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Testing Blockchain-Based Systems in the Financial Domain: A Review of the Literature

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ABSTRACT

The application of blockchain technology has rapidly seen an increase in adoption and has already been implemented in various areas, including supply chains, the financial sector, government, and healthcare systems. Financial sectors are adopting blockchain technology to react to global economic growth and increasing financial significance. The implementation of blockchain by financial service providers is to improve security, transparency, and efficiency as well as to create more revenue opportunities. Since the blockchain-based system in the financial sector caters to millions of individuals and handles daily transactions involving trillions of dollars, blockchain-based systems testing is necessary to ensure the blockchain meets its purpose. As blockchain technology continues to evolve, the academic community needs a review of relevant and related literature to identify solutions to newly emerging potential challenges in blockchain-based systems testing in the financial industry. At the same time, a review of the literature concerning blockchain-based systems testing in the financial sector has yet to be carried out. Hence, this study aims to acquire a deeper understanding of the existing studies of blockchain-based systems in the financial domain and to discuss the performance and security testing of blockchain-based systems in the financial industry. This study also identifies the significance of blockchain-based systems testing in the financial domain. This research provides an in-depth review of the current papers on testing blockchain-based systems in the financial domain published between 2017 and 2022. The literature was gathered from several sources and platforms. Based on the literature collected and reviewed in this research, it has become evident that there is a limited number of research available concerning blockchain-based systems testing in the financial domain. The current state of knowledge on this subject is still in its early stages, with many aspects yet to be explored and discovered.

Keywords:

Blockchain-based systems testing; Financial domain; Performance testing; Security testing

1. Introduction

The blockchain is a distributed or decentralized ledger that is shared, duplicated, and synchronized among the participants of a peer-to-peer network, whether that network is public or private [1]. Patil and Sangeetha [2] state that distributed ledger technology is immutable, secure,

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transparent, and trustworthy. The ledger is distributed to every member of the network and retains a permanent record of all transactions between members in a linear and chronological order. A timestamp and cryptographic signature are also assigned to every transaction in the ledger [1]. Figure 1 shows the difference between centralized and distributed ledgers [1]. In addition, all network participants should agree on a common consensus protocol to update and verify records in the shared ledger, in which the transactions no longer rely on a third party. When data is stored on the blockchain, it cannot be altered or tampered with.

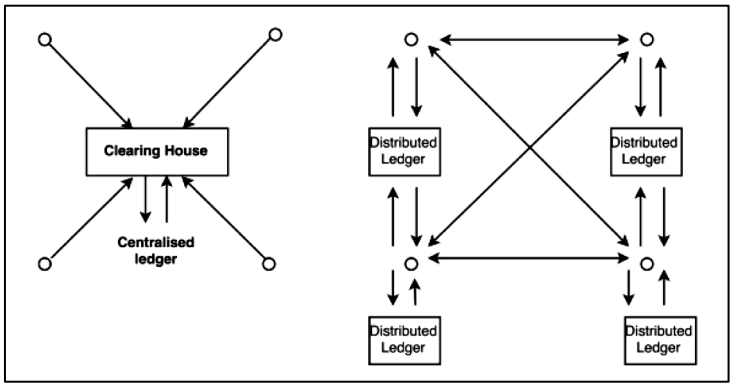

Fig. 1. Centralized ledger and distributed ledger [1]

Blockchain supported financial technology (FinTech) and was initially designed as a distributed ledger for recording bitcoin transactions [3]. At a certain point, blockchain was dominated by the bitcoin craze but has recently begun to draw attention and become the core and most promising advanced technology in FinTech [3,4]. Due to the growing popularity of blockchain, commercial banks are hastily developing and implementing blockchain technology to enhance the current centralized banking system [5]. According to Sriman and Kumar [6], the central system manages or regulates everything in the financial sectors, and some are unwilling to develop an API which causes an issue in the financial industry.

Adopting blockchain technology is very much needed and expected in the financial sector as it provides secure, trustworthy, and transparent conduct of financial transactions [7]. At the same time, Chang *et al.,* [5] also added that prior products and services provided by the financial sector were inefficient and costly. The lack of transparent and explicit financial system regulations has exposed businesses to frequent errors and misinterpretations of information [7]. Most of these issues are addressed by blockchain technology, which also greatly reduces financial risk.

A survey of 132 use cases for blockchain technology was conducted in a research study by Hileman and Rauchs [8]. It was observed that almost one-third are related to the finance and banking industries, indicating that the major interest is in financial applications. Digital currency, trade finance, and international payments are among the financial services applications that employ blockchain technology [9]. Thus, the financial industry anticipates blockchain technology as a promising technological innovation that will enhance performance, and security while addressing financial markets' fundamental problems. Therefore, it is essential to make sure that a blockchain-based system's performance and security, are optimal before it is released to various industries, particularly the financial sector. Considering how profoundly different the blockchain-based system is from conventional systems, software testers should be equipped with appropriate testing techniques. Thorough testing is necessary to identify flaws and errors that may result in various security concerns or asset losses.

Since the financial sector handles trillions of dollars daily, performance and security have become the central focus. To ensure that all transactions are transmitted effectively, the performance of a blockchain-based system in the financial domain must be optimal. At the same time, when money and assets are involved, the blockchain-based system's security must be preserved so that trust can be developed and the participant's identity remains confidential. Therefore, without a proper testing mechanism in place for these issues, the blockchain-based system may be compromised, resulting in asset loss and identity exposure. As blockchain technology develops in the financial domain, the research community needs to review the current literature to get an up-to-date overview for future research and innovation in the financial industry. At the same time, a review of the literature concerning blockchain-based systems testing in the financial sector has yet to be carried out. Hence, the primary research objectives for this study are to study the existing studies of blockchain-based systems in the financial domain, discuss the performance, and security testing of blockchain-based systems in the financial domain and identify the significance of blockchain-based systems testing in the financial domain.

2. Methodology

With a growing number of blockchain-based systems testing publications in the financial domain, it is challenging to review the relevant articles. Therefore, this study overviews the relevant studies of blockchain-based systems testing in the financial domain and classifies testing based on different issues, including performance and security. This research also highlights and discusses the significance of blockchain-based systems testing. Several databases and platforms were used to retrieve the literature, including IEEEXplore, Scopus, SpringerLink, Google Scholar, ResearchGate, and Elsevier. The literature was selected based on the performance and security of blockchain-based system testing in the financial domain. This study offers a comprehensive review of the most recent papers published on testing blockchain-based systems in the financial domain between 2017 and 2022.

The article selection process adheres to strict criteria, ensuring the reliability and credibility of the paper. Only reputable and primary sources from esteemed journals and conferences are considered for inclusion. These stringent standards help to maintain the quality and accuracy of the content. Furthermore, all selected articles are written in English, the universally accepted language for scholarly communication. This linguistic consistency allows the authors to access and comprehend the findings and conclusions presented in the articles. The designated search terms were generated in order to gather all necessary information for addressing the entirety of the research inquiries. The chosen keywords encompassed "blockchain system in finance", "blockchain in crowdfunding", "blockchain in insurance", "blockchain in banking", "blockchain in cryptocurrency market", "blockchain in trade finance", "blockchain in supply chain", "performance testing in blockchain finance", " performance evaluation in blockchain finance ", "security evaluation in blockchain finance", and "security testing in blockchain finance".

Variations in plurality, synonyms, and alternative spellings were considered to formulate combinations of keywords. By employing this robust selection process and language standardization, the compilation of articles provides valuable insights and information, eventually enhancing the knowledge base and promoting advancements, particularly in blockchain-based systems testing in the financial domain.

3. Related Work

In the context of blockchain-based systems testing in the financial domain, it is essential to explore the existing body of related work that has contributed to understanding the subject matter. Numerous researchers have delved into the topic from various perspectives, shedding light on different facets and uncovering valuable insights. Some studies have focused on the theoretical and conceptual frameworks, providing a solid foundation for this research. Others have employed empirical approaches, conducted experiments and gathered data to support their hypotheses. In this article, the authors aim to build upon the existing body of knowledge by presenting novel findings. By doing so, the authors seek to enhance comprehension regarding blockchain-based systems testing in the financial sector while identifying potential future research directions. Figure 2 below visually delineates and presents the comprehensive taxonomy that encapsulates all the reviewed papers discussed in the subsequent sections.

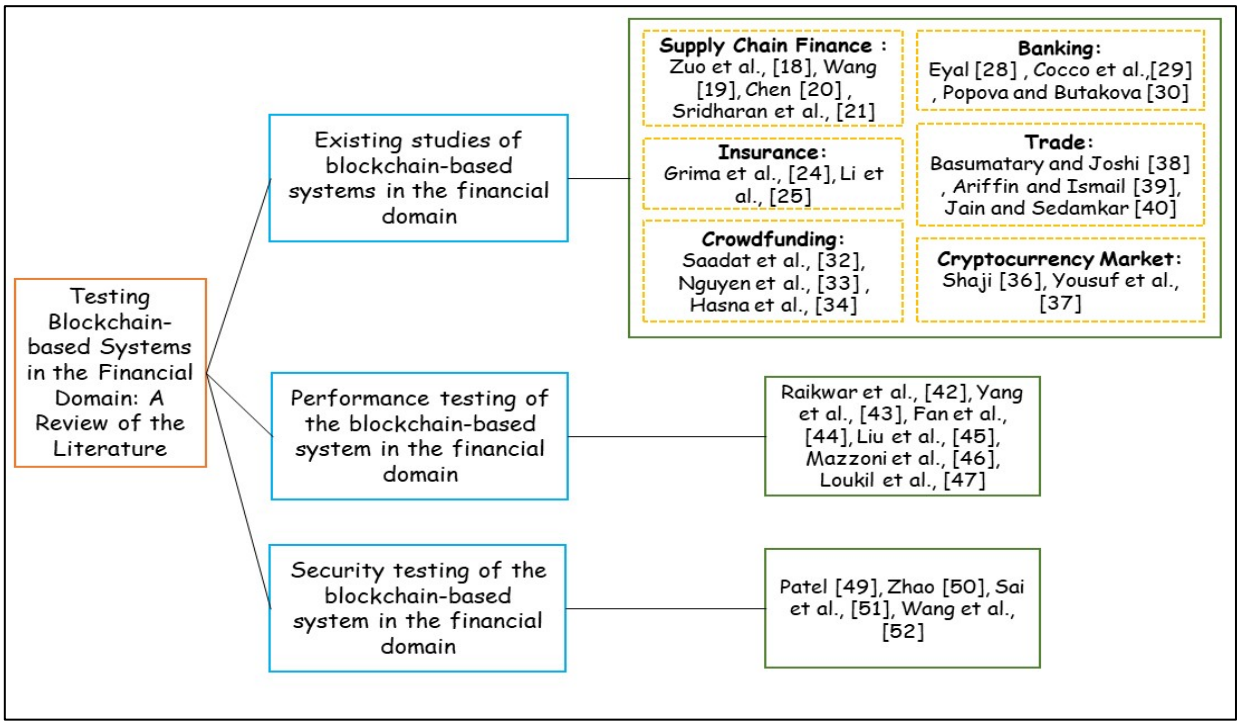

Fig. 2. Taxonomy of reviewed papers

3.1 Existing Studies of Blockchain-Based Systems in the Financial Domain

Access to financial services has evolved, and these developments are now feasible due to advancements in Fintech. Financial technology, or Fintech, describes utilizing new technology such as blockchain, cloud computing and artificial intelligence for financial services [10]. This study focuses on blockchain technology used in the financial domain as it is significant in the financial sector since it helps to build trust and reduces the necessity for third-party verification. At the same time, the financial industry may also benefit from the advancement of blockchain technology in many different ways. For example, Decentralized Finance, or DeFi, has arisen due to the use of blockchain technology in financial services [11]. Studies have shown that there has been an increase in blockchain-based systems in the financial domain, including insurance, banking, crowdfunding, cryptocurrency market, trade and supply chain finance [12-14]. Hence, this section will discuss the existing studies of blockchain-based systems in financial services.

3.1.1 Supply chain finance

According to Wu and Duan [15], a product's supply chain comprises the process of acquiring raw materials, production of products, and lastly, the distribution of products, which connects suppliers, manufacturers, distributors, retailers, and consumers. On the other hand, supply chain finance is the integration of business, capital, information, and logistics flows in the transaction process, taking into account financial data and operational circumstances throughout a sequence of processes to accomplish supply chain objectives [16]. Tang *et al.,* [16] added that supply chain finance is an efficient framework for businesses with limited funds. The rise of supply chain finance is a result of the financing difficulties faced by medium and small-sized businesses.

Supply chain finance mainly aims to serve as a comprehensive financial solution to a supply chain business or downstream and upstream businesses based on core enterprise credit, self-compensation transactions, and product circulation value [15]. The financing of the supply chain differs from conventional financing services, whereby it does not provide credit on a one-to-one basis to individual businesses but instead relies on the supply chain's comprehensive information and the credit endorsement of core businesses [17]. Nevertheless, since supply chain finance is still in its early stages, the core businesses cannot penetrate the entire industrial chain. They can only offer credit transfers to first-tier vendors or distributors. Apart from that, based on Sun [17] research study, data barriers and poor data quality significantly impact the financial supply and the function of supply chain finance. Due to supply chain finance features encompassing various parties and intricate operations, blockchain technology establishes information exchange and collaborative management within peer-to-peer networks [17].

Many researchers have highlighted the importance of blockchain in supply chain finance in their research studies. In a research study by Zuo *et al.,* [18], a blockchain and supply chain finance system has been developed to overcome the existing challenges in traditional supply chain finance. These include a wide range of upstream and downstream businesses that necessitate comprehensive collaboration between businesses. Apart from that, the financing cost for small and medium-sized enterprises is very high and challenging in data review. As a result, blockchain is introduced to improve finance in the supply chain to be safer, more explicit, and more efficient. They also show that the blockchain-based supply chain finance system can produce a variety of smart contracts and integrate commodity transactions on the supply chain finance with existing financial operations.

On the other hand, a research study by Wang [19], developed supply chain finance within the Beibu Gulf region bank by utilizing blockchain technology to solve the information asymmetry issue, which is the most significant issue in financial institutions. The research study used the principal-agent model to create the incentive contract between core businesses of the blockchain supply chain and financial service providers to assist blockchain technology implementation and develop more rapidly in the supply chain finance sector. The findings indicate that financial service platforms for supply chain operations based on blockchain technology may benefit from the separation incentive contract.

At the same time, Chen [20] analysed the capability of blockchain technology in revolutionizing supply chain finance and proposed how it might be used to improve financial services. Figure 3 below depicts the blockchain-based supply chain finance system, whereby small and medium enterprises can directly secure financing by leveraging this platform by accepting asset certificates from the core enterprise, eliminating the necessity for complicated intermediary processes often present in traditional supply chain financing [20]. They discovered that blockchain technology had made significant advancements in supply chain financing by eliminating the issue of asymmetric information, thereby creating a vast development space for the swift take-off of supply chain finance.

Sridharan *et al.,* [21] proposed the integration of the supply chain and blockchain technology that offers generic architecture and a solution for tracking, performing transactions, and tracing without a third party in a transparent and secure way. In addition, they also emphasize that their research has effectively applied microfinance, saving farmers from high debts.

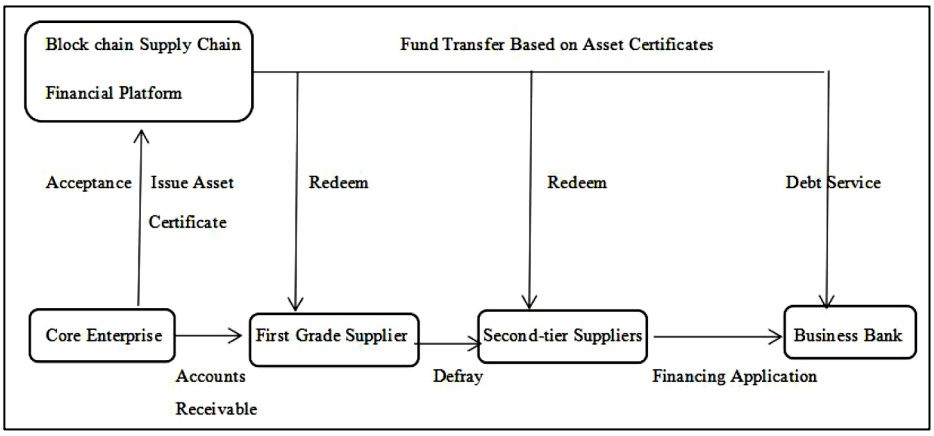

Fig. 3. Blockchain-based supply chain finance system [20]

3.1.2 Insurance

The insurance industry consists of companies that aid policyholders in dealing with issues in such a way that the insurer protects the policyholder from potential misfortunes in exchange for a nominal premium [22]. It is also known as a slow-growing, investor-friendly industry. There are various insurance policies, including life and health insurance. According to O'Dair and Beaven [23], the industrial structure demonstrates it is competitive, mature, and likely to have robust stakeholder networks with established processes, which is essential to employ blockchain technology effectively.

Apart from that, Grima *et al.,* [24] also analysed the factors that might impact the adoption and proliferation of blockchain in the insurance sector. The results show that the demographic trends are creating a more educated, tech-savvy population and generally accepting of decentralized control, particularly when it comes to personal data storage. On top of that, a survey was then conducted with high-ranking insurance professionals, and they discovered that those who have a more profound understanding and insight of such technologies are less likely to implement them into their businesses, highlighting the fact that there is a way ahead before people are persuaded its potential use [24].

Meanwhile, Li *et al.,* [25] developed an IoT and blockchain-based prototype for fine-grained transportation insurance. Real-world GPS data is used to create a prototype system, and system performance data is reported on AWS VMs. The prototype system can be further improved by adjusting platform features to match real-world application requirements, including insurance calculation model accuracy and city-scale transportation [25]. All in all, blockchain technology can be applied to various use cases in the insurance industry to track assets and fraud detection. Blockchain in insurance is also more secure, cheaper and faster than traditional insurance [26].

3.1.3 Banking

A growing number of banks have started to focus more and recognize blockchain technology. Based on a research study by Guo and Liang [27], various blockchain industrial consortiums have emerged to aid in advancing blockchain technology and its applications. They also added that over

forty of the world's most prominent financial institutions, including Citigroup, Bank of America, Deutsche Bank, Barclays Bank and Morgan Stanley have joined the R3 blockchain consortium, thereby improving the interactions and cooperation amongst leading financial institutions via blockchain technology. Thus, this has made the financial institution and the researcher have greater expectations concerning blockchain application in the banking industry.

Eyal [28] explored the potential consequences of using the blockchain to manage the banking industry, whereby his study aimed to determine the blockchain's potential in administering the account and the fund. He also reported that Bitcoin is filling these gaps, and as FinTech adopts DLT, new challenges and possibilities will develop, but blockchain technologies will only reach their full potential through effective and direct collaboration between FinTech and the blockchain and engineering community.

In addition, Cocco *et al.,* [29] examined the challenges and opportunities of implementing blockchain technology in capital markets and banking. Several banks are adopting blockchain technology to boost economic growth and green technology development. Therefore, their paper analysed the performance of Bitcoin system to understand the potential of blockchain technology towards the financial system. The authors claim that the current blockchain issues, including excessive energy consumption and expensive equipment costs found in Bitcoin can be fixed so that blockchain technology can be employed in financial cycles.

On the other hand, Popova and Butakova [30] in their study, discussed how to utilize Blockchain technology without mining (i.e., without tokens) to secure data regarding financial transactions, such as credit card information, transfer amounts, and participant names. This paper also analyses the assurance elements of appropriated data sets and offers a solution to the issue of maintaining the dependence of the data's uniqueness on blockchain innovation without tokens. Furthermore, they discovered that a mining-free blockchain would significantly improve the process of data confidentiality and uniqueness in banking transactions.

3.1.4 Crowdfunding

Crowdfunding refers to obtaining financial support for an enterprise from many individuals through the Internet [14]. In the investment industry, the concept of crowdfunding can be interpreted as a technique to expand the investment industry whereby the investment sector may benefit from this strategy since it frees up the vast amount of regular capital investors hold [31]. The primary feature of crowdfunding is direct access to the funding source without needing an intermediary institution [14]. According to Hartmann *et al.,* [31], in recent years, especially in 2017 and 2018, crowdfunding utilizing blockchain technology has emerged as a significant economic phenomenon and, more specifically, a significant approach for financing startups. The Initial Cryptoasset Offerings (ICOs) and Security Token Offerings (STOs) are examples of blockchain-based crowdfunding.

Many scholars have emphasized the importance and development of blockchain-based crowdfunding. In a research study by Saadat *et al.,* [32], they proposed a solution to the primary problem faced by current crowdfunding: that campaigns are unregulated, some are fraudulent, and some projects are delayed. They proposed employing smart contracts in a crowdfunding system, in which the contract can hold a contributor's funds until a specified date or goal is accomplished. As a result, using smart contracts for spending requests can also let people know how their money is being spent.

Besides that, Nguyen *et al.,* [33] explored how blockchain technology could be applied to socially oriented crowdfunding platforms (SCPs) to improve the social value creation of crowdfunding. Their

study discovered the factors that promote social value creation through blockchain technology and the challenges to adopting this application in terms of legal requirements and development expenses. The authors found that applications based on blockchain technology have not yet become mature enough to be used for all SCP processes. However, blockchain technology has enhanced SCP transparency, particularly in providing users with a decentralized information network.

Hasna *et al.,* [34] proposed a novel crowdfunding strategy based on blockchain technology to offer a transparent, secure, and safe way for crowdfunding. The proposed financing model is influenced by Islamic finance and represents a financial innovation that incorporates ethics and the social dimension into modern banking practices. They also demonstrated that the proposed financing system employed on the Ethereum platform is safe since the process of signing and initiating the transaction for contribution using a digital signature wallet administered by a cryptographic algorithm.

3.1.5 Cryptocurrency market

Cryptocurrency is a type of digital currency that employs cryptographic principles and operates on a blockchain-based platform, and Bitcoin represents the first cryptocurrency that utilizes blockchain technology [35]. According to Sharvani and Anjum [35], in 2008, Satoshi Nakamoto created a decentralized, open-source software known as Bitcoin. Many people downloaded this software, leading to the formation of the Bitcoin network. The cryptocurrency market is a platform for exchanging cryptocurrency, where users can buy and sell.

The emerging technology of blockchain and cryptocurrency has garnered significant attention from researchers who have explored its various aspects. Shaji [36] developed a system to enhance the cryptocurrency wallet's security by implementing a location-based authentication mechanism for accessing the wallet whereby access to the hot wallet or exchange platform restricts to users within the predetermined boundaries or parameters. They also added that the main objective of implementing a geofence is to oversee device entry and leaving within the designated perimeter and offer location-based services to users. Fencing can also enforce policies or constraints based on device location. The study conducted by the author showed that the web wallet's security improved by incorporating a location-based authentication mechanism.

On the other hand, Yousuf *et al.,* [37] discussed an overview of blockchain-based cryptocurrency systems, consensus algorithms employed in these systems, and blockchain technology. Cryptocurrency is a vital and sensitive blockchain application that requires the highest level of security, fast transaction processing, and dependability. However, certain cryptocurrencies require significant computational resources, resulting in high energy consumption, while some are more centralized [37]. The selection of a specific consensus algorithm is based on the particular application. The analysis conducted by the authors indicates that consensus algorithms for cryptocurrency systems should possess certain desirable characteristics, such as permission-less access, low power consumption, efficient transaction processing with minimal latency, and robust safety features.

3.1.6 Trade

Trade finance facilitates financial transactions between buyers and sellers located worldwide by offering credit, payment guarantees, and insurance [38]. But the conventional techniques utilized in trade financing pose challenges, such as the physical paper documents having to travel back and forth between the parties engaged in the transaction process. According to Basumatary and Joshi [38], these circumstances lead to certain limitations, such as the substantial financial investment required,

the long duration of the entire procedure, and a higher vulnerability to errors due to the presence of physical documents. However, implementing blockchain technology in the trade finance industry has significantly enabled organizations to mitigate the limitations.

In addition, Basumatary and Joshi [38] examined the use of blockchain technologies within trade finance and evaluated their impact on financial transactions and security measures by analysing different use cases. The authors later found that the impact on a company's security and transaction process depends on the blockchain platforms adopted. Each platform presented distinct features and benefits to the organizations, aligning with the industry demands and suiting the nature of the company's operations [38].

Apart from that, Ariffin and Ismail [39], in their research study, describe the implementation and design of blockchain-based trade finance applications. Over the year, blockchain projects have increased, but blockchain applications and system architecture are still poorly understood and unexplored. Thus, the authors employ software connectors to serve as a tool to investigate the fundamental components of software interaction and their integration into complex interactions. According to them, no empirical performance evaluations have been conducted to assess the performance attributes of this methodology. At the end of their research, they claim that identifying essential components of software connectors and thorough discourse on using them in the context of blockchain-based application architecture is a fundamental basis for constructing similar architecture in the future [39].

Jain and Sedamkar [40] proposed utilizing blockchain technology to enable smart contracts, which would effectively ensure the security and trustworthiness of the trade ecosystem. They stated that the proposed system offered resolutions to security concerns in the trade sector, whereby blockchain technology's security features can promote trust within a network and guarantee the integrity and reliability of the information while facilitating comprehensive monitoring of the process.

In conclusion, this section presented various research initiatives on blockchain-based systems within the financial sector, encompassing insurance, banking, crowdfunding, the cryptocurrency market, trade, and supply chain finance. Numerous scholars have emphasized the significance and concerns pertaining to blockchain-based systems, specifically with regard to their performance and security measures in the financial domain. This also highlights the importance of conducting performance and security testing to mitigate any possible challenges in implementing blockchain technology within the financial domain.

3.2 Performance Testing of the Blockchain-Based System in the Financial Domain

In general, a blockchain-based system can be examined from multiple angles, including usability, functional testing, block analysis, smart contracts, integration, DApps, networks, security, and performance testing, which is the primary focus of this article. According to Smetanin *et al.,* [41], there is currently an absence of standardized tools and methods for assessing the performance and monitoring the behaviour of blockchains, despite a growing number of associated applications. Without any preliminary performance review, developing blockchain-based systems that are extraordinarily sophisticated and dynamic in nature can have disastrous consequences. Performance testing offers to analyse network size and transaction processing capability to identify potential hardware and software bottlenecks and future operational expenses [41]. Several articles have been published about the integration of blockchain technology into financial services, yet only a limited number of research papers have focused on evaluating the performance of blockchain in financial domain. In this section, we will explore the current practices and techniques used for testing the performance of blockchain-based systems in financial services.

Raikwar *et al.,* [42] conducted a research study showing how adopting a blockchain-based solution improves the security and performance of insurance processes. The manual interactions inherent in traditional insurance systems result in slow processing and prolonged payment settlement time. Therefore, an insurance framework was proposed, and thorough experiments have been conducted on the network to assess the resilience of the proposed insurance framework. A comprehensive analysis of the latency was performed, considering a range of different parameters and the correlation between network size and transaction latency was investigated in the experiment. The experiment encompassed various parameters, including 20 to 30 transactions, 10 to 20 block size, 2 to 4 seconds batch timeout, Solo consensus protocol, and 20 iterations. The results of the scalability experiments provided clear evidence that the selection of parameters during blockchain creation should be carefully considered, as they significantly impact the network's latency.

On the other hand, Yang *et al.,* [43] introduced an off-chain payment scheme utilizing a consortium blockchain to enhance the system's trading efficiency by incorporating state channel technology into the consortium blockchain in a secure and efficient manner. They also address the performance issues associated with executing small amounts and high-frequency transactions in the blockchain system. A lightweight consensus mechanism is implemented for reliable off-chain settlement outcomes. Through extensive experimentation, the performance of the consortium blockchain was accessed, and the outcome showed a remarkable 300% increase in transaction throughput compared to the original design. In a similar line, Fan *et al.,* [44] proposed Blockchain-based Distributed Banking (BDB) as a solution to utilize the distributed consensus and storage capabilities of blockchain. BDB aims to ensure transparency and integrity in transactions by addressing the existing limitations in currently distributed banking implementations, which lack mechanisms for tracking transactions processed by distributed banking agents. Experiments were conducted to compare the cost-effectiveness of Ethereum cryptocurrency and the proposed BDB scheme. The experiment involved utilizing three virtual machines to form a blockchain network based on Ethereum with identical specifications. Based on the results, the proposed BDB scheme performs better than Ethereum, and its computational cost remains stable despite increasing difficulty levels. Therefore, BDB can avoid the computational challenges of mining-based cryptocurrencies.

Liu *et al.,* [45] created a financial platform that integrates both blockchain technology and supply chain to meet each participant's specific business requirements and system needs within the supply chain model. The system can also substantially assist enterprises' daily financial management, enhancing financing efficiency and boosting capital flow. The system performance testing was conducted to assess the platform’s capabilities and performance. Performance testing involves running various tests on the system, such as stress tests, load tests, and others. The primary tool employed during the financial management platform's testing was the Load Runner Tool, which conducted stress tests. As a result, even when the number of test users increases from 50 to 300, the platform maintains regular operation and a response time of five seconds, which meets all performance requirements. Therefore, this shows that the financial management platform utilized blockchain's features to enhance transaction processing and system security.

Besides that, Mazzoni *et al.,* [46] presented a practical assessment of the Quorum blockchain and its consensus algorithms, focusing on scalability and applicability. The evaluation workflow is implemented on the financial use case, but the method can apply to any permissioned blockchain. Experiments were conducted using the Amazon EC2 instance; Hyperledger Caliper and Docker are used as the benchmarking and deployment tools, respectively. Tests were conducted on each protocol with public and private transactions in four, eight and sixteen node networks to assess the system's scalability regarding throughput and latency depending on the number of peers. The results show that in terms of scalability, testing the three consensus protocols with private transactions

shows a notable decrease in throughput as the number of peers in the network increases, and although the input rate increases, it does not lead to a significant throughput increase. On the other hand, in terms of latency, it shows a general increase across all network topologies.

Loukil *et al.,* [47] developed a collaborative insurance scheme built on the blockchain called CioSy to process and monitor insurance transactions to achieve secure and transparent data transmission. CioSy's purpose is to automate the processing of insurance policies, the administration of claims, and the payment processes by utilizing smart contracts. Experiments were carried out to assess the performance of the proposed scheme. In this case, the computing costs were analysed concerning time, gas consumption, scalability overhead and computational cost associated with claim authorization. The proposed smart contract is deployed within the Ethereum test network, and the Remix tool is employed to test and debug the smart contract on the Ethereum blockchain. In assessing processing time, the execution of functions within the InsurancePolicy smart contract is examined. One thousand insured accounts are created for scalability, and a smart contract is deployed for each account. Gas costs for executing transactions within the smart contract functions are also evaluated. The findings indicate the proposed scheme's viability, which enables cost and time reductions while simultaneously reducing overall expenditures.

Implementing blockchain technology in the financial domain addresses several performance issues, including slow processing, prolonged payment settlement time, limitations in currently distributed banking implementations, poor trading performance, inefficient financing performance, lack of trust in insurance transactions, poor capital flow and scalability. Thus, the researchers presented and developed novel frameworks, schemes, models, workflow, and approaches to address these challenges as well as improve the system's performance. The performance evaluation was conducted to ensure the developed methods achieved the objective. In the performance evaluation, extensive and repetitive experiments were generally conducted with transaction throughput, latency, scalability overhead, time, gas and computational cost as the metrics indicator. Some of the tools utilized during the performance evaluation were Hyperledger Caliper (benchmarking tool), Remix tool, Docker (deployment tool) and Load Runner Tool (stress tests).

3.3 Security Testing of the Blockchain-Based System in the Financial Domain

Blockchain technology forms the foundation of a novel internet paradigm, enabling the distribution of digital information without duplication. This technology establishes an internet framework where transactions are recorded in immutable records and distributed across several participant nodes. The applications of blockchain technology are experiencing rapid expansion, primarily focused on facilitating authentication, ensuring data integrity, and enabling secure data sharing [48]. Numerous articles have discussed the incorporation of blockchain technology in financial services. Still, only a few research papers have concentrated explicitly on assessing the security of blockchain in the financial domain. In this section, we will examine the existing methods and approaches employed to test the security of blockchain-based systems in financial services.

Patel [49] proposed a novel credit-recommender system designed for public blockchains called KiRTi that utilize deep learning technology. Its primary purpose is to enable efficient and secure smart lending operations between potential borrowers and potential lenders by removing the reliance on third-party credit-rating agencies for generating credit scores. The proposed scheme (KiRTi) undergoes a security assessment to detect potential weaknesses in executing smart contracts, and it is carried out by using Mythril security open-analysis tool, which provides an efficient client system designed to manage responses swiftly, characterized by its lightweight nature, ensuring minimal latency. Ethereum virtual machine is utilized to execute the proposed smart contract whereby in the

security assessments, control-flow checking, taint, and concolic analysis are essential to identify flaws in the proposed smart contract. The findings from the analysis demonstrate that Mythril performs better than other open-source security assessment tools, which ensure the safe transmission of stakeholder identities over the blockchain.

In a similar line, Zhao [50] developed the credit evaluation procedure and implemented personal credit assessment technology. The data related to personal credit evaluation is securely incorporated into the blockchain to ensure protection within the timeout period and block generation time. The test evaluation employs response time indicators (Ave, Min, Max), while verification involves simulating and testing 1000 virtual users with recorded parameters. The system's security verification load test result shows consistent user response. Even under the load of 1000 users, the system maintains a response time below 10 ms, which shows high efficiency. They also added that the proposed scheme enhances information transparency and data security in the credit information tracing process, enables effective information tracking, and offers an implementable solution for developing Internet finance.

Apart from that, Sai *et al.,* [51] analyses the security of frequently used Android cryptocurrency applications and evaluates them for common vulnerabilities since the cryptocurrency wallets, unlike conventional financial service applications, do not have to adhere to the same strict security standards imposed on regulated counterparts. The security and privacy aspects of cryptocurrency applications are assessed by employing network data analysis and static code analysis. Static code analysis involves using automated tools such as Droidsafe, while network data analysis employs the Android emulator and Wireshark to identify application features and monitor traffic for sensitive information, respectively. Through manual testing, the authentication and cryptography components of the test application are accessed to identify any potential presence. Findings show that cryptocurrency and banking applications have similar security levels, but banking applications prioritize user privacy more than cryptocurrency applications and banking applications also exhibit approximately half the number of cryptography-related issues compared to cryptocurrency applications.

Moreover, a research study by Wang *et al.,* [52] introduced BLOCKEYE, a real-time intrusion detection system designed for Decentralized Finance (DeFi) projects operating on the Ethereum blockchain; since DeFi becomes vulnerable to a significant attack surface due to the feature of blockchain technology. BLOCKEYE works in a two-step approach. Initially, it conducts symbolic analysis on the smart contracts of a given DeFi project during the first phase. Subsequently, in the second phase, BLOCKEYE deploys a runtime monitor in vulnerable DeFi projects to identify external attacks [52]. In the preliminary evaluation, BLOCKEYE was compared with Codefi Inspect by using eight DeFi projects on Ethereum, and the findings show that BLOCKEYE accurately detects all vulnerable DeFis without generating false positive or negative alerts. Then, BLOCKEYE was further evaluated to detect arbitrage transactions in two DeFi projects by enforcing different slippage thresholds. As a result, the proposed solution can identify potential attacks previously unreported.

Based on previous research, integrating blockchain technology in financial services primarily emphasized reinforcing security in the system, such as removing third-party in smart lending operations, improving the security of personal credit evaluation and analysing the security of cryptocurrency wallets. As a result, researchers invented and established systems and protocols to tackle security concerns and enhance the overall system's security. The security assessments included thorough testing focusing on the safe transmission of stakeholder identities, data security in the credit information tracing process, and the detection of potential attacks as key security indicators. Several tools are utilized during the security assessments, including Mythril security open-analysis tool, Droidsafe, Android emulator and Wireshark. The Table 1 below illustrates the summary

of all reviewed papers in performance and security testing of blockchain-based systems in the financial domain.

Table 1
The summary of all reviewed papers in performance and security testing of blockchain-based systems in the financial domain

Type of testing	Authors	Frameworks/ Analysis proposed	Advantages	Testing techniques	Limitation
Performance testing	Raikwar *et al.,* [42]	Insurance frameworks	Improves the security and performance of insurance processes.	Experiments were conducted considering various parameters and the correlation between network size and transaction latency.	The smart contract in this model is not included in the individual transaction level.
	Yang *et al.,* [43]	Off-chain payment scheme utilizing a consortium blockchain.	Enhance the trading performance of the blockchain system.	The performance of the consortium blockchain was accessed through experiments, and transaction throughput was compared with the original design.	The transaction execution decision problem requires a dynamic partitioning algorithm, which, in theory, can provide a potential solution to the problem without guaranteeing a definitive solution.
	Fan *et al.,* [44]	Blockchain-based Distributed Banking (BDB)	To ensure transparency and integrity in transactions.	Experiments were conducted to compare the cost-effectiveness of Ethereum cryptocurrency and the proposed BDB scheme.	The analysis was limited to Ethereum cryptocurrency.
	Liu *et al.,* [45]	A financial platform that integrates blockchain and supply chain.	To assist enterprises' daily financial management, enhancing financing efficiency and boosting capital flow.	The stress test was conducted using the Load Runner tool on the financial management platform.	Only three modules were considered in system functionality testing because of limited space.
	Mazzoni *et al.,* [46]	Workflow evaluating the performance of permissioned blockchain platforms and associated consensus algorithms.	To understand a blockchain platform's performance and to lower the analysis cost.	Experiments were conducted using the Amazon EC2 instance; Hyperledger Caliper and Docker are used as the benchmarking and deployment tools, respectively.	The security aspects were not considered in this research.

	Loukil *et al.,* [47]	CioSy, a collaborative insurance scheme.	To process and monitor insurance transactions.	Experiments on computing costs were analysed concerning time, gas consumption, scalability overhead, and computational cost associated with claim authorization.	The evaluation of the proposed scheme only focuses on the performance of the scheme.
Security testing	Patel [49]	Kirti, credit-recommender system.	To enable efficient and secure smart lending operations between potential borrowers and potential lenders.	Security assessment was carried out by using the Mythril security open-analysis tool.	This research did not implement early stopping in the regularisation parameter training samples.
	Zhao [50]	Credit evaluation procedure and implemented personal credit assessment technology.	To ensure data protection within the timeout period and block generation time.	Conduct security validation load tests on the system, establish a block generation interval of 60 seconds, and choose security-related data from various periods.	This research object is limited to Internet finance projects.
	Sai *et al.,* [51]	Perform security and privacy evaluations of cryptocurrency applications.	To assess the security features of frequently used Android cryptocurrency applications.	Employ network data analysis (use the Android emulator and Wireshark) and static code analysis (utilize Droidsafe).	Static code analysis has limitations. Using threat vectors in non-security areas might not create a security risk, but the static code analysis overlooks this aspect.
	Wang *et al.,* [52]	BLOCKEYE, a real-time intrusion detection system.	To detect attacks in Decentralized Finance (DeFi) projects on the Ethereum blockchain.	In the preliminary evaluation, BLOCKEYE was compared with Codefi Inspect using eight DeFi projects on Ethereum. Then, BLOCKEYE was further evaluated to detect arbitrage transactions in two DeFi projects by enforcing different slippage thresholds.	The proposed system considered only decentralized finance.

4. Discussion

Many government agencies throughout the world, especially in Malaysia, have focused on the potential benefits that could be acquired by incorporating Blockchain technology into their daily operations. According to Latif and Zakaria [53], based on news reported by MIMOS Berhad, the Malaysian Ministry of Science, Technology, and Innovation (MOSTI) is actively exploring Blockchain

technology to guarantee that Malaysia remains competitive in technological advancements. Blockchain technology is significant due to its immutability, decentralization, security, transparency, and ability to execute complex business logic through smart contracts securely. These features not only create new business prospects and benefits for companies but also bring new perspectives requiring attention from the testing community. Blockchain-based systems testing plays a crucial role in the financial industry, with numerous significances worth highlighting. Firstly, as the adoption of blockchain technology grows across various domains especially the financial domain, conducting thorough testing becomes significantly crucial to identify and address potential bugs, vulnerabilities, and security threats that might result in asset losses. This can be achieved through security testing in financial applications, which plays a crucial role in ensuring the robustness and reliability of financial applications leveraging blockchain technology. Secondly, conducting extensive testing will provide the company stakeholders and regulators confidence in the finance application's ability to handle transactions securely and maintain the integrity of the underlying blockchain technology. Not only that, but testing also ensures the protection of valuable assets and enhances trust in blockchain technology within the financial domain.

Furthermore, it is also crucial to identify the components within blockchain applications that require thorough testing to be executed effectively. Blockchain applications differ from other applications not utilizing blockchain technology, which have unique requirements and acceptance criteria that must be met during testing. One of the unique features of a blockchain-based system is the smart contract. According to Lal and Marijan [54], the significance of smart contracts lies in their irreversibility once implemented. Therefore, any errors in a deployed smart contract can lead to the need for a complete code revision in a production system. Additionally, the efficiency of the system performed under high workloads is determined by the smart contract code. On top of that, according to Zilin *et al.,* [55], smart contracts also allow settlements and payments to be automated under predetermined regulations, which could eventually reduce delays and transaction costs. Hence, conducting thorough performance testing becomes essential to ensure the smart contract works correctly. This section discusses in regards to the significance of blockchain-based systems testing in the financial domain, which eventually addresses the third research objective for this article.

5. Conclusions

The primary objective of this research is to gain a comprehensive understanding of the current research on blockchain-based systems within the financial domain. The focus is specifically on the performance and security testing of blockchain applications in the financial domain. Additionally, the study aims to highlight the importance and relevance of blockchain-based systems testing in the financial domain. This research study covered diverse research endeavours related to blockchain-based systems in the financial sector, including insurance, banking, crowdfunding, cryptocurrency market, trade, and supply chain finance. Scholars have emphasized the importance and concerns surrounding blockchain-based systems, particularly in terms of their performance and security in the financial domain. This highlights the significance of conducting performance and security testing to address potential challenges in implementing blockchain technology in finance.

In terms of performance testing, blockchain implementation in finance tackles performance issues like slow processing, prolonged settlement times, limitations in distributed banking, poor trading and financing performance, lack of trust in insurance transactions, inefficient capital flow, and scalability challenges. Researchers developed innovative frameworks and conducted performance evaluations using tools like Hyperledger Caliper, Docker, Remix and Load Runner Tool to ensure their methods achieved the objective. Meanwhile, previous research on blockchain

adoption in finance emphasized enhancing system security by eliminating third-party involvement in smart lending, improving personal credit evaluation security, and analysing cryptocurrency wallet safety. Researchers developed innovative systems and protocols to address security concerns. Security testing prioritized the safe transmission of stakeholder identities, data security in the credit information tracing process, and detection of potential attacks, utilizing tools like Mythril, Droidsafe, Android emulator, and Wireshark.

The literature gathered and reviewed during this research reveals a limited number of studies related to blockchain-based systems testing in the financial domain. Numerous unexplored aspects are awaiting further investigation and exploration. In conclusion, as blockchain technology continues to shape the financial domain, a deeper understanding of testing strategies will be critical to unlock its full potential while mitigating risks and ensuring the integrity of financial systems. Therefore, future research should focus more on testing tools to support security and performance testing and explore other types of blockchain-based systems testing in the financial domain.

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