedia Comp	Elsevier	2020	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study
N1	(Saito & Iwamura, 2019)	Saito, K., & Iwamura, M. (2019). Ho	characteristics	Future Generat	Elsevier	2019	N/A	N/A	N/A	N/A	N/A	N/A	technical paper
O1	(Zachariadis et al., 2019)	Zachariadis, M., Hileman, G., & Sco	Governance and control in distributed ledgers: Understanding the challenges faci	Information an	Elsevier	2019	N/A	N/A	N/A	N/A	N/A	N/A	Survey paper
P1	(Li et al., 2021)	Li, C., Tian, Y., Chen, X., & Li, J. (202	An efficient anti-quantum lattice-based blind signature for blockchain-enabled systems		Elsevier	2021	N/A	N/A	N/A	N/A	N/A	N/A	technical paper
Q1	(Erdin et al., 2020)	Erdin, E., Cebe, M., Akkaya, K., Sola	A Bitcoin payment network with reduced transaction fees and confirmation times	Computer Netv	Elsevier	2020							technical paper
R1	(Nerurkar et al., 2021)	Nerurkar, P., Patel, D., Busnel, Y., Lu	Dissecting bitcoin blockchain: Empirical analysis of bitcoin network (2009–2020)	Journal of Netv	Elsevier		N/A	N/A	N/A	N/A	N/A	N/A	Empirical study
S1	(Presthus & O'Malley, 2017)	Presthus, W., & O'Malley, N. (2017	Motivations and Barriers for End-User Adoption of Bitcoin as Digital Currency	Procedia Comp	Elsevier	2017							Empirical study
U1	(Biryukov & Tikhomirov, 2019)	Biryukov, A., & Tikhomirov, S. (201	Security and privacy of mobile wallet users in Bitcoin, Dash, Monero, and Zcash	Pervasive and I	Elsevier	2019	N/A	N/A	N/A	N/A	N/A	N/A	Empirical study

Appendix E: Initial priori themes

Final first order priori themes based on the identified application



Under each identified application: the priori theme: Motivation/ drivers e.g.



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