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Design Practices for Wholesale Central Bank Digital Currencies from the World

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Abstract: Over four thousand digital currencies have been issued by private sector actors since the release of Bitcoin in 2009. Private sector issuance of distributed ledger technology (DLT)-based digital currencies such as Bitcoin and other altcoins threatens the stability of financial market infrastructures (FMIs) and preservation of monetary policy (MP). Facing the threat of disruption of MP and FMIs by the private sector digital currency issuances, many central banks and monetary authorities have delved into research on central bank-issued digital currencies (CBDCs). In this paper, we present a survey of selected DLT-based wholesale CBDC (W-CBDC) experiments with completed proof-of-concepts to enable the understanding of the practices, motivations and technologies for W-CBDC experiments. Ultimately, our paper organizes all the relevant DLT-based W-CBDC experiments-to-date in one place to serve as a reference point for CBs, MAs and researchers studying about DLT-based CBDCs.

Keywords: CBDC, central bank, DLT, FMI, monetary authorities, monetary policy, W-CBDC.

1 Introduction

A central bank (CB) controls economic activity in a given nation-state through the use of monetary policy (MP) and other relevant economic management tools. CBs implement MP by controlling the money supply, managing interest rates and maintaining price stability or inflation for goods and services in a given economy [1]. CBs, therefore, enjoy a legal monopoly on the issuance of currency in a given economy [2].

The invention of Bitcoin [3] in 2009, however, has given rise to the global issuance of alternative forms of currencies referred to as digital or crypto-currencies by private actors, a role reserved solely for CBs. In less than a decade since the introduction of Bitcoin, private sector actors have issued more than four thousand digital currencies [4] that lack intrinsic value and are not backed by any tangible resources. Besides Bitcoin [3] , other notable private sector-issued cryptocurrencies include Ethereum, Ripple, Tether, Stellar and other altcoins.

Facing the threat of monetary policy and financial market instability by such private sector digital currency issuances, many CBs have delved into research and experimentation on central bank-issued digital currencies (CBDCs) to guarantee financial system stability and monetary policy preservation [5, 6].

In a recent survey conducted by the Bank for International Settlements (BIS), of the 63 CB respondents of the survey, more than 70 per cent are currently investigating the possibility of issuing a CBDC [7]. The 63 CBs that participated in the survey represent jurisdictions covering about 80% of the world population and over 90% of its economic output [7]. 65% of the survey participants were from emerging market economies (EME) while 35% were from advanced economies. Overall, survey participants from EME cited financial inclusion and domestic payment efficiency as their motivation for investigating CBDCs and thus indicated the strongest preparedness among the survey participants to issue a CBDC over the medium term (1-6 years). In total, about 30% of all CBs in the survey indicated a preparedness to issue a CBDC in the medium term.

In this paper, we present a survey on the motivations and the practices of wholesale CBDC (W-CBDC) experiments from different parts of the world with the goal of understanding the factors and design principles that influence the technical design considerations of such experiments.

With the myriad ongoing and planned CBDC experiments loosely organized in various literature, we organize all the relevant W-CBDC experiments in one place to serve as a reference point for CBs and monetary authorities (MAs) desiring to learn more about CBDCs in general and W-CBDCs specifically. We develop an experiment selection criteria to identify the relevant W-CBDC experiments to include in our survey. Following the identification and selection of the relevant W-CBDC experiments, we undertake an in-depth comparison of the motivations of our selected CBDC experiments in order to map the stated goals of each CBDC experiment to the project's design principles and a further mapping of the design principles to the choice of technology for each experiment.

The rest of the paper is organized as follows. In Sec-

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tion 2, we present a background on CBDC research and experiment initiatives by various CBs from across the world. In Section 3, we discuss similarities between CB-issued money and CBDCs. Further, we discuss the concept and classification of CBDCs. In Section 4, we describe a CBDC-experiment selection criteria to enable us select the relevant CBDC experiments for inclusion in our survey. Consequently, using our experiment selection criteria, we identify and select the relevant CBDC experiments for our survey. In Section 5, we discuss CBs motivations for undertaking CBDC research and the practices that are relevant for achieving successful research outputs. We conclude our survey in Section 6 by providing a summary of CBs motivation, practices and choice of technologies for CBDC experiments.

2 Background

The Bank of England is considered the first CB to initiate research and experimentation into the issuance of distributed ledger technology (DLT)-based CBDC with its publication of the "One Bank Research Agenda" in 2015 [8] and the subsequent development of the RSCoin CBDC [9] on its behalf by researchers at the University College London in February 2016.

The Bank of Canada together with Payments Canada, and R3 initiated their Project Jasper CBDC experiment in March 2016 [10, 11], while the Monetary Authority of Singapore (MAS) begun its Project Ubin experiment in November 2016 [12]. The Hong Kong Monetary Authority [13, 14] as well as the Central Bank of Brazil [15] have also completed their respective CBDC experiments and are currently evaluating their research outcomes.

Other notable CBs such as the South African Reserve Bank [16], the Central Bank of Uruguay [17], the Bank of France [18], the Deutsche Bundesbank [19] , the Venezuelan Superintendency of Currency and Related Activities [20], and the Bank of Thailand [21] have all undertaken research experiments into the issuance of CBDCs.

Another group of CBs such as the Sveriges Riksbank [22,23] and the Bank of Lithuania [24,25] have recently begun research into the issuance of CDBCs with the goal of developing PoCs as part of their research.

A few other CBs including the US Federal Reserve Bank [26], Bank of Korea [27], Bank of Japan [28], the Bank of Israel [29], Norges Bank [30] and the Reserve Bank of New Zealand [31] have studied or conducted analysis about the implications of DLTs for FMIs without any immediate plans to issue CBDCs of their own.

A last category of CBs including the Bank of Finland [32], Danmarks Nationalbank [33] and the Swiss National Bank [34,35] have dismissed the value and/or prospects of CBDCs as they contend that DLT is less-mature and thus will pose significant risks to the stability of financial market infrastructures (FMIs).

On the bilateral level, the Bank of Canada and the Monetary Authority of Singapore have succeeded to make interoperable two CBDC experiments implemented on different DLT platforms to allow for efficient cross-border payments and settlements between Canada and Singapore [36].

On the same bilateral level, the European Central Bank and the Bank of Japan have implemented in three Phases, Project Stella to explore the potential benefits and challenges that DLTs could pose for FMIs in their respective regions [37–39].

On the multilateral level, the Bank of Canada, Bank of England and the Monetary Authority of Singapore have jointly developed alternative models to improve the efficiency of cross-border interbank payment and settlement by leveraging DLTs [40, 41].

We present the current CBDC experiment/research landscape organized in accordance with the year of announcement of each CBDC experiment in Fig.1.

3 CBDCs

At the basic level, CBs issue two types of money namely *physical money or cash* (bank notes and coins) and *electronic CB money* otherwise known as reserves or settlement accounts [42].

Cash, which we refer to as general purpose money is accessible by everyone in a given economy. General purpose money is non-interest bearing and can be used to make payments in a peer-to-peer anonymous manner [22, 43].

Reserves or settlement accounts which we refer to as wholesale e-money are accessible by only authorized financial institutions (FIs) such as commercial banks (CMBs) or high-value customers who maintain settlement accounts on the books of a CB. Wholesale e-money are interest-bearing and do not have the anonymity property of cash as all participants in an interbank payment settlement system must be pre-registered, authenticated, and authorized by the CB in order to access and conduct interbank payment settlements on the CB's FMIs [23, 42].

Similar to the CB money types, there are two types of CBDCs: *general-purpose CBDC* (G-CBDC) and *wholesale CBDC* (W-CBDC).

A CBDC may be defined as monetary value similar to CB money that is stored electronically and represents a claim on asset on the CB[68]. It can be distributed in a decentralized manner and used to make payments [43].

3.1 Classification of CBDCs

The BIS, widely regarded as the CB of all CBs provides a classification of money and CBDCs based on four key properties: *issuer* of money (CB or not); *form* (digital or physical); *accessibility* (widely or restricted) and *technology* (account-based or token-based) [44]. The BIS further develops the *money flower* to depict its classification of money. We present an annotated version of the BIS money flower in Fig.2 . In Fig.2, the dark grey shaded area represents the types of CBDCs issuable by a CB.

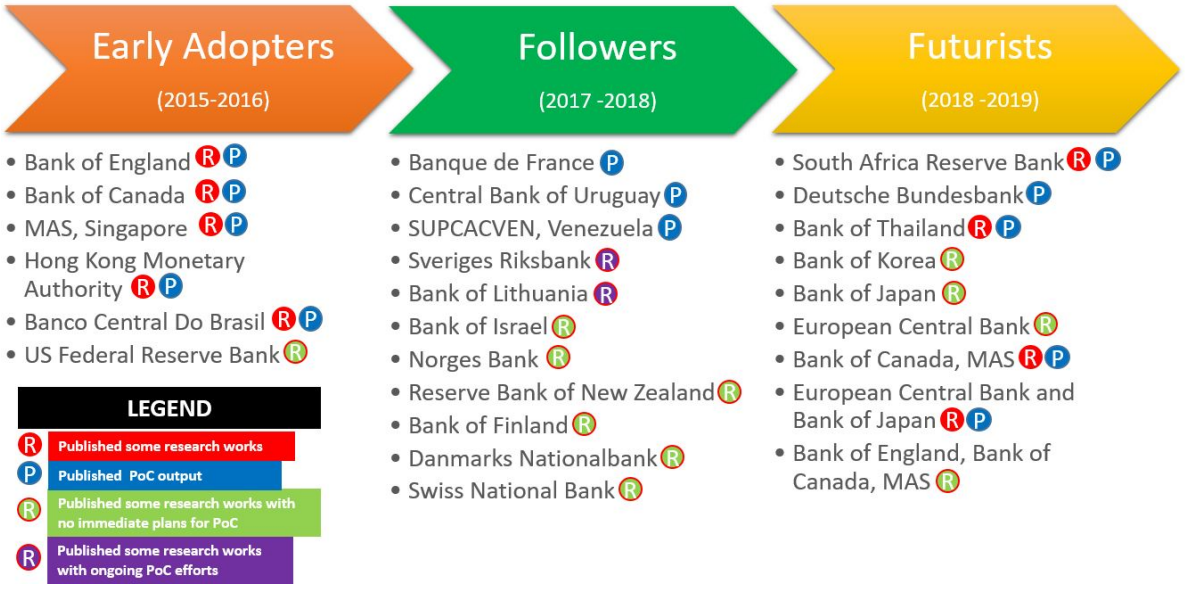

Figure 1: CBDC Experiment Landscape

3.1.1 W-CBDC

A W-CBDC is digital money similar to reserve and settlement balance accounts at a CB. A W-CBDC is accessible by only authorized FIs such as CMBs or high-value customers who are participants of a CB's interbank payments settlement system [5, 42, 46].

A W-CBDC is issued, distributed, stored and maintained solely by a CB or an entity designated by the CB to perform such a function.

All transactions relating to a W-CBDC are processed by a CB or an entity designated by the CB to perform such a function. A W-CBDC transaction has no anonymity requirement as all participants in an interbank payment settlement system must be pre-registered, authenticated, and authorized by the CB in order to access and conduct interbank payments settlement on the CB's FMIs [23, 42]. While there is no anonymity requirement for W-CBDC transactions, only parties involved in a specific W-CBDC transaction are able to access data relating to the said transaction, thereby guaranteeing data privacy for transaction participants in conformance with the *Principles for Financial Market Infrastructures* (PFMIs) [45].

3.1.2 G-CBDC

General-purpose CBDCs (G-CBDCs) are of two types: general-purpose account-based CBDC (GA-CBDC) and general-purpose value-based CBDC (GV-CBDC).

A **GA-CBDC** is a digital CBDC similar to a W-CBDC, but unlike a W-CBDC, a GA-CBDC is accessible by the general-public. A GA-CBDC is issued, distributed, stored and maintained solely by a CB or an entity designated by the CB to perform such a function. Issuance of a GA-CBDC grants the general-public direct access to accounts held at the CB. A GA-CBDC user will then access the CBDC using a mobile app (wallet) or other access mechanisms provided by the CB [23].

Similar to W-CBDC transactions, GA-CBDC transactions do not have the anonymity property of cash as a user of a GA-CBDC will be required to be pre-registered, authenticated and authorized by the CB before he/she can hold a GA-CBDC account with the CB.

A **GV-CBDC** is similar to cash, in that it is accessible by the general-public and may be imbued with anonymity properties similar to those associated with cash [22] [23].

A key difference between GV-CBDC and GA-CBDC lies in how both CBDCs are created, distributed, stored and/or transferred [7].

A GV-CBDC once issued by a CB may be distributed to CMBs or other authorized FIs for onward transmission to the general-public. The general-public will then store the CBDC locally on a card, mobile app (wallet) or through other user-defined means, similar to existing FinTech implementations of money such as mobile money [22].

Additionally, the anonymity property is another key difference between a GV-CBDC and a GA-CBDC.

4 CBDC Experiment Selection

To identify the relevant CBDC experiments for our survey, we crawled through the databases of a number of reputable institutions and journal publishing platforms. We searched the databases of WEF, a renowned global entity that is an active participant in world economic affairs and DLT related initiatives at https://www.weforum.org/. Secondly, the data stores of the BIS which is regarded as the CB of all CBs was explored at https://www.bis.org/. Further, we searched the databases of IEEE which is renowned for publishing high quality scientific and multidisciplinary articles at https://ieeexplore.ieee.org/. Due to DLTs strong

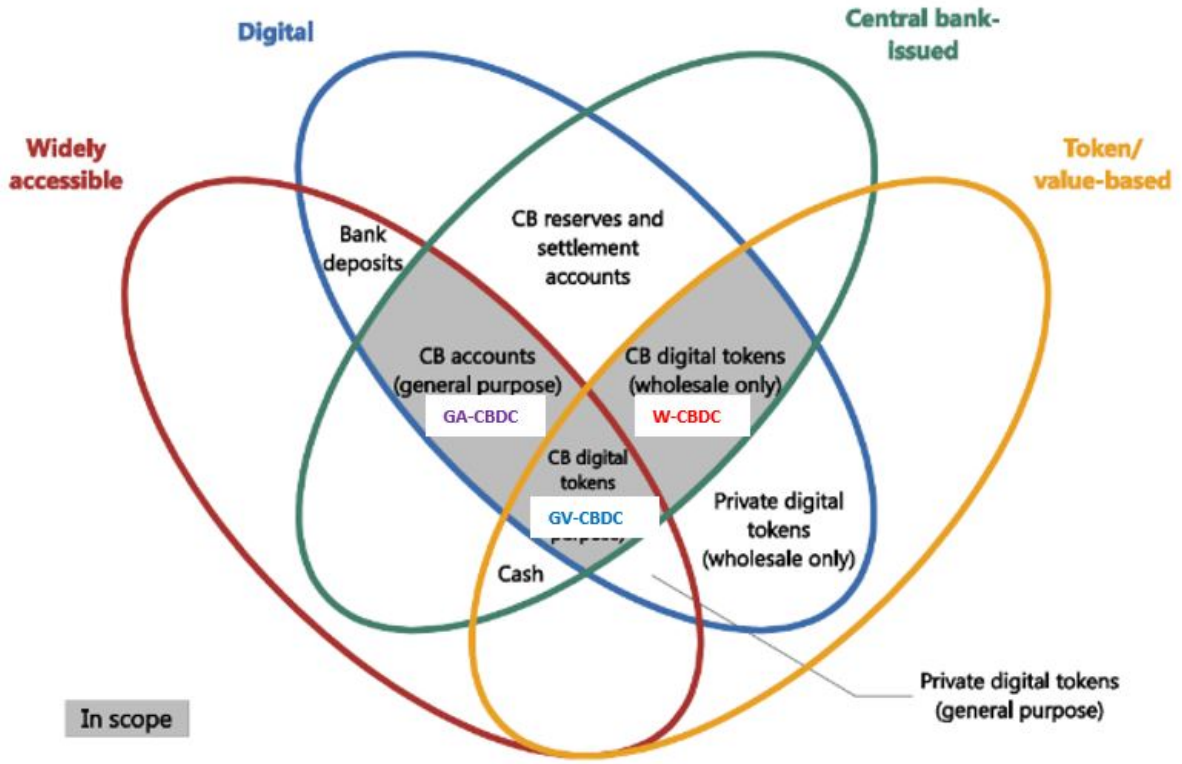

Figure 2: Annotated Money Flower [44]

cryptography underpinnings, we also combed through the IACR database at https://www.iacr.org/ to identify relevant articles that may meet our survey requirements. Finally, we searched WhitepaperDatabase.com, a renowned data source in the cryptocurrency world where whitepapers for leading cryptocurrency projects such as Ethereum, Ripple, Tether, Stellar and other altcoins were all published.

We searched for the following keywords on all the above-mentioned data stores: "central bank digital currency", "central bank digital currency experiment", "central bank digital currency project", "CBDC experiment", "CBDC project", "national digital currency experiment", "national digital currency project", "national cryptocurrency experiment" and "national cryptocurrency project".

4.1 Preliminary Selection Criteria

For an article or publication to be considered for selection and inclusion in our survey, it must have been written in English and published under the authorization of a CB, MA, or by the government of the country in which the CBDC experiment is to be implemented.

All articles and publications on CBDC experiments included in our survey must have been published on or before August 10, 2019.

4.1.1 Preliminary Selection Results

Firstly, we crawled through the databases of WEF and found a list of CBDC experiments/research curated at [6]. We followed all the URLs under the "Central Bank" and "Academia" categories to review their suitability for our survey and identified twenty-three CBDC experiment profiles matching our preliminary search requirement.

Secondly, we combed through data resources of the BIS and found one CBDC experiment [17] not curated by the WEF. Further, we searched the IEEE and IACR data stores and found no articles on IEEE that met our search requirement. We found one article [9] on IACR that matched our search requirement, which article had also been curated by the.

Lastly, we crawled the WhitepaperDatabase.com and found one result [20] matching our search requirement.

In total, we found twenty-six experiments through our preliminary selection process which are made up of twenty three experiments curated by the WEF; one experiment retrieved from BIS, IACR and WhitepaperDatabase.com respectively.

We could not find any documentation on the PoC of Bank of France's MADRE experiment in English, therefore, the MADRE experiment is excluded from the list of experiments surveyed in this paper based on our preliminary selection criteria.

We submit the remaining twenty-five experiments through a secondary screening criteria described below.

4.2 Secondary Screening Criteria

Our secondary screening criteria is organized in order of relevance to our research objectives, which is to identify DLT-based W-CBDC experiments with completed PoCs to enable the understanding of the practices, mo-

tivations and technologies for such experiments.

In line with our research objectives, the following secondary screening criteria is presented in order of importance.

Criteria 1: Goal of publication - does the final goal of the publication include the development of a PoC? If yes, move to **Criteria 2**. Otherwise, discard the experiment.

Criteria 2: PoC development - has a PoC been developed for the CBDC research under consideration? If yes, move to **Criteria 3**. Otherwise, discard the experiment.

Criteria 3: DLT – does the PoC use at least one of Quorum, Hyperledger Fabric, Corda, Ethereum or Elements DLT platforms for its implementation? If yes, move to **Criteria 4**. Otherwise, discard the experiment.

Criteria 4: Type of CBDC - does the CBDC experiment/research publication clearly state the type of CBDC implemented? If yes, does the CBDC experiment/research fit our CBDC classification in **Section 3.1**? If yes, indicate the type of CBDC and move to **Criteria 5**. If not explicitly stated, can the type of CBDC implemented be inferred from the available CBDC research publication taking into consideration our classification of CBDCs in **Section 3.1**? If yes, indicate the type of CBDC and move to criteria 5. Discard the experiment if the type of CBDC implemented is neither explicitly stated nor can it be inferred from the available research publication.

Criteria 5: PoC documentation - if a PoC has been developed, is there a detailed documentation publicly available? If yes, the experiment is selected. Otherwise, the experiment/research is discarded.

Criteria 6: Source code - if a PoC has been developed, is the source code publicly available? The experiment is selected, whether yes or no.

4.2.1 Secondary Screening Results

For our second round screening process, **Criteria 1 to 5** are mandatory. A CBDC experiment is discarded even if only one of the mandatory criteria is not met.

Experiments with publicly available source-codes are highly preferable, however, all experiments that fulfil the mandatory criteria are selected for our survey.

We note that, England's RSCoin experiment details a novel approach to issue CBDCs in a centralized, auditable and scalable manner; however, we are unable to infer from [9], the specific type of CBDC being implemented by the RSCoin experiment, whether a W-CBDC, GV-CBDC or GA-CBDC, therefore RSCoin is eliminated based on **Criteria 4**.

The Uruguayan e-Peso CBDC experiment did not use DLT for its implementation according to [7]; therefore, the e-Peso experiment is discarded and omitted from our survey based on **Criteria 3**.

The Sveriges Riksbank provides a detailed description of their planned CBDC experiment; however, the Riksbank did not make a determination on the specific type of G-CBDC it will be implementing yet in its research reports at [22] [23] therefore, the e-Krona experiment is excluded from the final list of experiments surveyed in this paper based on **Criteria 4**.

The Venezuelan Petro CBDC experiment [20] is a type of G-CBDC experiment, however, we could not infer from the available English documentation of the experiment whether it is a GA-CBDC or GV-CBDC, therefore the Petro experiment is omitted from our survey based on **Criteria 4**.

Lithuania's LBChain project is a fascinating CBDC experiment that seeks to promote the development of the country's FI through innovative blockchain applications that attract foreign direct investment into the country's financial sector, however, the Bank of Lithuania is yet to make a determination on the specific type of CBDC to implement as indicated the project implementation roadmap at [24, 25]. As a result, the LBChain experiment is excluded from the final list of experiments surveyed in this paper based on **Criteria 4**.

The concept of Fedcoin was proposed by various researchers [48–50] and not by the US Federal Reserve. The US Fed has not indicated plans to develop a Fedcoin PoC in the medium to long term, therefore, Fedcoin is eliminated from the final list of CBDC experiments surveyed in this paper based on **Criteria 1**.

The Bank of Korea [27], Bank of Japan [28], Bank of Israel [29], Norges Bank [30], Reserve Bank of New Zealand [31], Bank of Finland [32], Danmarks National bank [33], Swiss National Bank [34, 35], and the European Union Central Bank [51, 52] have all undertaken research activities about the issuance of DLT-based CBDCs and concluded that they may not issue CBDCs in the medium to long term. As a result, these CBs do not plan to implement PoCs over the medium to long term. These CBDC research are therefore omitted from the final list of CBDC experiments surveyed in this paper based on **Criteria 1**.

The joint research publication by the Bank of England, Bank of Canada, and the Monetary Authority of Singapore [40, 41] seeks to explore new models to improve the efficiency of cross-border payments. Much of the research effort is centered on improving cross-border W-CBDC transaction efficiency, however, an implementation of a PoC arising out of the joint research effort is not a stated goal of the publication. In this regard, the multilateral effort by the three (3) CBs is excluded from the final list of CBDC experiments surveyed in this paper based on **Criteria 1**.

The final list of CBDC experiments surveyed in this paper are therefore the CBDC experiments undertaken by Canada, Singapore, Brazil, South Africa, Germany, and Thailand.

Additionally, the joint experiments by Canada and Singapore, and the European Union and Japan are also surveyed in this paper.

The final list of CBDC experiments that meet our second round screening criteria and therefore surveyed in this paper are presented in Table 1.

Table 1: Selected CBDC Experiment List

Country	Responsible Institution	Experiment Name	Type of CBDC
Canada	Bank of Canada	Project Jasper	W-CBDC
Singapore	Monetary Authority of Singapore	Project Ubin	W-CBDC
Brazil	Central Bank of Brazil	Project SALT	W-CBDC
South Africa	South African Reserve Bank	Project Khokha	W-CBDC
Germany	Deutsche Bundesbank	BLOCKBASTER	W-CBDC
Thailand	Bank of Thailand	Project Inthanon	W-CBDC
Bilateral 1 (Canada, Singapore)	Bank of Canada, Monetary Authority of Singapore	Jasper–Ubin	W-CBDC
Bilateral 2 (EU, Japan)	European Central Bank, the Bank of Japan	Project Stella	W-CBDC

We note that, following the completion of our second round screening process, all the remaining CBDC experiments surveyed further in this paper are of type W-CBDC.

5 W-CBDC Motivations and Practices

CBs motivation for undertaking CBDC research is similar across board. The overarching motivation for CBDC research by CBs is to assess the impact of DLT on FMIs. In particular, the goals of security, safety, efficiency, scalability, resiliency and transparency are themes expressed across board the CBDC experiments surveyed in this paper.

A key practice for CBDC research initiatives is the collaboration between CBs, CMBs and technology service providers. CBs emphasize collaboration between the CB itself, CMBs and other FI participants and technology service providers as key to the success of exploring the potential of DLT and its applicability in the financial service industry as each stakeholder brings unique perspectives and experiences to bear in the development and execution of CBDC experiments.

6 Conclusion and Future Work

Many CBs and MAs from across the world are conducting research to assess the potential benefits and impacts of DLT to FMIs. Of particular interest to CBs and MAs are the security, safety, efficiency, scalability, resiliency and transparency benefits and constraints that DLT could pose on FMIs. As a result, current CBDC research has focused on a few use case scenarios across the financial service industry to evaluate the suitability and applicability of DLT to the financial service industry. Notable use cases for DLT being explored by CBs and MAs include the applicability of DLT for: wholesale interbank payments settlement, securities settlement, bond issuance, trade finance, crossborder payments settlements, and digital identity management or know-your-customer use case scenarios.

CBs emphasize the importance of close collaboration with other CBs, CMBs and other FI participants, and technology service providers at the onset of any W-CBDC research effort. They argue that the success or failure of any CBDC research lies in the strength of the collaboration between the stakeholders of the research.

With regards to technologies for CBDC experiments, an emerging trend observed in CBDC research efforts is a shift towards the use of permissioned DLT platforms for CBDC PoC development. Particularly, DLT platforms with capabilities for settlement finality and data privacy such as Corda, Quorum and Hyperledger Fabric are the dominant platforms currently in use for CBDC experiments. Other notable but less popular DLT platforms being used for CBDC experiments includes: Anquan which is developed and maintained by Anquan Capital; the Chain platform which is developed and maintained by Chain and Elements by Blockstream.

The ultimate goal for our research is to understand the motivations, practices and technologies for current CBDC experiments in order to design and develop the appropriate framework and protocols for the development of Afkoin. Afkoin is intended to be a model CBDC experiment backed by the fifteen Economic Community of West African States (ECOWAS) Member States as a solution to ECOWAS' quest to issue a single currency for use in the ECOWAS region.

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