Complex Systems Informatics and Modeling Quarterly (CSIMQ)
eISSN: 2255-9922
Published online by RTU Press, https://csimq-journals.rtu.lv
Article 161, Issue 28, September/October 2021, Pages 34–58
https://doi.org/10.7250/csimq.2021-28.03

Applicability of Blockchain Technology in Securities Settlement

Jānis Bauvars*

Institute of Applied Computer Systems, Riga Technical University,
Kalku iela 1, Riga, Latvia

Janis.Bauvars@gmail.com

Abstract. Technological advancements are often adopted by financial markets to improve their operations and safety. Blockchain technology has been recognized as one of the potential technologies to be utilized in capital markets. The goal of this article is to evaluate the applicability of using blockchain technology in the securities settlement process. First, the theoretical background of blockchain technology is reviewed and the current financial market infrastructure is examined. Then Central Securities Depositories Regulation and the current securities settlement processes are examined. The blockchain applicability framework designed by Gourisetti, Mylrea and Patangia is applied to assess blockchain technology's applicability to securities settlement. The results suggest that blockchain technology can be applied to securities settlement, and the blockchain type thus used should be a private blockchain with a Proof-of-Authority consensus mechanism. A blockchain architecture model, based on a model provided by Zhuang, Chen, Shae and Shyu, and potential node structure for securities settlement are developed, taking into account the existing literature on blockchain technology, financial markets, and Central Securities Depositories Regulation. The proposed blockchain architecture model and node structure are then evaluated against benefits and drawbacks of using blockchain for securities settlement and cross-border settlement efficiency, that are expected by researchers. The evaluation reveals that the proposed blockchain technology model can potentially improve some of the current securities settlement issues, such as costly reconciliation and difficult cross-border securities settlement. At the same time, using blockchain technology in securities settlement would be challenging because the practical implementation time would be lengthy and would require market-wide commitment. The main artefacts of this article are the proposed blockchain architecture model and node structure that would allow securities settlement processes to be executed using blockchain technology.
Keywords: Blockchain, Securities Settlement, Financial Markets, Decentralized Databases, Blockchain Architecture.

1. Introduction

Throughout decades the financial markets industry has leveraged technological advancements. From the days of recording operations on paper, physical trading on trading floors, and mutual arrangements, advanced technology has brought the industry to the digital age. Now all the steps

*Corresponding author

Reference: J. Bauvars, "Applicability of Blockchain Technology in Securities Settlement," Complex Systems Informatics and Modeling Quarterly, CSIMQ, no. 28, pp. 34–58, 2021. Available: https://doi.org/10.7250/csimq.2021-28.03

Additional information. PII S225599222100161X. Received: 31 August 2021. Accepted: 28 October 2021. Available online: 31 October 2021.

from securities issuance, listing on a stock exchange, trading, and post-trade settlement processes are executed using sophisticated IT systems. It has allowed the industry to provide more advanced, faster, and more secure services to all the market participants. Electronic accounting and modern computers have significantly improved not only the operational procedures of the financial market industry, but also have allowed the development of new products and services that were not imaginable a century ago.

Blockchain technology has the potential to be the technological driving force behind the next leap forward in the financial market industry. Current financial market participants, while focusing on serving their local markets, are standardizing processes, and accommodating cross-border relationships. Many financial market industry professionals have recognized the potential of blockchain technology that could significantly improve the currently existing processes and solve many of the existing inefficiencies [1]. One of the processes identified that could significantly benefit from blockchain technology is the securities settlement process. Also referred to as securities post-trade, the process involves a lot of intermediaries, especially when there are long chains of custody and cross-border settlements. The nature of the financial market ecosystem, where there are centralized entities that execute securities settlement processes and contain large numbers of intermediaries, indicates a potential where blockchain technology could be used. Researchers support it and claim that an environment with multiple intermediaries can benefit from blockchain technology in the areas of data reconciliation efficiencies, reduced risks, increased transparency, and other benefits [2].

Because the securities settlement practices and legislative requirements vary from country to country, it is hard to generalize blockchain's potential in securities settlement on a global scale. Since financial markets in the European Union (EU) are operating under the same or similar legislations, the financial market practices and structures in the EU countries have been harmonized. Therefore, the scope of this article is to examine the applicability and usability of blockchain technology within the EU, considering the current EU-level rules and regulations. It extends the paper presented at the 1st Workshop on Blockchain for Trusted Data Sharing [3] with the inclusion of analysis and evaluation details.

Considering the nature of the current securities settlement process and the financial market ecosystem, the aim of this study is to **assess the applicability of using blockchain technology in the securities settlement process** in the current regulatory environment in the EU. In particular, the author of this article intends to evaluate whether blockchain technology can be used to ensure successful securities settlement, and, if it can, then investigate what would be the possible blockchain architecture and node structure. To achieve the aim of the study, the following tasks are defined:

- Investigate blockchain technology's basics and core functionality,
- Examine the current financial market infrastructure,
- Examine the applicable regulations for securities settlement in the EU,
- Evaluate the blockchain solution's applicability for securities settlement:
    - Evaluate if using blockchain technology is suitable for securities settlement,
    - Define the suitable type of blockchain,
    - Identify the potential consensus mechanism,
- Develop a blockchain architecture model and node structure that describes potential blockchain usage for securities settlement,
- Assess the benefits and drawbacks of the proposed blockchain architecture model and node structure.

The description of the current financial market ecosystem and the regulatory requirements in the EU, presented in Section 2 of the article, is based on the relevant legal acts, international financial market standards, and available literature. The blockchain technology analysis, as well as blockchain technology's applicability to financial markets and securities settlement, discussed in Section 3, is based on an extensive literature review and a blockchain applicability framework developed by Gourisetti, Mylrea and Patangia [4]. The blockchain architecture model, shown in Section 4, is designed by applying a modeling approach used by Zhuang, Chen, Shae and Shyu [5]. The proposed blockchain architecture model and node structure is then, in Section 5, evaluated using Beno's, Garratt's and Gurrola-Perez's [6], and Schaper's [7] expectations of what benefits and challenges a blockchain solution in securities settlement might possess. The article is concluded in Section 6.

2. Blockchain and Financial Markets

In order to study the principles of blockchain technology and identify and evaluate its applicability to securities settlement processes, thorough analysis of the existing literature on blockchain technology and financial market infrastructure in the EU was performed. Since the focus of this article is to evaluate the applicability of blockchain technology, not to analyze the technology itself, the chosen literature on blockchain technology covers only the basics of the technology and highlights only the main principles and components. The current financial market infrastructure is analyzed in order to understand the key activities that each component of the infrastructure does. Knowing the existing financial market infrastructure, market participants, processes involved, and practices used is imperative for us to make an applicability assessment for the use of blockchain technology [8]. The existing literature on blockchain technology's potential applications in financial markets also is reviewed. The review allows us to recognize the potential benefits and drawbacks of using blockchain technology, and also indicates how the financial market infrastructure components would be affected if blockchain technology was used in securities settlement.

2.1 Blockchain Technology Basics

Blockchain technology was first highlighted when an anonymous author or authors using the name Satoshi Nakamoto published an article in 2008 describing how the technology could be used to create and maintain a peer-to-peer network of electronic cash [9]. This article became the basis on which the cryptocurrency Bitcoin was built in 2009. Even though the roots of blockchain technology and the principles of how a cryptocurrency would work were discussed earlier, in the 1990s, Nakamoto's article gained support and increased the popularity of peer-to-peer networks and their use for digital money [10]. The technology behind Bitcoin was soon recognized as potentially usable for other purposes besides cryptocurrencies, and captured the attention of experts and researchers in other areas, such as the health industry, finance, and others [11].

There are multiple definitions of what blockchain technology is. From a technological perspective Bashir defines blockchain technology as a "peer-to-peer distributed ledger that is cryptographically secure, append-only, immutable (extremely hard to change), and updateable only via consensus or agreement among peers" [12]. From a business perspective, he claims that blockchain is a platform where parties using transactions can exchange digital value without having a central governing party. Other peers support this definition and claim that blockchain technology is a type of distributed ledger technology (DLT) that mainly stores information of transactions or digital events [13]. DLT is a type of decentralized database infrastructure where multiple parties (nodes) hold a copy or a part of a shared database, and that operates using certain protocols, to ensure data correctness, updates, and immutability. In academia and practice blockchain and DLT are used as synonyms. However, blockchain includes grouping transactions in blocks and cryptographically signing them, thus, making an immutable list of records, while DLT is the underlying database infrastructure that ensures consensus [13]. Therefore, DLT can be considered to have a broader definition than blockchain. In this article both DLT and blockchain definitions are considered as interchangeable so as to cover a wider spectrum of existing literature and, also, not to exclude potential modeled processes due merely to different interpretations of definitions.

There can be different types of blockchain networks – public permission-less networks and private permissioned networks [12]. Public blockchains are freely accessible by any party. Anyone can become a member of the network, become a node, and participate in the decision-making process. Permission-less networks allow any individual to access the network, receive a copy of the database, and interact with the network. Chiu and Koeppl state that in permission-less blockchain the peer-to-peer network itself manages the ledger, without any central governing party, even when the network participants have diverging interests [14]. These networks have known consensus mechanisms, and anyone can become the validator of the transactions that are happening within the network. The consensus mechanism is necessary for the network to collectively agree on the state of the ledger and ensure that all transactions are correctly recorded. The most common consensus protocol of the pubic blockchains is proof-of-work, also known as mining [14]. During the mining process, the network participants are computing mathematical problems, and the party who solves the problem first, receives the right to create a new block in the blockchain, as well as typically receiving a reward (usually in the form of cryptocurrency). Another popular public blockchain consensus mechanism is proof-of-stake, where the network state is validated based on participants' ownership of the underlying digital assets [15].

To summarize, blockchain technology is a peer-to-peer, distributed, de-centralized network with certain protocols in place to ensure correct operation of the network. There can be different types of blockchain, each having a different set of characteristics that are more useful for particular cases, but less useful for others.

2.2 CSD Role in Financial Market Infrastructure

This section describes the current financial market infrastructure in the EU region and the role of the Central securities depositories (CSDs) securities settlement process. The financial market infrastructure consists of multiple components that are interconnected with each other and allow securities' (also called financial instruments) transactions between the parties. The financial market landscape in different regions and countries can vary and have different components and business practices. However, for this article the focus is on the EU region where the financial market landscape is standardized by similar regulatory standards and requirements. The countries within the EU are regulated by the same laws and regulations that are dictating how the financial markets are operating. To define the current financial market infrastructure, the following information sources were used – CSDR [16], T2S Framework Agreement [17], T2S User Detailed Functional Specifications [18], standards published by Securities Market Practice Group (SMPG) [19], and literature provided by Benos, Garratt and Gurrola-Perez [6]. Using the information provided by the listed sources, Figure 1 is created to describe the main components of the financial market. Each component is either directly involved in the securities settlement process or is providing services that lead to securities transfer.

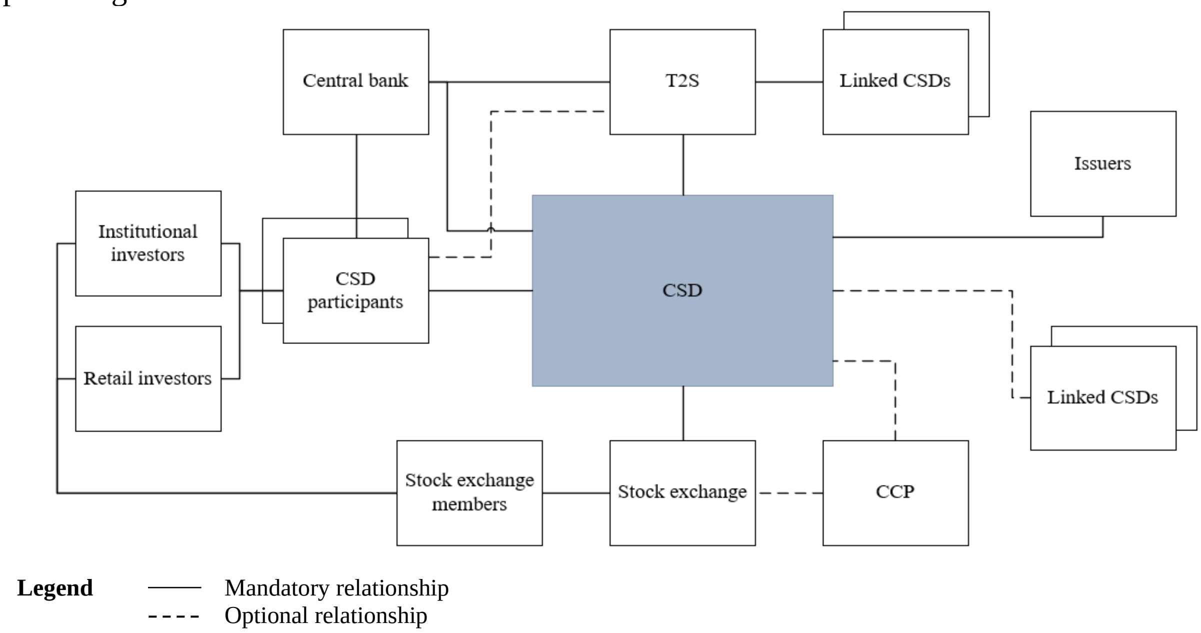

Figure 1. Financial market components and relations (available also in [3])

Central securities depositories (CSDs) have a crucial role in the financial market infrastructure. According to some authors, the CSDs themselves are defined as financial market infrastructures because of their position in the securities settlement chain [20]. All securities transactions that are conducted on stock exchanges or otherwise are processed by the CSDs. According to Regulation (EU) No 909/2014 of the European Parliament and of the Council (CSDR), “securities settlement systems operated by CSDs are of a systemic importance for the functioning of securities markets” [16]. Because of their importance in the financial market infrastructure, the CSDs are highly regulated, usually by the local competent authorities of the country where each CSD operates, such as financial services authorities. The importance of CSDs in the financial market infrastructure is crucial since the ultimate ownership change of securities is registered in CSDs [21]. CSDs operating in the European Union (EU) must comply with EU level regulations, the main one being CSDR. CSDs are entities that operate securities settlement systems (SSS), provide notary services (initial recording of securities in a book-entry form), and provide central maintenance services (registration of securities accounts at the top tier level) for CSD participants – banks or brokerage companies. CSDR defines these functions as core CSD services. For different CSDs operating in different countries, there may be variation in the scope that they provide, but they usually provide the same set of core services.

Since CSDs are often servicing their local countries or regions, there has been a need for connecting various CSDs to enable an extended coverage of securities so that they can be transferred across countries. Therefore, CSDs can make technical and legal links between themselves, thus making securities registered in one CSD available in another CSD. To ease such cross-border settlement in Europe, a separate system was created for European CSDs – TARGET2-Securities (T2S). T2S is a common platform for CSDs that performs securities registration and settlement. It is particularly efficient for linked CSDs because it allows a common cross-border infrastructure for securities settlement without the necessity of linking individual CSDs with varying standards [7].

CSDs and financial markets in the EU are regulated by central securities depositories Regulation (CSDR). The aim of this regulation is to synchronize how CSDs function and how securities settlement is organized within the EU. According to the regulation’s objective and scope, it “lays down uniform requirements for the settlement of financial instruments in the Union and rules on the organization and conduct of CSDs in order to promote safe, efficient and smooth settlement.” Similar operational and legal requirements set by the CSDR also improve the environment to achieve more streamlined cross-border settlement across the EU [16]. CSDR considers the existing global standards issued for financial market infrastructures by the Committee on Payments and Settlement Systems and the International Organization of Securities Commissions.

For this article it is important to understand the legal requirements and implications concerning securities settlement. The current laws and regulations are technology-agnostic and do not specifically define what technological solutions are allowed or not allowed to be used for securities settlement. Therefore, any solutions that are used should be compliant with the legal and regulatory environment. Since blockchain technology, as such, is considered as disruptive and could potentially replace or drastically change the operations of some financial market infrastructure components, it is important that the changes imposed are still compliant with the relevant legal and practical requirements defined by the law. When modeling the potential blockchain solution that could be used for securities settlement, the general principles and operational requirements defined by CSDR must be considered.

To summarize, the financial market infrastructure consists of multiple participants. In particular, the securities settlement process is managed by CSDs, which are interconnected with multiple other entities. There can be a long chain of intermediaries where in the financial instruments are processed. Having multiple parties operating as intermediaries indicates that there might be a potential benefit for optimizing the connections and business process flows, by having a de-centralized infrastructure, such as blockchain [22].

2.3 Blockchain in Post-Trade Industry

Blockchain technology, by its nature, has the potential to disrupt the existing infrastructure and business processes in the financial industry [23]. The authors of [23] claim that even though the technology is relatively undeveloped, it already demonstrates significant potential to be able to introduce innovative solutions. Guo and Lian [1] supplement this view by claiming that blockchain technology can be used to tackle various issues being raised in the financial industry. One of many potential applications of the technology is using blockchain for data sharing. Since blockchain allows storing encrypted data among many participants, a logical conclusion is to use it for business processes where similar information needs to be shared among different parties. In the current securities settlement process, there are regular reconciliation processes happening between CSD, CSD participants, linked CSDs, T2S, and others, to ensure the integrity of the securities issue and to validate that the balances match in all the intermediaries. Blockchain technology, by its nature, could ease the currently complex and time-consuming reconciliation processes because of the way that data is shared among the distributed databases [1].

It has been identified by Meijer that distributed technologies could radically change how securities settlement is being processed [21]. In the current market infrastructure setup, the environment is extremely fragmented, with a lot of intermediaries involved. Each of the intermediaries may be operating archaic systems that are hard to coordinate with each other, especially in an environment with many counterparties. Meijer claims that it leads to inefficiencies, requiring significant efforts to manage risks and ensure proper reconciliation between the parties and systems. Considering these inefficiencies, a blockchain platform could allow cost reductions, easier securities issuance, and simpler securities settlement. Meijer argues that blockchain technology is able to perform multiple activities that CSDs are currently providing, including issuance of securities, managing ownership, as well as processing securities settlement. However, it does not mean that a CSD would cease to exist. Instead, the CSDs could pivot and perform a different role in the financial market ecosystem, compared to that which they currently have. The CSDs could become the managers of the blockchain networks, set the relevant rules, define processes, and provide supervisory or governance functions.

At the same time, Meijer claims that the exact financial market infrastructure and the related process changes are unknown. To enable the full potential of blockchain efficiencies, a collaborative blockchain solution among CSDs would be needed. Other researchers agree that blockchain technology would de-centralize the current post-trade processes, and reduce the number of intermediaries; however, only a few solution providers are likely to remain and these would dominate the market [6]. Several CSDs could try to leverage the first mover advantage and build a blockchain solution that would be used by other financial market participants. It could also happen that the pursuit to build the first operating large-scale network could suffer from inappropriate design, security risks or other flaws.

Altogether, there are conflicting views as to whether the blockchain technology itself can improve the financial market ecosystem. As Mori states, the majority of obstacles that prevent blockchain adaptation to CSDs are due to the existing business processes. Only a fraction of the issues can be attributed to the technology itself [22]. Therefore, without changing the underlying business processes and legislation, the use of the technology itself would not solve the existing inefficiencies.

3. Blockchain Applicability for Securities Settlement

In order to achieve the aim of this article and evaluate whether blockchain technology is applicable to securities settlement, the author applies a blockchain applicability framework [4]. It allows the measurement of the applicability of blockchain technology for a particular application. After the blockchain applicability framework is used, the results are analyzed to assess the blockchain technology’s applicability for securities settlement.

3.1 Blockchain Applicability Framework

In this section we use the blockchain applicability framework designed by Gourisetti, Mylrea and Patangia [4] to evaluate blockchain technology's applicability to the securities settlement process previously described. This applicability framework was chosen because it allows the following tasks of this article to be achieved – to evaluate whether blockchain technology can be used for securities settlement, define the most appropriate type of blockchain, and identify the most suitable consensus mechanism.

Gourisetti, Mylrea and Patangia recognize that blockchain technology can be used in applications other than cryptocurrencies; such applications being in various industries and to realize the usefulness of the technology in each case, the blockchain applicability framework was built. When using the framework, first the control questions are checked, and then the control questions are analyzed under each of the categories displayed. Then the answers for each category are counted in order to calculate the percentage distribution of those answers.

The framework answers the following questions (defined by its authors) regarding blockchain's applicability:

1) Does the application need a blockchain?
2) If the application needs a blockchain, does it need a private blockchain or permissionless/public blockchain?
3) What kind of consensus is most suitable for the application?

Regarding the applicable consensus mechanism, the framework evaluates four consensus mechanisms – Proof-of-work (PoW), Proof-of-stake (PoS), Proof-of-burn (PoB), Proof-of-authority (PoA).

The blockchain applicability framework asks 92 control questions to determine the applicability of each question. The authors of the framework claim that the controls are designed by evaluating numerous operating blockchain solutions, their core concepts, similarities, and differences; as well as by analysis of consensus mechanisms, and other aspects [4]. Within the framework, the controls are categorized in five distinct groups - data and participation, technical attributes, security, trust parameters, and performance and efficiency.

The framework states that answering the control questions gives a mathematical result for a particular situation – in this case, applicability of the blockchain solution for securities settlement. After the control questions are answered, the applicability framework indicates three different possible classes:

1) Blockchain versus no blockchain,
2) Permissioned/private versus permission-less/public,
3) PoW versus PoS versus PoB versus PoA.

For each of the control questions, there can be four states, each one having a different weight [4]. The control question can also have multiple states, if covering multiple classes. Table 1 summarizes the possible states and their weights.

Table 1. Control question states and their weights

State	Abbreviation	Weight
Fully applicable	F	2
Largely applicable	L	1
Partially applicable	P	1
Not applicable	N	2

Next, in this article, the control questions in Tables 2–6 are answered, where all states and their corresponding weights are selected. The answers are grouped by the respective domains in the tables below. The column "Controls" displays each control question, columns "F/L" and "P/N" represent the possible states described in Table 1. Their values indicate the following possible target classes:

- Y – blockchain / N – no blockchain,
- V – permissioned, private / U – permissionless, public,
- W – PoW / B – PoB / S – PoS / A – PoA.

The column "State" contains the answers to the control questions and is completed by the author of this article. The answers are based on the previously recognized literature as well as regulatory requirements. The respective source, which was used to derive the answer, is indicated in column "Reference". Each answer indicates the applicable state for each control question, and the respective weight is specified in column "Weight".

Domain 1: Data and participation. This domain summarizes, in Table 2, the control questions on data attributes, authority nodes, readers and writers and their characteristics, Table 2 displays the control questions and the respective selected states of this domain. The assessment of the answers was made, based on the previous literature on blockchain's applicability to securities settlement, where it was indicated that CSDs could maintain their role of governing who could access the network and what would be the participants' rights [21].

Table 2. Domain 1 of the blockchain applicability framework [4]

Domain 1: Data and Participation						
Data Attributes						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
1	Is there a need to store data?	Y	N	F	2	[12]
2	Is all the data coming from a single entity?	N	Y	N	2	[19]
3	Does a traditional database technology meet the needs?	N	Y	L	1	[21]
4	Is the database likely to be attacked?	Y	N	F	2	[16]
5	Is there a need to modify historical data?	N	Y	N	2	[16]
Authority Nodes						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
6	Is there a need to have authorized access in the blockchain such that there is access control over which of the data is public and private?	V	U	F	2	[21]
7	Are there authority nodes to maintain the database in the blockchain?	V	U	F	2	[21]
Readers and Writers						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
8	Are there multiple parties/participants?	Y	N	F	2	[16]
9	Is there a need for more than one participant to update the data?	Y	N	F	2	[16]
10	Can any peer join the blockchain as a reader without needing approval at any time?	U	V	P	1	[16]
11	Can any peer join the blockchain as a writer without needing approval at any time?	U	V	N	2	[16]
12	Is there a need for a relatively large number of writers in the blockchain?	U	V	P	1	[16]
Reader and Writer Characteristics						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
13	Are the identities of the readers known?	V	U	F	2	[16]
14	Are the readers trusted in the system?	N	Y	P	1	[21]
15	Are the identities of the writers known?	V	U	F	2	[16]
16	Are the writers trusted in the system?	N	Y	P	1	[21]
17	Do the writers have unified or well-aligned interests?	NV	YU	F	2	[16]

Additionally, control questions that require the determination of the environment of the application were answered, based on the current definitions set by the CSDR. The control question answers indicate that the participants of the potential network would be known, and their access would be regulated. Namely, the nodes of the network would be CSD participants and their ability to operate would be assessed by the CSD, as the current regulation requires. Table 2 displays the control questions and the respective selected states of this domain.

Domain 2: Technical attributes. This domain includes sections of codebase and networks, smart contracts, transaction constraints, transaction processes, and miners and consensus sub-domains. The answers to these control questions were based on the current financial market infrastructure and the specifics of the securities settlement process defined by the CSDR, and the evaluation of the blockchain applicability by other researchers. As previously identified by Mori, if blockchain is used in securities settlement, the blockchain network should ensure close to real-time settlement; it should be cryptographically safe and accurate; moreover, the transactions and securities ownership should be traceable [22]. This view is reflected in the control question answers; where the transactions should be private, there is no need for public access to the network, just as there is no need to have a voting-based consensus mechanism. Table 3 displays the control questions and the respective selected states of this domain.

Table 3. Domain 2 of the blockchain applicability framework [4]

Domain 2: Technical Attributes						
Codebase and Networks						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
18	Is there an involvement of an online trusted third party (TTP) in the system?	N	Y	F	2	[21]
19	Is there a need to have the ability to manage the blockchain centrally?	V	U	F	2	[21]
20	Is the core blockchain code an open-source code?	U	V	L	1	[16]
21	Is there a need to have same people updating both the code and the blockchain?	V	U	F	2	[21]
22	Is there a need that the blockchain nodes be uncertain about the exact number of nodes currently participating in the blockchain?	U	V	N	2	[16]
23	Is there a need to have the guarantee that all the nodes' experience with the blockchain to be consistent with each other?	V	U	F	2	[16]
24	Has every node unrestricted full authority and capability to interact with other nodes by creating an address on the blockchain network?	U	V	P	1	[21]
25	Is the blockchain network massively distributed?	UWBS	A	P	1	[16]
Smart Contracts						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
26	Are policies and (smart) contracts involved and managed?	Y	N	F	2	[12]
27	Can anyone participate in the process of block verification and to create smart contracts in the blockchain?	U	V	P	1	[21]
28	May the blockchain nodes (who can create smart contracts) also have restricted access?	V	U	L	1	[21]
Transaction Constraints						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
29	Are exchanges and transactions involved?	Y	N	F	2	[16]
30	Do the blockchain need to first provide the nodes with the rights to view the transactions?	V	U	F	2	[16]
31	Is there a requirement to get authorization to validate transactions in the blockchain?	VA	UWBS	F	2	[21]
32	Is there a need for the transactions to be validated by votes/consensus?	Y	N	N	2	[21]
33	Is the transactional fee required to carry out transactions very small (or null)?	V	U	F	2	[22]

Table 3. Continued

Transaction Processes, Miners and Consensus						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
34	Are the transactions private?	V	U	F	2	[22]
35	Are there high performance and fast transaction needs?	V	U	F	2	[22]
36	Should data-in-transit or transactions between the nodes be encrypted (or needs more encryption)?	V	U	F	2	[22]
37	Is there a strong need or emphasis on the security of the blockchain transactions?	V	U	F	2	[22]
38	Is a time-consuming transaction verification process in the blockchain acceptable?	UWB	VA S	N	2	[22]
39	Is there a need for short transaction frequency in the blockchain?	V	U	F	2	[22]

Domain 3: Security. This domain includes governance, security activities, and access control sub-domains shown in Table 4, which displays the control questions and the respective selected states of this domain. Answers to these control questions were based on the technical requirements originating from CSDR. CSDR is clear on the responsibilities of the CSDs and what are the necessary security measures that the CSDs and their SSSs must ensure. Should a blockchain solution either partially or fully replace the CSDs and their SSSs, it would still be required to be compliant with the applicable regulations, including the ones regarding security and proper governance of securities settlement. This means that the CSD participants would need to be vetted, counterparties should be able to access only the data that is relevant to them, and the integrity of securities issuances, transactions and balances would need to be compliant with the applicable standards and regulatory requirements.

Table 4. Domain 3 of the blockchain applicability framework [4]

Domain 3: Security						
Governance						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
40	Is there a need for miners in the blockchain?	VA	UWSB	N	2	[24]
41	Is there a need to have presence of an additional authentication and authorization layer on miners in place in the blockchain?	VS	UWB	F	2	[21]
42	Can any node join the blockchain at any time and become a miner?	UWB	VAS	N	2	[24]
43	Is there a need to improve the speed and data storage capacity of a blockchain by removing miners from it?	VA	UWSB	N	2	[24]
44	Can anyone join the protocol execution in the blockchain?	UWB	VAS	N	2	[24]
45	Is there requirement for all the nodes to participate in the consensus process?	U	V	P	1	[24]
46	In an environment where anyone can be a miner, is there a requirement that certain miners should be prioritized over other miners?	S	WB	F	2	[24]
47	For more efficiency and less block creation time, is it acceptable for only certain nodes to have consensus power?	SAB	W	L	1	[16]
48	Is recursive hashing required for the consensus process?	W	SAB	P	1	[12]
49	For increased trust and ease of verifiability, is it acceptable (and required) if the nodes are required to sacrifice their tokens to form consensus?	B	WAS	N	2	[12]

Table 4. Continued

Domain 3: Security						
Governance						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
50	Should the creator of the new block be chosen in a deterministic way such as wealth of the node, willingness for the node to sacrifice some wealth, etc.?	SB	WA	N	2	[12]
51	Is there a requirement for the miners to be rewarded for block creation?	WB	SA	N	2	[24]
52	For block creation, should the reward depend on the wealth burned to create the block?	B	WAS	N	2	[24]
53	Is there a need of censorship in the system?	N	Y	N	2	[16]
54	Is there a need to have a censorship-resistant blockchain?	U	V	P	1	[16]
55	Is lack of governance in the blockchain acceptable?	U	V	N	2	[16]
Security Activities						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
56	Is there a need to trust authority nodes to secure the blockchain network?	V	U	F	2	[16]
57	Is there a requirement for the blockchain to maintain privacy of user data without consolidating power with a single organization?	V	U	F	2	[16]
58	Is there a need to have privacy and security access in the blockchain such that there is access control over which the data is public and private?	V	U	F	2	[16]
59	Is there a need to hold more data in a block without slowing things down or threatening its security in the blockchain?	V	U	F	2	[16]
60	Arbitrarily, can any protocol participants drop off and new participants join in the blockchain without compromising with the security properties for newly joined nodes?	U	V	L	1	[16]
61	Is there a need for the communication between blockchain nodes to take place over authenticated channels?	V	U	F	2	[16]
Access Control						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
62	Is there a need to control who can make changes to the blockchain software?	V	U	F	2	[16]
63	Is the blockchain history open to any participating node (without the need of authorization)?	U	V	N	2	[16]
64	Is there an open access to read the information but require permission to access or transact on the blockchain network?	V	U	F	2	[16]
65	Is there a need to have a borderless blockchain?	U	V	P	1	[16]

Domain 4: Trust parameters. This domain includes visibility, integrity, and validation sub-domains. The answers to these control questions were based on both CSDR requirements and Mayer's view on the future tasks of the CSDs. The parties involved in the securities transactions should be known, but the data scope they access should be limited to themselves. For instance, a CSD participant should be aware of the transactions and balances of its own clients, but not the clients of another CSD participant. There should be a party that governs the access rights and defines the rules on what information can be accessed by which party [21]. Table 5 displays the control questions and the respective selected states of this domain.

Table 5. Domain 4 of the blockchain applicability framework [4]

Domain 4: Trust Parameters						
Visibility						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
66	Will all the nodes have different view of the system state based on the centralized system decision?	N	Y	N	2	[16]
67	Will all nodes have the same view of the system state of the blockchain without requiring approval?	U	V	L	1	[16]
68	Is there a need for a fully transparent system?	Y	N	L	1	[16]
69	Is it required for some nodes to not see information/transactions performed on the blockchain?	N	Y	F	2	[16]
Integrity						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
70	Is there a centralized system to ensure the integrity of the data?	N	Y	F	2	[21]
71	Are there authorized nodes to ensure the integrity of the transactions and architecture of the smart contracts?	VA	U	F	2	[21]
72	Can a peer without permission be trusted with the integrity of the data?	U	V	N	2	[21]
Validation						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
73	Can any node verify the change in the state of the blockchain system, without any additional authorization?	UWSB	VA	N	2	[21]
74	Is there a centralized system to verify the change in the state of the system?	N	Y	F	2	[16]
75	Can a blockchain user acquire "the right to validate" in exchange for their identity disclosure (voluntarily)?	VA	U	N	2	[21]
76	Are the content on the blockchain publicly verifiable?	U	V	N	2	[16]
77	Is there a need for the blockchain nodes to elect a leader, which will have the role of validating transactions and extending the blockchain?	A	WSB	N	2	[21]

Domain 5: Performance and Efficiency. This domain includes system performance, expandability, and market design sub-domains. According to CSDR, the system that operates securities settlement should be capable of ensuring that the volumes of the peak amounts of securities transactions can be accommodated. Therefore, the answers to the control questions allow for no compromises on the latency, throughput, and performance of the system. Additionally, the blockchain solution should be capable of scaling up to ensure cross-border securities settlement and also function as the current CSD link to other entities. Table 6 displays the control questions and the respective selected states of this domain.

After answering all the control questions, the respective target classes were aggregated according to their weights. This allowed the generation of a representative view of blockchain's applicability for securities settlement. In the next section the results of the applicability framework are presented and analyzed.

Table 6. Domain 5 of the blockchain applicability framework [4]

Domain 5: Performance and Efficiency						
System Performance						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
78	Is compromise with the system performance in terms of latency acceptable?	Y	N	N	2	[22]
79	Is slow system latency acceptable in the blockchain?	U	V	N	2	[22]
80	Is compromise with the system performance in terms of throughput acceptable?	Y	N	N	2	[16]
81	Is there a need of high throughput in the blockchain?	V	U	F	2	[16]
82	Is compromise on the efficiency of the blockchain acceptable?	U	V	P	1	[16]
Expandability Attributes						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
83	Is there a need of high immutability with access controlled by authority nodes in the blockchain?	V	U	F	2	[16]
84	Is there a need for the blockchain to be able to scale easily?	V	U	F	2	[16]
85	Is there a need for the blockchain to have more customizability?	V	U	L	1	[16]
86	Is there a need for the blockchain to have more adaptation options?	V	U	L	1	[16]
87	Is there a need to have compatibility across different versions throughout blockchain lifecycle to avoid problems such as possible forking, chain splits, etc. in the blockchain?	V	U	F	2	[16]
Market Design						
ID	**Controls**	**F/L**	**P/N**	**State**	**Weight**	**Reference**
88	Is a contractual based market approach needed?	Y	N	F	2	[16]
89	Is price volatility a concern in the blockchain?	U	V	N	2	[16]
90	Are reputation risks of certain nodes accepted while incentivizing them?	VA	U	F	2	[16]
91	Do the benefits outweigh the associated costs?	Y	N	F	2	[16]
92	Is the risk that originates from probable single point failure an acceptable tradeoff as per business needs?	V	U	N	2	[16]

3.2 The Results Obtained Using the Blockchain Applicability Framework

This section depicts and analyzes the results of evaluating the securities settlement process within the blockchain applicability framework. After aggregating and comparing the weighted answers (target classes) to the control questions, it was possible to evaluate the decisions according to the comparative legend described by the framework [4]. The results of the comparisons are summarized in Figure 2.

The blockchain applicability framework indicates that blockchain is indeed suitable to be used for securities settlement (61% vs 39%). This result is consistent with the previously reviewed literature that indicates blockchain's potential usage in the financial markets [25]. Identification of the potential to use blockchain technology allows analysis of the appropriate type of the technology to proceed.

By a large margin (90% vs 10%) the framework suggests that, for securities settlement, the most appropriate type is private permissioned blockchain. Again, it is consistent with the reviewed literature and can be explained by the regulatory and practical need to have a governed control over the blockchain network [12], [23]. Furthermore, it also complies with the possibility that the

CSD will maintain its governance role in the financial market ecosystem and become the gatekeeper of the network [6].

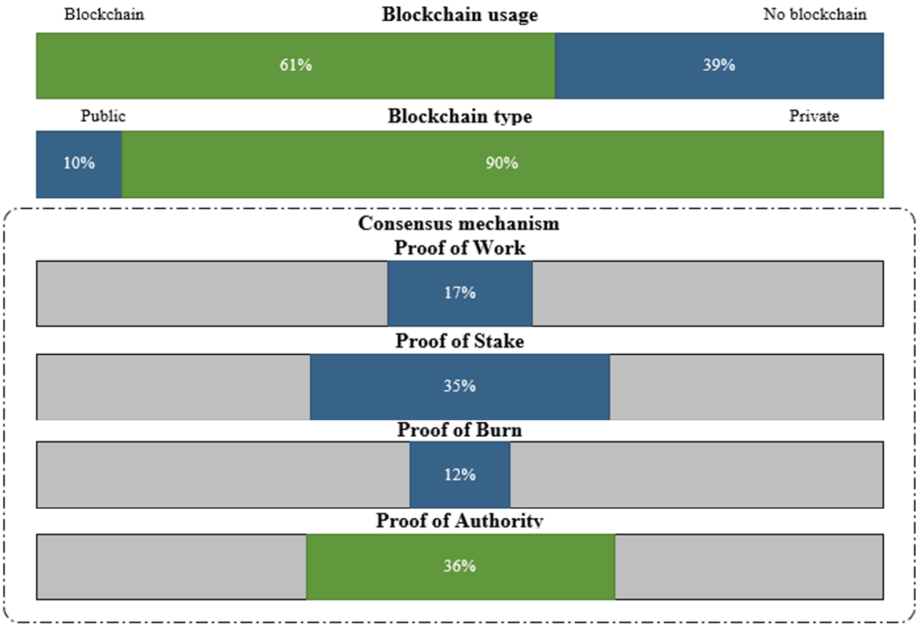

Figure 2. Results of blockchain applicability analysis (available also in [3])

Regarding the most suitable consensus mechanism, two distinct mechanisms are considered more suitable than two of the others. In particular, proof-of-stake and proof-of-authority consensus mechanisms are considered to be the most suitable ones for securities settlement (36% and 35% vs 12% and 17% for others). Not considering the proof-of-work consensus mechanism as applicable is in line with the need to facilitate fast and high-volume transactions and information exchange between the blockchain participants. However, the proof-of-work consensus mechanism is computationally expensive and can result in limed performance capabilities by the network [12]. Also, it is understandable that the proof-of-burn consensus mechanism was not indicated as a suitable one. According to CSDR and the business logic, investor holdings should not be affected by non-relevant activities and, therefore, they should not be decreased just to ensure the operations of the underlying blockchain. Additionally, the proof-of-burn consensus mechanism is more suitable for cryptocurrencies, not for cases where the underlying asset is a security [4]. Regarding the suitable consensus mechanisms, there is no distinct indication from the framework as to which would be more suitable for securities settlement. However, respecting the assessment of Meijer on the potential role of the CSD as the governing party, the proof-of-authority consensus mechanism could be more suitable than the proof-of-stake consensus mechanism [21], [26]. If the proof-of-stake consensus mechanism is chosen, then it becomes unclear which entity would fulfill the governing responsibilities of the network [12].

4. Modeling Blockchain for Securities Settlement

In this section the main artefact of the article – the model of how blockchain technology can be accommodated in securities settlement – is presented. The model consists of two parts – the blockchain architecture model and node structure definition. In Section 4.1 the blockchain architecture model that has been developed is discussed. In Section 4.2 the potential node structure of the securities settlement on blockchain is depicted.

4.1 Blockchain Architecture Model

To define and represent the overlay of the blockchain architecture, a modeling approach used by Zhuang, Chen, Shae and Shyu [5] is adapted for securities settlement on blockchain. These researchers have defined a generalized blockchain architecture for healthcare applications [5]. This architecture was chosen from among others because the model developed represents the main components of a blockchain architecture, and also indicates the information exchange principles, which is consistent with the goals of defining the blockchain architecture in this article. Additionally, the model is using a private blockchain environment, which is suitable for securities settlement as outlined in the results of the blockchain applicability framework. Lastly, the model is agnostic regarding the underlying blockchain solution and consensus mechanism, as it uses blockchain as one of the layers of the architecture. The current environment of a healthcare system, as described, is also relatable to the financial market ecosystem. In healthcare the personal client information, health records and other information are highly sensitive, and are stored in encrypted form by the local healthcare facilities in protected IT networks [5]. As the current financial market infrastructure description depicts, storing information about the individual holding of securities is also sensitive data that is being book-kept by individual facilities – banks or brokerage companies.

The blockchain architecture model proposed by Zhuang, Chen, Shae and Shyu [5] assumes three layers – an application layer, an interfacing layer, and a transaction layer. Each of the layers allows different functions to be performed.

Transaction layer. At the core of the transaction layer is the blockchain network itself and the smart contracts used for automated processes. At this layer the nodes would maintain the distributed databases at their premises and ensure operation of the underlying blockchain solution. The transaction layer also ensures data encryption and safe transfer between the blockchain network's participants. In the context of securities settlement, the information being transmitted on the transaction layer would be similar to the currently exchanged information between the CSD and CSD participants as per ISO 20022 messaging standards. The data scope would be close to the ISO 20022 messaging standard because it contains the mandatory information fields required by CSDR. In their model, Zhuang, Chen, Shae and Shyu [5] use defined smart contracts in the transaction layer to exchange information between the blockchain network members and also to manage information access. However, when securities settlement is considered, the intended functions of the smart contracts would be different from the ones defined by the authors, because the processes that a blockchain solution for securities settlement includes would differ from the ones ensuring healthcare information exchange. Additionally, usage, scope definition, and functions of smart contracts are dependent on the specific underlying blockchain solution that is used for building the network [12]. Therefore, in the model developed for securities settlement, specific smart contracts are excluded so that the model would be agnostic when applied to any specific blockchain solution.

Interfacing layer. The proposed model by Zhuang, Chen, Shae and Shyu [5] includes 4 methods for interacting with the blockchain network:

- Get: to receive certain data from the network participants,
- Store: to save certain data in the network,
- Post: to enter metadata or requests in the blockchain,
- Send: to deliver data to an authorized recipient.

For securities settlement process defined by CSDR, settlement should be initiated by submitting settlement instructions. This requirement can be fulfilled by the *Post* method. The CSD participants or other entities, such as supervisory authorities, may need to reconcile their systems with the blockchain network. Therefore, the *Get* method could be used for such a purpose. The same method can be used by the CSD participants in order to receive updates on the settlement instructions they have submitted, as well as perform internal data reconciliation. When securities are registered and issued, information concerning them must be stored and shared on the blockchain network. For this purpose, the *Store* method could be used. The CSD can use the *Send* method to deliver settlement related information to the network participants, such as information about securities issuance, corporate actions, and other matters. Therefore, all four methods – *Send*, *Get*, *Store*, *Post*, can potentially fulfill all the necessary actions for securities settlement on blockchain.

Application layer. The application layer allows various applications to interact with the data stored on the blockchain. It uses the interface layer to collect the data or instruct data to be transmitted to the blockchain. The applications themselves do not have direct interaction with the blockchain network, and they cannot change or impact the settings of the network [5]. In the context of securities settlement, the main applications in this layer would be the relevant banking systems, or other systems, used by the CSD participants for keeping records of the CSD participants' client information. Most blockchain solutions are unsuitable for keeping large sets of information on the blockchain itself and thus require such information to be stored off-blockchain [5]. Therefore, it follows that the CSD participants should not keep all the information about their clients on blockchain. The blockchain network should ensure the security of information exchange primarily related to securities settlement. The CSD participants would need to integrate their own internal banking or other systems, where the client information is kept, in the application layer of the blockchain architecture. At the same time, other relevant applications, such as analytical tools, reporting applications, and reconciliation applications would also be able to process data gathered on blockchain in the application layer.

Figure 3 displays the proposed layered blockchain architecture for securities settlement. It indicates the application, interfacing and transaction layers present at each node of the blockchain network.

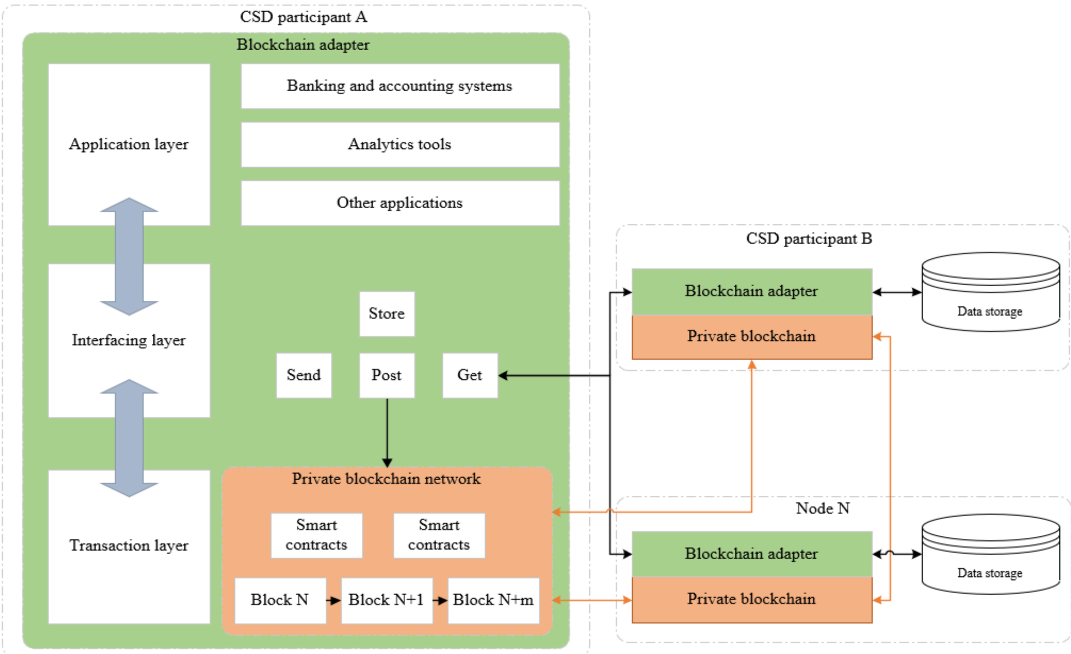

Figure 3. Layered blockchain architecture model for securities settlement (available also in [3])

The proposed layered blockchain architecture model would allow securities settlement to occur as follows:

1) CSD participant A initiates securities transfer in its banking or accounting system,
2) The securities transfer is communicated to the blockchain network using Post method (equivalent to settlement instruction),
3) The counterparty CSD participant receives the relevant information about the initiated securities transfer using Get method,

4) Depending on the underlying blockchain solution, the counterparty CSD participant either approves (signs) the proposed transaction, or does so, and also communicates transfer information to the blockchain network (equivalent to settlement instruction),
5) Depending on the underlying blockchain solution, the securities are settled either by the smart contract configuration or other pre-defined process,
6) The CSD validates the securities settlement and the state of the network,
7) The CSD participants update their banking or accounting systems according to the information received from the blockchain network using Get method.

4.2 Node Linkage Structure

When the blockchain architecture is defined at each node's level, it is also important to define the node linkage structure itself, in order to describe the financial market infrastructure, if blockchain is used for securities settlement. According to the proposed blockchain architecture model, each of the network participants that hold and exchange information on blockchain, should be a node – a holder of a copy or part of a copy of the shared database. This approach is also consistent with the literature on blockchain fundamentals, where nodes are the individual parties that interact with the distributed system, can send and receive information to the network, and work in an organized manner according to the network's rules [12]. In the context of the current securities settlement process, all parties that are directly involved in sending securities settlement instructions to the CSD, should become nodes of the blockchain network. Therefore, for securities settlement on blockchain, the nodes should be banks and brokerage companies that are currently CSD participants.

Currently, to ensure successful cross-border securities settlement, the CSDs have to establish technical and legal links with each other, to allow securities issued in one CSD to be settled in another CSD. If a blockchain solution were to be used for securities settlement, the usage of CSD links would be dependent on the geographical and legal participation of the linked CSD's participants in the blockchain network. If they are technically and legally capable of being a part of the blockchain network, then there is no need for having links between the CSDs, and the linked CSD's participants can become nodes, or participants, of the blockchain network themselves. However, if they are not capable or willing to become members of the blockchain network, the linked CSD itself can become a node of the network and ensure cross-border interoperability between the CSD participants on the blockchain network and off the blockchain network.

Since there can be multiple scenarios with various kinds of combinations of how CSD links are established, this article does not consider all the possibilities and details of such relationships, as these are not within the article's scope. Therefore, the possibility of a potential link with an off-blockchain CSD, and consequently with its participants, is recognized only in general terms. Similarly, T2S, as the central hub between the CSDs within the EU, is considered as a potential, but not definitely necessary, part of the blockchain network.

Central banks can have a dual role – they are involved in the cash transfer part of securities settlement, and they can also be CSD participants themselves. Since they have to interact directly with the network (the cash settlement leg of the securities transfers), they have to be part of the blockchain network as nodes as well.

According to other researchers, even though the CSDs are not the ones managing an SSS and directly ensuring securities settlement, they can still be part of the blockchain network and provide supervisory, validatory or gate-keeper functions of the network [21].

Additionally, there can be other interested parties that could become members of the blockchain network, such as supervisory authorities. These parties could access the relevant data directly from the network.

Figure 4 summarizes the components of the current financial market ecosystem that would become nodes of the blockchain network for securities settlement.

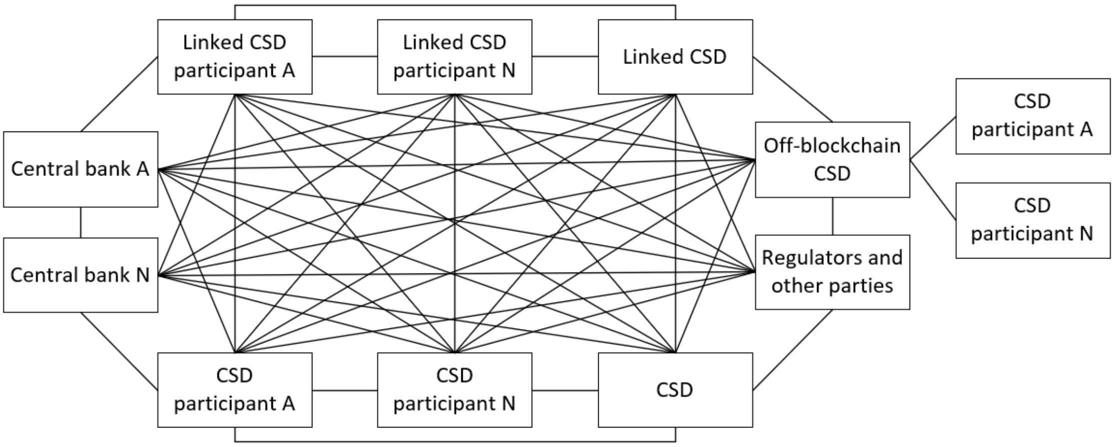

Figure 4. Proposed node linkage structure for securities settlement on blockchain (available also in [3])

5. Evaluation of Securities Settlement on Blockchain

This section evaluates the proposed blockchain architecture model and node linkage structure for securities settlement on blockchain. It reviews the existing literature on identifying benefits and drawbacks of using distributed systems for securities settlement. Two sources have been selected to evaluate the model. They have been selected because they allow the usefulness of using blockchain technology, instead of traditional systems for securities settlement, to be evaluated.

First, in Section 5.1 the impact on the existing securities settlement frictions is analyzed using Benos, Garratt and Gurrola-Perez's [6] assessment. They identify the potential benefits and drawbacks of using blockchain technology in securities settlement. The proposed blockchain architecture model and node linkage structure is evaluated against each of the potential benefits and concerns that they have identified. Then, in Section 5.2, Schaper's analysis of the integration of European securities settlement is used to evaluate the efficiencies of using blockchain for securities settlement in a cross-border setting when multiple markets are connected. The proposed blockchain architecture model and node linkage structure is evaluated against other models that have different characteristics for cross-border settlement.

5.1 Impact on Frictions of Securities Settlement

Benos, Garratt and Gurrola-Perez [6] have analyzed how blockchain technology could potentially solve the frictions (issues) in the traditional securities settlement process. They consider various practical and theoretical benefits stemming from using a distributed network to settle securities [6]. Their finding, concerning the theoretical implications of the issues respecting the traditional securities settlement process, are compared with the proposed blockchain architecture model and node linkage structure, in order to investigate whether that model and structure would bring the expected benefits and solve the issues described by the authors of [6].

The potential benefit (and also drawback) applicability is measured by identifying the following values: applicable (benefit is realized by the modelled blockchain), neutral (the modeled blockchain does not have an impact), not applicable (the benefit is not realized by the modeled blockchain).

Table 7 lists the potential benefits of using blockchain technology for securities settlement identified by Benos, Garratt and Gurrola-Perez [6]. The applicability and the relevant reasoning are assessed by the author. The basis of the applicability evaluation and the reasoning is the previously identified literature, as well as the attributes and intended functions of the proposed architecture model and node structure.

Table 7. Evaluation of benefits of the proposed blockchain architecture model and node structure

Benefits	Description	Applicability	Reasoning
Reducing reconciliation and data management costs	Shared, distributed, and synchronized records of ownership would automate data reconciliation and back-up system costs.	Applicable.	Traditional reconciliation between the CSD and CSD participants is done using reports from the CSD. On blockchain, the reconciliation becomes simplified as the nodes already have access to the shared database [21].
Flexible settlement times	Duration of settlement cycle could be reduced, reducing settlement risk (if pre-positioning of cash and securities is possible).	Not applicable.	The settlement cycles are not defined by the underlying technological solution, but by the regulatory requirements and market practices.
Automated clearing	Blockchain should include netting algorithms to reduce operational risks and liquidity demands.	Neutral.	The netting algorithm or pre-funding can be implemented in the blockchain solution using smart contracts [22].
Direct ownership	Custody chains could be reduced due to facilitated direct ownership, thus leading to greater transparency of holdings and beneficial owners, and lower intermediation costs and operational risks.	Applicable.	If multiple CSD participants, especially linked CSD participants perform the transactions on beneficial owner accounts, greater transparency and lower intermediation is achieved.
Traceability and transparency	Immutability of the blockchain could allow full traceability of securities and money flows.	Applicable.	The nature of the blockchain solution would improve immutability, traceability, and transparency of the transactions on the blockchain [24].
Enhanced security and resilience	No single point of failure reduces the failure risk and improves recovery time in case of attacks. Encryption and cryptographic signatures improve the security.	Applicable.	The distributed nature of the blockchain solution would reduce failure risks [24].

The theoretical implications of the issues of the traditional securities settlement process are compared with the proposed blockchain architecture model and node structure, in order to investigate whether the proposed model and node structure would bring the expected benefits and solve the issues described by the authors. Besides recognizing the potential benefits, Benos, Garratt and Gurrola-Perez [6] also acknowledge potential problem areas that might be caused, either by using a blockchain solution, or by the blockchain solution not being compatible with the existing regulatory requirements. Table 8 summarizes the potential issues they have recognized. Similarly, to the benefit applicability analysis, the potential issue applicability for the proposed blockchain architecture model and node linkage structure, is evaluated by the author of this article, using the same methodology and classification as for the benefit applicability analysis.

The analysis of the potential concerns listed by Benos, Garratt and Gurrola-Perez [6] indicates that these concerns are, in the main, not applicable to the proposed blockchain model. The CSD would serve as the maintainer of the blockchain network and provide a notary function. Cash settlement would be ensured by the central banks, since they are members of the network in the proposed node linkage structure. Legal ownership definition, error management, and identity management could be defined by the particular blockchain solution’s configuration and management rules. Confidentiality and scalability could be provided by using a private blockchain and the appropriate consensus mechanism.

Table 8. Evaluation of possible issues of the proposed blockchain architecture model and node linkage structure

Challenges	Description	Applicability	Reasoning
Notary function	Not clear who would ensure the integrity of the ledger, securities issuance, and transfer of ownership. Potential legal issues regarding the current role of the CSD.	Not applicable.	The CSD would serve as the maintainer of the ledger. It would ensure integrity of the data on blockchain (as the validator node), and issue securities on the network [21].
Depository function	Needed regulatory framework for existing security tokenization and digital asset issuance.	Neutral.	The existing regulatory framework would be applicable. Potential changes needed to technical requirements defined by CSDR [27].
DVP transactions	Blockchain should interact with cash accounts to transfer money. It could be done either by moving digital cash or using an interface with external cash accounts.	Not applicable.	In the proposed node linkage structure, the central banks are part of the blockchain network, as cash settlement in central bank money is required by CSDR. The central banks would be able to either provide tokenized cash or settle cash outside the blockchain network.
Settlement finality	Regulation requires clear definitions of risk transfers - settlement finality and transaction irrevocability. Blockchain might have probabilistic finality that converges to 1 over time.	Applicable.	Settlement finality can vary depending on the specific blockchain solution used and it should be compliant with the regulatory requirements.
Legal ownership	Formal transfer of ownership needs to be defined and the records in blockchain should represent proof of ownership.	Not applicable.	Blockchain can be used to transfer ownership between the shareholders if the settlement finality is defined according to the regulatory requirements [16].
Trade matching	Blockchain might not allow settlement instruction matching, mismatch or exception processing. Matching could happen before the record is entered in the ledger.	Neutral.	Absence of settlement instructions could cause issues for legal requirement to match the transactions. However, blockchain can be configured to allow both parties to confirm the transaction conditions.
Error management	Immutability and no central governor complicate exception management.	Not applicable.	Error management can be handled by the network administrator or by performing reverse transactions [24].
Confidentiality	If transaction validation involves multiple parties, otherwise limited transaction information could be shared with unwanted 3rd parties. Consensus mechanism that involves trusted authority could be needed or the design of the blockchain should increase anonymity via used protocols.	Not applicable.	The private blockchain can ensure that transaction information is not available to unwanted 3rd parties [12].
Identity management	CSDs could remain as party validators. However, necessary cryptographic key management and identity verification processes need to be in place.	Not applicable.	If CSD is entrusted as the manager of the network, it can manage cryptographic keys of the network members and validate the network participants [21].
Scalability	Securities settlement involves processing large number of transactions. The blockchain should have capacity to process transaction volumes at market peak volumes.	Not applicable.	Blockchain's throughput is dependent on the underlying solution and the consensus mechanism [12]. The used blockchain solution should be capable to withstand the expected data throughput by using Proof-of-Authority consensus mechanism.

5.2 Evaluation of Cross-Border Settlement Efficiencies

This section evaluates the proposed blockchain model against Schaper's assessment of cross-border efficiencies in securities settlement processes in Europe. Schaper reviewed the status of the securities settlement landscape within the EU when T2S was being developed to accommodate a unified approach to cross-border securities settlement [7]. He recognized that efficiency of securities settlement can be improved by harmonizing the technical and industry standards, as well as services and applications. By incorporating the harmonized elements of various financial market infrastructures, participants would make those financial markets more efficient and better integrated. Schaper identifies multiple models and approaches as to how securities settlement can be performed in the EU and compares them, according to multiple criteria. In this article, securities settlement on blockchain is added as another approach and compared with the previously identified models. It is important, for the purposes of this article, to perform such an evaluation, in order to to recognize whether the proposed blockchain architecture model and node linkage structure, for securities settlement on blockchain, improves the efficiency of securities settlement according to Schaper's defined criteria.

Schaper identifies 3 integration levels [7] that can be achieved among the financial market participants, namely, services and applications, industry standard, and technology standard levels.

According to these integration levels, the financial market efficiency can be achieved by synchronized technical standards, such as communication protocols. As identified before, CSDs and CSD participants are using ISO 15022 and ISO 20022 messaging standards to communicate with each other. However, even though these standard messages are implemented across multiple market participants, the application of those messages is not standardized and can vary from party to party [7]. Using blockchain technology as the transaction layer in the proposed model, the standardization of the communication protocols becomes implicit. Regarding industry standards, in the case where blockchain technology is used, it should follow the existing regulatory requirements defined by CSDR. These requirements enable the harmonizing of the securities settlement processes on blockchain with the traditional securities settlement process to the greatest possible extent. Lastly, efficiency could be achieved by integrating centralized services or applications. In the current financial market landscape in the EU, T2S is an example of such a centralized application and service. Schaper has also used T2S as the centralized application in his evaluation [7]. In the context of blockchain, the blockchain solution would harmonize the processes between the parties involved, serving as a central application and service, using the same technical solution and standards among all the network members.

In Schaper's model comparison, four models are considered – CSD-link model, Link-up model, T2S, and European CSD. Link-up markets was a link agreement among multiple European CSDs for the purpose of standardizing national systems so as to improve cross-border securities transactions. The European CSD model assumes a single CSD in Europe that ensures settlement services for all European countries. This model would exclude any necessity for linked CSDs, as a single CSD would serve all its participants across the EU. However, European CSD is a theoretical model, and has not been implemented in practice.

The models are evaluated and compared with each other by using different criteria. Table 9 displays Schaper's analysis of various models designed to improve the securities settlement processes. In addition, the column "blockchain" has been added by the author, and this represents the proposed blockchain architecture model and node structure. This column indicates the assessment of the model and the node structure according to Schaper's criteria.

The securities settlement risk on blockchain would be low, since a single technical solution is used to guarantee securities settlement. If compared to the other models, it is similar to T2S and European CSD since, in these cases too, a single technical solution is ensuring the securities settlement process. Technical solution integration dramatically lowers the settlement risk [7].

Table 9. Modified Schaper's comparison of securities settlement models

	CSD-link model	Link-Up markets	T2S	European CSD	Blockchain
Settlement risk	0	0	++	++	++
Settlement costs	--	-	-	+	++
Implementation time	+	++	-	--	--
Technical integration	0	+	++	++	++
Integration of cross-border settlement	-	0	+	++	++
Integration of other post-trade services	+	+	-	++	0
Integration of cash settlement	-	-	++	+	++
Legend: ++ very good, + good, 0 neutral, - bad, -- very bad					

It is not possible to measure settlement costs for securities settlement on blockchain because they are dependent on the exact technical solutions used, market participation and many other dependencies. However, since the CSD participants would deliver information directly to the blockchain network, known costs associated with delivering messages to the CSDs, using either the proprietary messaging networks, or international channels, like SWIFT, would be eliminated.

There would be a lengthy implementation period for the blockchain solution, especially if compared with establishing links between CSDs. Linked CSDs rely on the existing market standards and practices. However, establishing not only a technical solution, but also changing the underlying fundamentals of how securities settlement is traditionally processed, would require a long time to implement. It would also require commitment and resources from the central banks and the CSD participants involved [24], [28].

Securities settlement on blockchain would require full technical integration by the parties involved. The proposed blockchain architecture model includes layered blockchain integration that allows nodes to fully integrate their own systems with the blockchain network. Other models also require a high level of technical integrity, but the highest technical integrity is achieved if just one technical platform is used for securities settlement [7].

Full integration of cross-border settlement is supported by the proposed blockchain node structure. The blockchain solution would be capable of operating as an international EU-level solution. The factor limiting cross-border integration would be the applicable regulatory limitations [23]. However, these limitations are also applicable to other listed models.

The proposed blockchain architecture model and node structure are intended to be suitable for the securities settlement process. Integration of other post-trade solutions would be dependent on the CSDs and CSD participants involved. The blockchain network itself would not provide such ancillary services, but they could be provided by the network participants themselves.

The integration of cash settlement is required by the CSDR, and, since the proposed node linkage structure assumes that the central banks would be the nodes of the network, cash settlement would be provided according to the CSDR requirements.

In general, the proposed blockchain architecture model and node linkage structure indicate higher cross-border settlement efficiencies than other proposed models, especially with respect to potential settlement cost reductions and cross-border settlement integration. Additionally, since a single technological solution would be used among all the parties involved, the settlement risk is relatively low as compared with linked CSD models, where each of the CSDs has its own system. It is consistent with Schaper's own evaluation that a higher level of integration leads to cross-border efficiencies [7]. The proposed blockchain architecture model assumes that all the nodes can be fully integrated within the network and use the same technological solutions and industry standards. Thus there would not be any discrepancies among the network nodes in the transaction layer of the proposed blockchain architecture model. Therefore, the nodes would not face the challenges encountered by linked CSDs that use variations of ISO 15022 and ISO 20022 standard messages [7]. The benefits of the proposed blockchain architecture model and node structure are similar to the ones provided by the theoretical European CSD. Both models use a single technological solution to ensure successful cross-border settlement. However, Schaper does not specify what would be the underlying technology of the European CSD. At the same time, implementation of a single technological solution, in a cross-border setting, would require long term and market-wide commitment, especially as compared with creating links among CSDs' participants [24].

6. Conclusion

The main goal of the article was to assess blockchain technology's applicability for securities settlement in the current regulatory environment in the EU. Additionally, if blockchain technology were suitable for securities settlement, the potential blockchain architecture and node structure would be proposed. The evaluation of blockchain technology's applicability for securities settlement was achieved by applying a blockchain applicability framework developed by Gourisetti, Mylrea and Patangia [4]. 92 control questions in five domains were answered in order to evaluate the blockchain's applicability for securities settlement. The results of the applied framework revealed that blockchain technology can be used for securities settlement. Additionally, they indicated that the most appropriate type of blockchain for securities settlement would be private permissioned blockchain with a Proof-of-Authority consensus mechanism. To define the possible blockchain architecture, a blockchain architecture modeling approach used by Zhuang, Chen, Shae and Shyu [5] was applied. The proposed blockchain architecture model consists of 3 layers – transaction layer, interfacing layer, and application layer. Further on, the potential node linkage structure of the blockchain network for securities settlement was proposed. The proposed node structure contains the members of the financial market ecosystem where blockchain technology would be used – CSDs, CSD participants, central banks, and others.

The proposed blockchain architecture model and node linkage structure were evaluated. Benos, Garratt and Gurrola-Perez's [6] estimated impact of using blockchain technology for securities settlement was analyzed. The analysis indicated that the proposed blockchain architecture model and node structure could solve the existing issues in the securities settlement process. Schaper's [7] evaluation of cross-border efficiencies was also applied. It suggested that the proposed blockchain architecture model and node linkage structure would be beneficial for cross-border settlement, but that it would require a lengthy implementation period and market-wide commitment.

The findings of the article, as well as the artefacts that have been developed, can be considered as a contribution to the scientific body of knowledge, and can be used by anyone who is interested in further elaboration of more specific applications of blockchain technology in securities settlement, or in extending blockchain's usage to financial market processes other than securities settlement. These findings can also be used by the current financial market infrastructure participants to design and implement blockchain-based securities settlement systems.

Besides investigating blockchain technology's applicability for securities settlement and proposing the blockchain architecture model and node linkage structure, several complementary tasks were defined by the author of the article. These tasks were completed throughout the article and their results can also be considered as a contribution to the scientific body of knowledge. Blockchain technology's basics were reviewed and, within this review, the core concepts of blockchain technology were amalgamated. The current financial market infrastructure was examined so as to identify the financial market components. This examination allowed the production of a financial market component and relationship description and its graphical representation (Figure 1). This can be considered as an additional artefact that can be used by other researchers to navigate the financial market ecosystem and understand the relationships between its components. Also, the current regulation for securities settlement in the EU was examined. This examination allowed the identification of the main regulatory requirements, defined by CSDR, and the general applicable regulatory landscape for securities settlement in the EU.

Even though the findings in this article have indicated that blockchain technology can be used for securities settlement in the EU, it has to be noted that a practical application of a blockchain solution for securities settlement would be a complex implementation project, that would require commitment from many financial market participants, as the related research shows [24], [28]. Additionally, it would require more thorough analysis of how a specific blockchain solution could be used to fulfill all of the technical and legal requirements stipulated by CSDR. Further research in this area could review specific blockchain solutions that could be used as the basis for the proposed blockchain architecture model (transaction layer). Additionally, analysis of blockchain's applicability in other settlement related services could be explored further, for instance, voting services for elective corporate actions, or securities collateralization services. Moreover, evaluation of the applicability of blockchain technology for securities settlement outside the EU regulatory framework could be considered.

References

[1] Y. Guo and C. Liang, "Blockchain application and outlook in the banking industry," *Financial Innovation*, 2006.

[2] E. Avgouleas and A. Kiayias, "The Promise of Blockchain Technology for Global Securities and Derivatives Markets: The New Financial Ecosystem and the 'Holy Grail' of Systemic Risk Containment," *European Business Organization Law Review*, pp. 81–110, 2019. Available: https://doi.org/10.1007/s40804-019-00133-3

[3] J. Bauvars and M.Kirikova, "Blockchain Applicability for Securities Settlement," 1st Workshop on Blockchain for Trusted Data Sharing (B4TDS 2021), Ceur-ws.org, vol.2991, pp. 113–127, 2021.

[4] S. N. Gourisetti, M. Mylrea, and H. Patangia, "Evaluation and Demonstration of Blockchain Applicability Framework," *IEEE Transactions on Engineering Management*, pp. 1142–1156, 2020. Available: https://doi.org/10.1109/TEM.2019.2928280

[5] Y. Zhuang, Y.-W. Chen, Z.-Y. Shae, and C.-R. Shyu, "Generalizable Layered Blockchain Architecture for Health Care Applications: Development, Case Studies, and Evaluation," *Journal of Medical Internet Research*, vol. 22, no. 7, 2020. Available: https://doi.org/10.2196/19029

[6] E. Benos, R. Garratt, and P. Gurrola-Perez, "The Economics of Distributed Ledger Technology for Securities Settlement," *Ledger*, vol. 4, pp. 121–156, 2019. Available: https://doi.org/10.5195/ledger.2019.144

[7] T. Schaper, "Integrating the European Securities Settlement," *International Federation for Information Processing*, pp. 385–399, 2009. Available: https://doi.org/10.1007/978-3-642-04280-5_30

[8] B. A. Scriber, "A Framework for Determining Blockchain Applicability," *IEEE Software*, vol. 35, no. 4, pp. 70–77, 2018. Available: https://doi.org/10.1109/MS.2018.2801552

[9] S. Nakamoto, *Bitcoin: A Peer-to-Peer Electronic Cash System*. 2008.

[10] L. Swartz, "What was Bitcoin, what will it be? The technoeconomic imaginaries of a new money technology," *Cultural Studies*, vol. 32, no. 4, pp. 623–650, 2018. Available: https://doi.org/10.1080/09502386.2017.1416420

[11] C. Xu, K. Wang, and M. Guo, "Intelligent Resource Management in Blockchain-Based Cloud Datacenters," *IEEE Cloud Computing*, pp. 50–59, 2019. Available: https://doi.org/10.1109/MCC.2018.1081060

[12] I. Bashir, *Mastering Blockchain*. Birmingham: Packt Publishing, 2007.

[13] R. Beck, M. Avital, M. Rossi, and J. B. Thatcher, "Blockchain Technology in Business and Information Systems," *Business & Information Systems Engineering*, vol. 59, no. 6, pp. 381–384, 2017. Available: https://doi.org/10.1007/s12599-017-0505-1

[14] J. Chiu and T. V. Koeppl, "Blockchain-Based Settlement for Asset Trading," *The Review of Financial Studies*, vol. 32, no. 5, pp. 1716–1753, 2019. Available: https://doi.org/10.1093/rfs/hhy122

[15] R. Lewis, J. W. McPartland, and R. Ranjan, "Blockchain and Financial Market Innovation," *Economic Perspectives*, vol. 41, no. 7, 2017.

[16] European Parliament and the Council. Regulation (EU) No 909/2014 of the European Parliament and of the Council of 23 July 2014. Official Journal of the European Union. 2014.

[17] Eurosystem. T2S Framework agreement. 2011.

[18] Target2-Securities. User Detailed Functional Specifications v6.0. 2021.

[19] Securities Market Practice Group. Securities Market Practice Group. 2021.

[20] S. Li and M. Marinč, "Economies of scale and scope in financial market infrastructures," *Journal of International Financial Markets, Institutions & Money*, vol. 53, pp. 17–49, 2018. Available: https://doi.org/10.1016/j.intfin.2017.09.010

[21] C. R. Meijer, "The roles of CSDs in a blockchain environment," *Journal of Securities Operations & Custody*, vol. 12, no 2, pp. 167–174, 2019.

[22] T. Mori, "Financial technology: Blockchain and securities settlement," Journal of Securities Operations & Custody, vol. 8, no. 3, pp. 208–217, 2016.

[23] R. Yang, R. Wakefield, S. Lyu, S. Jayasuriya, F. Han, X. Yi, and S. Chen, "Public and private blockchain in construction business process and information integration," *Automation in Construction*, vol. 118, 2020. Available: https://doi.org/10.1016/j.autcon.2020.103276

[24] S. Everett, A. Calitz, and J. Greyling, "The case for a 'sovereign' distributed securities depository for securities settlement," Journal of Securities Operations & Custody, vol. 9, no. 3, pp. 269–292, 2017.

[25] R. Priem, "Distributed ledger technology for securities clearing and settlement: benefits, risks, and regulatory implications," *Financial Innovation*, vol. 6, 2020. Available: https://doi.org/10.1186/s40854-019-0169-6

[26] C. T. Nguyen, D. T. Hoang, D. N. Nguyen, D. Niyato, H. T. Nguyen, and E. Dutkiewicz, "Proof-of-Stake Consensus Mechanism for Future Blockhain Networks: Fundamentals, Applications and Opportunities," *IEEE Access*, vol. 7, pp. 85727–85745, 2019. Available: https://doi.org/10.1109/ACCESS.2019.2925010

[27] M. Krasnova, "Technological innovations as a factor driving the evolution of central securities depositories' business," *Journal of Securities Operations & Custody*, vol. 11, no. 3, pp. 222–232, 2019.

[28] D. Bullmann and A. Pinna, "The future of European financial market infrastructure: A business case for distributed ledger technology?" *Journal of Securities Operations & Custody*, vol. 9, no. 1, pp. 38–46, 2016.