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The Role of Smart Contracts and NFTs in Shaping Urban Experiments

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Abstract

This dissertation examines the role of smart contracts and non-fungible tokens (NFTs) in shaping urban experiments, exploring how these technologies are being utilized and tested in cities to transform governance, services, and citizen engagement.

Nowadays, blockchain technology, a cutting-edge sector in fintech (which stands for financial technology, referring to innovations that improve financial services through technology), has grown exponentially with diverse applications across various fields. The rapid evolution of this technology can be attributed to its inherent features of decentralization, transparency, security, reliability, traceability, and censorship-resistance. These characteristics make blockchain an attractive solution for creating certificates and attestations between parties, ensuring contract validity without the need for legal authorities.

This study explores cases from cities worldwide, including Singapore, Dubai, New York, Seoul, Barcelona, Eindhoven, Zurich, Toronto, Tokyo, and Copenhagen. These cities serve as testbeds for blockchain applications in areas such as public procurement, land registry, financial services, energy management, and digital identity. By examining these real-world examples, the research identifies the current status of implementation, key stakeholders involved, and the challenges and opportunities encountered in integrating blockchain technologies into urban settings. Key findings reveal the potential of smart contracts and NFTs to transform urban governance by streamlining processes, reducing corruption, and enhancing citizen participation. However, challenges such as regulatory compliance, technical scalability, interoperability, and public acceptance present significant barriers.

Overall, the intersection of smart contracts, NFTs, and urban governance represents a pivotal moment in the evolution of cities. As urban areas increasingly seek technological solutions to enhance transparency, accountability, and citizen-centric governance, blockchain emerges as both a tool and a framework for reimagining how urban systems operate. This dissertation offers an examination of the practical applications and limitations of these technologies, presenting an overview of ongoing urban experiments and providing insights into the conditions under which they are tested, as well as the factors that influence their success or failure.

Keywords: Blockchain Technology, Smart Contracts, Non-Fungible Tokens (NFTs), Urban Planning, Urban Governance, Decentralization, Transparency, Urban Testbeds, Regulatory Compliance.

Abstract in lingua italiana

Questa tesi esamina il ruolo dei contratti intelligenti (smart contracts) e dei token non fungibili (NFT) nel plasmare esperimenti urbani, analizzando come tali tecnologie vengono utilizzate e testate nelle città al fine di trasformare la governance, i servizi e il coinvolgimento dei cittadini.

Attualmente, la tecnologia blockchain, settore all'avanguardia nel campo della tecnologia finanziaria (fintech), ha conosciuto una crescita esponenziale grazie alle sue molteplici applicazioni in diversi ambiti. L'evoluzione rapida di questa tecnologia è riconducibile alle sue caratteristiche intrinseche: decentralizzazione, trasparenza, sicurezza, affidabilità, tracciabilità e resistenza alla censura. Tali qualità rendono la blockchain una soluzione particolarmente attrattiva per la creazione di certificati e contratti tra parti, garantendo la validità contrattuale senza la necessità di un'autorità legale centrale.

La ricerca analizza casi provenienti da diverse città del mondo, tra cui Singapore, Dubai, New York, Seul, Barcellona, Eindhoven, Zurigo, Toronto, Tokyo e Copenaghen. Queste città rappresentano laboratori sperimentali per l'applicazione della blockchain in settori quali gli appalti pubblici, la registrazione fondiaria, i servizi finanziari, la gestione dell'energia e l'identità digitale. Attraverso l'esame di questi esempi concreti, lo studio individua lo stato attuale dell'implementazione, gli attori chiave coinvolti e le sfide e opportunità che emergono nell'integrazione delle tecnologie blockchain nei contesti urbani. I risultati principali evidenziano il potenziale dei contratti intelligenti e degli NFT nel trasformare la governance urbana, attraverso la semplificazione dei processi, la riduzione della corruzione e il rafforzamento della partecipazione civica. Tuttavia, permangono ostacoli rilevanti, quali la conformità normativa, la scalabilità tecnica, l'interoperabilità e l'accettazione da parte del pubblico.

In sintesi, l'intersezione tra contratti intelligenti, NFT e governance urbana rappresenta un momento cruciale nell'evoluzione delle città. Poiché le aree urbane ricercano sempre più soluzioni tecnologiche per aumentare la trasparenza, la responsabilità e una governance centrata sul cittadino, la blockchain si configura sia come strumento sia come quadro di riferimento per ripensare il funzionamento dei sistemi urbani. La presente tesi offre un'analisi delle applicazioni pratiche e delle limitazioni di tali tecnologie, fornendo una panoramica degli esperimenti urbani in corso e proponendo riflessioni sulle condizioni nelle quali tali tecnologie vengono testate, nonché sui fattori che ne influenzano il successo o l'insuccesso.

Parole chiave: Tecnologia Blockchain, Contratti Intelligenti, Token Non Fungibili (NFT), Pianificazione Urbana, Governance Urbana, Decentralizzazione, Trasparenza, Laboratori Urbani Sperimentali, Conformità Normativa.

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1. Introduction

1.1 Background

Urban planning and policy design have been my academic focus throughout my undergraduate studies, and currently, I am furthering my expertise in this field as a master's student. My passion for shaping urban environments has always been intertwined with a keen interest in emerging technologies. Over the years, I have delved into the world of Bitcoin and blockchain, fascinated by their potential to revolutionize various sectors. While studying for my degree, I also started a blockchain-based company, which focuses on trading cryptocurrencies and forex, developing automated trading systems (robot traders), and training individuals who aspire to become traders in financial markets. This dual interest has driven me to explore the intersection of urban planning and blockchain technology in my dissertation research.

The story of blockchain begins in the first decade of the new millennium. Alongside the global financial crisis of 2008, a paper was published by an anonymous author under the pseudonym of Satoshi Nakamoto. The paper was titled “Bitcoin: A Peer-to-Peer Electronic Cash System” and introduced a new form of technology that later would be recognized as blockchain. What started as a decentralized way to execute monetary transactions eventually laid the foundation for a multitude of new applications. Cryptocurrencies, smart contracts, and non-fungible tokens are some of the applications that have found their way to the general domain, colloquially known as decentralized finance. As of now, asset tokenization is an area that has experienced the most explosive growth within the blockchain industry.

The evolution of blockchain technology has introduced innovative services such as smart contracts and non-fungible tokens (NFTs). Smart contracts are self-executing contracts with the terms of the agreement directly written into code. They facilitate, verify, and enforce the negotiation or performance of a contract, potentially transforming numerous urban planning processes by increasing transparency, efficiency, and security. NFTs, on the other hand, are

unique digital assets verified using blockchain technology. Their indivisible and unique nature has sparked interest in various applications, from digital art to real estate. Therefore, more and more experiments are cropping up at the interface of NFTs and real estate capitalization (Zohar & Habib, 2020).

Despite the hype around blockchain innovations, much remains to be understood. Makridakis and Christodoulou (2019), for example, describe the difficulties to assess the actual potential of blockchain technology and all of its future applications. They argue, however, that blockchain has forever altered the way financial transactions are conducted.

Blockchain technology has significant potential to transform urban governance and city planning by addressing issues of transparency, record-keeping, and data integrity. Its decentralized and immutable nature offers a secure platform for managing public services, ensuring transparency in processes such as public procurement, voting, and financial transactions. Cities can use blockchain to create transparent and traceable systems, as seen in Istanbul's blockchain-based procurement platform, which reduces corruption and inefficiency (Zohar & Habib, 2020). Smart contracts can automate agreements in urban development, such as property transactions and zoning changes, minimizing fraud and mismanagement (Deloitte, 2019). Additionally, blockchain can support decentralized identity management, as demonstrated by Estonia's use of blockchain for secure digital identities, enabling citizens to access services while safeguarding privacy (Swan, 2015). In the context of sustainability, blockchain can improve urban energy management by enabling decentralized energy markets and tracking renewable energy transactions, as explored by the Energy Web Foundation (2020). Finally, blockchain can enhance citizen engagement by providing secure, transparent platforms for data sharing and participatory governance, as seen in the use of blockchain for election transparency in Kenya (Münch, 2020). These applications showcase blockchain's potential to revolutionize urban governance, making cities more transparent, efficient, and citizen-centric.

To answer this question, this dissertation seeks to examine the impact of smart contracts and

tokens on urban governance through a comparative study of global cities at the forefront of blockchain experimentation. By analyzing cases from diverse urban contexts, this work aims to elucidate the opportunities, challenges, and implications of integrating blockchain technology into municipal systems and processes. Key areas of investigation will include the utilization of smart contracts and tokens in sectors such as real estate, transportation, energy, and governance mechanisms. By examining the experiences of cities ranging from Dubai to Barcelona, Singapore to San Francisco, the research underpinning this dissertation will offer a comprehensive understanding of the varying strategies, outcomes, and lessons learned in the adoption of blockchain technology within urban contexts.This dissertation argues that smart contracts and NFTs are being used in urban testbeds as experimental tools to explore new ways of managing city services and governance. These testbeds allow cities to test blockchain applications on a small scale before wider implementation.

This dissertation argues that smart contracts and NFTs are being used in urban testbeds as experimental tools to explore new ways of managing city services and governance. Urban testbeds are controlled environments where cities pilot new technologies like blockchain on a small scale to assess their practical impact before wider implementation (Marres & Stark, 2020). These testbeds help reduce risks, support data-driven decision-making, and engage the public with emerging digital services (Marres & Stark, 2020). The thesis of this work is that the application of blockchain technology to urban governance requires controlled testbeds to reach scalability and widespread adoption. At the same time, urban testbeds have inherent limitations due to the controlled nature of their experimental environments, which often focus on select technical or procedural aspects while excluding broader social, political, and economic complexities. This selective scope means that certain real-world challenges such as regulatory diversity, stakeholder resistance, and long-term sustainability may remain unaddressed during initial pilots. Therefore, while testbeds are crucial for mitigating risks and iterating on blockchain solutions, they cannot fully capture the multifaceted dynamics of urban governance, underscoring the need for ongoing evaluation and adaptive frameworks as these technologies

transition from experimentation to mainstream use.

By examining cases from cities around the world, this study shows that the success and influence of blockchain technologies depend not only on their technical features, but also on local laws, political goals, institutional capacity, and citizen responses. The research finds that while blockchain has the potential to improve transparency, efficiency, and public trust in urban governance, its real-world impact varies significantly depending on how and to what it is applied.

1.2 The Technology of libertarianism? The politics of bitcoin

Blockchain Technology is often celebrated for its potential for decentralization, distribution, privacy, and a lack of intermediaries and coordinators for transactions and general governance.

Because of these features, blockchain technology, and, in particular, its most famous inauguration the bitcoin blockchain, is frequently identified with libertarianism. The ideological inflections of blockchain technology are primarily right-wing or right extremist (Korhonen & Rantala, 2021) . According to this view, blockchain is valued for its potential to add business and financial transaction value and efficiency and make the financial industry quicker, more transparent, and globally formalized. Milder characterizations of blockchain's ideological presuppositions link the development history of blockchain technology with"libertarian-esque" ideas of the crypto anarchists and cypherpunks, including John Gilmore,Julian Assange, Eric Hughes, and Hal Finney (Korhonen & Rantala, 2021). On the other hand, it is often said that blockchain technology manifests a number of ideas from new social movements, cooperativism, and the sharing economy (Korhonen & Rantala, 2021).

Many argue that blockchain, like any other technology, is not politically neutral. According to Francesco Galati, blockchain technology is not ideology-free and should be discussed in terms of ideology rather than added value. Blockchain is essentially a political, not a technological, idea

dating back to the teachings of Lao Tzu. For Galati, the libertarian elements in blockchain's ideological background are both left- and right-wing libertarian. In each case, it is deeply ideological and, thus, any governance using it will incorporate and spread the ideology. A more nuanced view is that it is the human operationalization of a technological application in a material-physical environment that imprints the operations in question with ideological content (Korhonen & Rantala, 2021).

The blockchain itself does not "speak" or "intend" materialism, cooperativism, corporate governance, right or left libertarianism, or hierarchy any more than a hammer or a hydrological dam, even if it can be utilized in performing skills, including governance skills, that project these ideological visions. Libertarianism emphasizes individual autonomy, minimal government intervention, and free-market principles. These ideals align closely with the decentralized nature of blockchain technology, which operates without central authorities and promotes peer-to-peer transactions (Korhonen & Rantala, 2021).

The emergence of politically themed cryptocurrencies, such as the $TRUMP meme coin, exemplifies the intersection of digital assets and ideological movements. Launched in January 2025, the $TRUMP token rapidly gained significant market value, reflecting both political support and the speculative nature of meme coins. This phenomenon underscores how cryptocurrencies can serve as tools for political expression and fundraising, while also raising ethical and regulatory considerations. In recent years, meme cryptocurrency Tokens have surged in popularity, evolving from online jokes and viral social media trends to become a key point of interest for young retail investors globally. These digital assets, characterized by their speculative nature and reliance on hype, have captivated audiences through their alignment with internet culture and the involvement of high-profile influencers. The initial surge in the price of $TRUMP demonstrates the power of a high-profile figure in driving market interest, particularly among politically aligned communities. However, questions about its long-term viability and tokenomics such as the significant allocation of initial supply to creators highlight

the risks inherent in meme coin investments (Krause, 2025).

These anecdotes highlight the importance of understanding the political nature of blockchain and its broader implications. However, this dissertation takes a different point of view and instead traces the experiments through which blockchain technologies are embedded into the programs and projects of city governance.

1.3 Research Objective

This dissertation investigates the utilization of smart contracts and non-fungible tokens (NFTs) in urban governance through real-world applications piloted in urban testbeds. It focuses on understanding their impacts, challenges, and transformative potential in administrative processes, service delivery, and citizen engagement.

Using a qualitative, document-based case approach, the research examines implementations across global cities within sectors such as real estate transactions, public service platforms, and digital identity systems. By analyzing these cases, the study explores how these technologies influence urban planning processes, governance structures, and citizen participation, ultimately reshaping traditional models of urban development and decision-making.

Furthermore, the dissertation addresses the challenges and opportunities associated with adopting smart contracts and NFTs, including legal complexities, technical hurdles, and social or economic considerations. It assesses the extent to which these technologies can effectively tackle urban issues while enhancing the efficiency, transparency, and inclusiveness of city management.

Finally, the research identifies key trends in the adoption of blockchain-based solutions in urban governance, arguing that these technologies are building a transformative framework for the future of city planning and administration.

1.4 Conceptual background

Opinions on blockchain technology in urban governance are divided. Some view blockchain-based tools such as smart contracts and decentralized ledgers as transformative mechanisms that enhance transparency, reduce bureaucracy, and improve efficiency. Optimists often cite successful implementations like Dubai's, where blockchain has been used to streamline government services and build trust through automation.

Others, however, emphasize blockchain's limitations, including scalability issues, regulatory uncertainty, and technical complexity. Critics question whether blockchain addresses core urban challenges or merely introduces new forms of complexity and exclusion.

Positioned between these perspectives, urban testbeds emerge as both a conceptual and practical framework for experimentation. Urban testbeds are designated zones, projects, or initiatives within cities where new technologies and governance models can be trialed in a controlled, real-world setting. They allow city governments, technology providers, researchers, and citizens to collaborate on testing innovations under local conditions before committing to large-scale deployment (Christidis & Devetsikiotis, 2016).

In cities like Singapore, Barcelona, and Amsterdam, testbeds have been used to pilot blockchain applications in domains such as land registries, public procurement, digital identity, and urban mobility. These environments offer a space for experimentation that balances risk management with learning opportunities. By simulating operational conditions, testbeds allow stakeholders to observe technical performance, institutional fit, regulatory implications, and public acceptance of blockchain systems.

This dissertation examines how urban testbeds function as platforms for blockchain experimentation, bridging the gap between optimism and skepticism. By analyzing real-world implementations, it aims to provide insights into the feasibility, limitations, and potential scalability of blockchain in urban governance.

1.5 Methodology

This dissertation adopts a qualitative case approach to examine how smart contracts and NFTs are experimented with in urban testbeds. Given the complexity of blockchain integration in urban governance, this methodology allows for a nuanced analysis of its implementation, challenges, and opportunities across different city contexts. The study is structured around a comparative case analysis, focusing on cities at the forefront of blockchain experimentation, such as Dubai, Singapore, New York, and Barcelona. These cities were selected based on geographical diversity, application scope, and the availability of documented blockchain initiatives. The methodology consists of three key components to ensure a structured analysis of blockchain testbeds in urban governance.

The first component is case selection criteria. Cities were chosen based on their active role in blockchain-based urban innovations, particularly in public procurement, land registry, financial services, and digital identity. The selection process also considered the maturity of implementation, ensuring that both experimental and more developed blockchain initiatives were analyzed to provide a balanced perspective.

The second component involved data collection methods. The study relies on document analysis, drawing from government reports, policy documents, industry white papers, and academic literature that discuss blockchain implementations in urban governance. Additionally, a comparative framework was applied, focusing on key themes such as blockchain's role in decentralization, efficiency, and transparency. This approach allowed for an analysis of common patterns and uniqueness across cases.

The third component is the analytical framework, which employs the urban testbed model as a conceptual tool to assess how blockchain applications are being piloted before large-scale adoption. The study identifies key trends, regulatory challenges, and technological limitations

Overall, this methodological approach allowed me to compare different examples in a structured manner, , highlighting both successful implementations and existing barriers to adoption in urban governance.

1.6 Key insights

This dissertation presents critical insights into the implementation of blockchain technology in urban testbeds, highlighting its potential advantages and the challenges associated with its adoption. Urban testbeds function as controlled environments in which cities can pilot blockchain applications prior to full-scale implementation. These testbeds offer several key benefits. One significant advantage is risk mitigation; by testing blockchain solutions within a limited setting, cities can reduce the likelihood of large-scale failure (Khan , 2022). Furthermore, testbeds facilitate data-driven decision-making by allowing governments to gather performance metrics and refine applications based on empirical evidence (Halpern , 2013). Urban testbeds help cities experiment with new technologies like blockchain in a safe, controlled environment. They reduce risks, support data-driven decisions, engage the public, and encourage innovation before full-scale implementation. They also serve as a means of fostering public engagement, enabling citizens to interact with blockchain services directly, thereby increasing awareness and encouraging adoption (Marres & Stark, 2020).

Through the analysis of global cases, the research uncovers common patterns, barriers, and success factors in the deployment of smart contracts and non-fungible tokens (NFTs) within urban governance. Cities such as Dubai, New York, and Barcelona are pioneering the use of blockchain to improve transparency, security, and administrative efficiency Dubai, for example, aims to transition all government transactions to blockchain by 2025 to reduce paperwork and fraud. Key implementation areas include digital identity, where cities like Zurich and Singapore have adopted blockchain for secure citizen verification, enhancing access to public services; land

registry systems, as seen in Estonia and Singapore, where blockchain streamlines property transactions and reduces the risk of fraud; and public procurement, with Barcelona utilizing blockchain to improve transparency and accountability in government contracting. Despite these advancements, significant challenges remain. Technical issues such as scalability, high computational costs, and slow transaction speeds particularly evident in cities like Tokyo pose obstacles to widespread adoption. Regulatory concerns also hinder progress, as seen in Seoul and Toronto, where privacy issues and unclear legal frameworks complicate integration, especially in sensitive domains like healthcare and finance. Moreover, public engagement and cultural acceptance are pivotal to successful implementation. Efforts in Seoul, including public seminars and blockchain literacy programs, aim to foster citizen participation in e-governance, while Toronto emphasizes collaboration between public institutions and private startups to balance innovation with regulatory oversight. Overall, the research underscores blockchain's expanding role in urban governance and provides a nuanced understanding of its practical applications, limitations, and future potential in reshaping how cities are managed. My key thesis is also that, for these reasons, urban testbeds play a crucial role in enabling blockchain technology to expand beyond its traditional applications in fintech. They provide a controlled environment where new ideas can be tested, evaluated, and improved, allowing cities to explore the broader potential of blockchain in areas such as public administration, infrastructure, and citizen engagement.

While the insights gained from cases reinforce the strategic value of testbeds in piloting blockchain innovations, it is equally important to acknowledge their inherent limitations.

The limits of urban testbeds, however, must also be critically considered. While they offer structured and low-risk environments for piloting blockchain technologies, they do not fully replicate the complex, diverse, and politically contested realities of actual urban life (Marres & Stark, 2020). Many testbeds operate under the assumption that urban populations are digitally literate and institutionally ready, overlooking barriers such as financial exclusion, lack of internet

access, and public mistrust factors that are particularly pronounced in marginalized communities.

Moreover, testbeds often prioritize technical innovation over social impact, treating blockchain as an inherently beneficial tool without addressing deeper governance issues such as surveillance, data ownership, or unequal power dynamics (Halpern, 2013). Controlled environments rarely account for cross-border legal conflicts, privacy concerns in blockchain identity systems, or variations in local regulatory capacity, all of which significantly influence the success or failure of implementation at scale.

These limitations underscore the need for caution when generalizing insights from testbeds to full-scale urban governance. Policymakers and planners must critically assess whether solutions tested in controlled conditions are adaptable, inclusive, and ethically sound in real-world settings. Ultimately, while testbeds are indispensable for early-stage innovation, they should be seen as starting points, not endpoints, in the journey toward meaningful, equitable blockchain integration in cities.

1.7 Outline of the dissertation

This dissertation is structured into six main chapters, each exploring different aspects of blockchain technologies, particularly smart contracts and NFTs, as they are being tested in urban settings through testbeds and experimental governance initiatives. The Introduction chapter presents the research topic, providing background on blockchain technology in urban governance, and outlines the research objectives, conceptual framework, methodology, and key insights. The Background chapter reviews the evolution of blockchain, smart contracts, and NFTs, explaining their theoretical foundations and relevance to urban governance, while also discussing the role of urban testbeds in promoting technological innovation. In the Methodology chapter, the qualitative research approach adopted in the study is explained,

including the criteria for case study selection, data collection methods, and the analytical framework used to explore how cities experiment with these technologies. The Urban Testbeds and Blockchain Experimentation chapter presents case studies from global cities that have implemented blockchain technologies in governance, finance, and public services. It evaluates the role of urban testbeds in facilitating blockchain experimentation and discusses the challenges and success factors in implementation. The Key Findings and Analysis section synthesizes the main findings from the case studies, highlighting common trends, barriers, and opportunities. It specifically addresses issues such as regulatory challenges, public engagement, scalability, and the feasibility of integrating blockchain beyond testbeds. The dissertation concludes with the Conclusion chapter, which summarizes the key insights to guide future applications of smart contracts and NFTs in urban governance.

2. Background

2.1 Evolution of Blockchain Technology

Blockchain is the technology behind Bitcoin. Introduced in Satoshi Nakamoto's white paper in 2008, blockchain works like a public ledger, ensuring that transaction data is accurate and secure (UK Government, 2015). A blockchain is a type of distributed ledger, meaning that its data is copied and shared across multiple locations worldwide.

In a traditional database, data is stored in tables. In blockchain, data is stored in "blocks" that are linked together in a chain. For Bitcoin, each block contains information about the sender, receiver, and amount of each transaction (Swan, 2015). The key feature of blockchain is the use of "hashes," which are like digital fingerprints. Each block has its own hash and also includes the hash of the previous block, creating a secure link between them. If any data in a block changes, its hash changes too, affecting all subsequent blocks (Abdolee et al., 2019). This makes the blockchain very secure, as altering one block would require changing all the blocks that come after it. The first block in a blockchain is called the Genesis block.

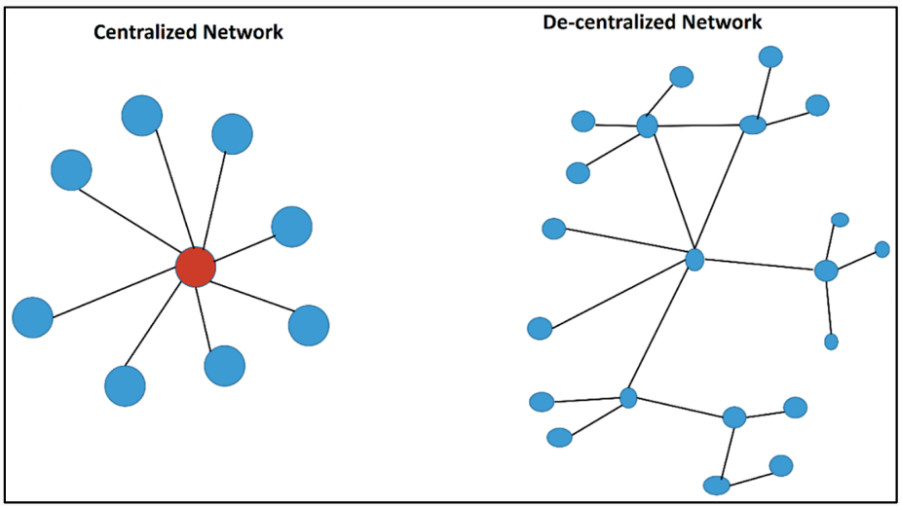

Figure 1. Centralized versus decentralized network (Chattu et al., 2019).

Blockchain is also unique in the way the information is structured (Mazonka, 2016). In general, information is structured in table format. In a blockchain, these tables are structured into blocks that are chronologically added into a chain (Abdolee et al., 2019). Each block has a hash and the hash of the previous block. A hash can be interpreted as a fingerprint verifying the block. If the information in a block is changed or manipulated, the hash of the block also changes. Consequently, the subsequent blocks become invalid, as they refer to an invalid previous hash. As such, information cannot be changed unless the entire blockchain is changed. As the blockchain is stored in each node of the decentralized computer network, a majority of the nodes must approve or be controlled in order to change the blockchain. Figure 2 shows a visualization of a blockchain (Mazonka, 2016).

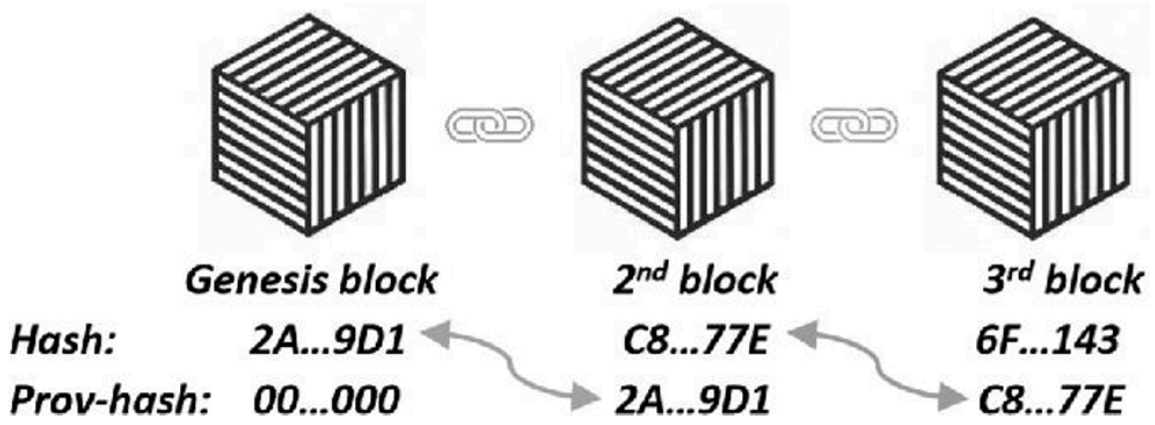

Figure 2. A blockchain and the hash mechanism (Abdolee et al., 2019).

Blockchains use 'consensus protocols', which contain rules and verification procedures to validate data, letting the network agree about adding data to the blockchain (Bashir, 2018). Proof of Work (PoW) is the protocol used for Bitcoin (Nakamoto, 2008). It works by having nodes in the network solving a complex mathematical problem to be able to add new blocks to the blockchain. The first one to solve the problem adds their new block to the blockchain to be

verified by the network. When a block is verified and added to the chain, the node that solved the problem receives compensation in the form of a block reward and/or a transaction fee (Nakamoto, 2008). Nodes that try to add new blocks are often referred to as miners. The problem can be solved simultaneously by different miners in the network. The network then bases its choice on the amount of accumulated work, also referred to as the longest chain. This is called the longest chain rule which assumes that the longest chain is the valid one (Abdolee et al., 2019).

2.2 Smart Contracts and Tokens: Concepts and Characteristics

In 1994, Nick Szabo, an American computer scientist, introduced the concept of smart contracts, which are digitized real-world contracts. The concept is defined as a "computerized transaction protocol that executes the terms of a contract" (Christidis and Devetsikiotis, 2016). With the advent of blockchain technology, smart contracts have gained renewed attention, as the decentralized and cryptographic features of blockchain provide an ideal platform for executing these contracts more efficiently and securely. This resurgence has allowed smart contracts to be leveraged in various fields, offering innovative solutions to traditional problems and enabling more transparent and automated processes (Mazonka, 2016).

The core components of tokenization are smart contracts and blockchain (Colliers International et al., 2020). Tokenization is the process of converting rights to an asset into a digital token on a blockchain. These tokens represent ownership or participation rights and can be easily transferred or traded within the blockchain network. A smart contract acts as a transaction protocol that automatically executes the terms of a contract when the predefined conditions are met (Szabo, 1994).

For instance, a smart contract can be attached to a blockchain, most commonly the Ethereum blockchain (Antonopoulos & Wood, 2018). Ethereum provides a platform for smart contracts

and the cryptocurrency Ether. Once a smart contract is deployed on the Ethereum blockchain, it can interact with Ether, facilitating the automatic execution and settlement of transactions or management actions, such as dividend distributions, when specific conditions are fulfilled (Christidis and Devetsikiotis, 2016).

Moreover, the execution of these actions is transparently recorded on the Ethereum blockchain, which serves as an immutable ledger. This record-keeping ensures transparency and security in all transactions, making blockchain and smart contracts powerful tools for automating complex processes in a reliable and decentralized manner (Antonopoulos & Wood, 2018).

Christidis and Devetsikiotis (2016) explain the mechanisms behind smart contracts in a paper titled "Blockchain and Smart Contracts For The Internet of Things". Smart contracts are scripts stored on the blockchain and because of their dependency on the chain, they also have a unique hash or identifier. When these contracts are triggered, they then execute independently and automatically in a predetermined procedure on every node in the network (Christidis and Devetsikiotis, 2016). Smart contracts function due to the following characteristics and attributes explained in the same paper :

- Smart contracts are self-controlled entities on the blockchain that can modify rows i.e. take custody of assets in the chain.
- Smart contracts understand business logic which can be embedded in the contracts (e.g.: trade 1 unit of X for 10 units of Y)
- Smart contracts contain a strategy for all possible outcomes
- Smart contracts are triggered by transaction requests sent to an address
- Smart contracts will always execute the same scripts regardless given the same input and it is not possible to write non-deterministic code in the world of blockchain as counterparties will not be able to reach consensus thus rejecting the transaction request
- Smart contracts exist in symbiosis with blockchain, allowing all network participants to inspect the code and view the unique cryptographical identifier (Christidis and Devetsikiotis, 2016).

2.3 The promises of Blockchain

Scholars such as Ølnes and colleagues (2017) have listed various benefits of using blockchain technology (BCT), as shown in Table 1. This long list of benefits sounds very promising, but it's unlikely that all of them will be achieved at the same time. There hasn't been a thorough review of these benefits yet, and many are not backed by strong arguments or evidence. The benefits are interdependent and whether they will be achieved depends on how the blockchain is designed and developed. Basic benefits include improved data integrity and secure transactions, which can lead to better traceability and help reduce corruption and fraud. However, it's important to note that distributed solutions like blockchain are generally less efficient than traditional centralized databases, harder to scale, and less flexible (Ølnes, 2016).

Category	Benefits and promises	Explanation
Strategic	Transparency	Democratizing access to data. History of transactions remain visible and every nodes has complete overview of transactions
	Avoiding fraud and manipulation	Hacks or unauthorized changes are difficult to made without being unnoticed, as information is stored in multiple ledgers that are distributed.
	Reducing corruption	Storage in distributed ledgers allows for preventing corruption. For example by storing landownership in a BT and having clear rules for changing ownership which cannot be manipulated

Organizational	Increased trust	Trust in process by increased control due to immutable recordkeeping and by verification of the data by multiple nodes.
	Transparency and auditability	Being able to track transaction history and create an audit trail. Also by having multiple ledger which can be accessed for consistency.
	Increase predictive capability	As history information can be traced back, this availability of the historic information increased the predictive capability.
	Increased control	Increased control by needing consensus to add transactions.
	Clear ownerships	Governance need clearly defined and how information can be changed.
Economical	Reduced costs	The costs of conducting and validating a transaction can be reduced as no human involved is needed.
	Increased resilience to spam and DDOS attacks	Higher levels of resilience and security reduces the costs of measure to prevent attacks
Informational	Data integrity and higher data quality	Information stored in a system corresponds to what is being represented in reality due to need for consensus

		voting when transacting and distributed nature. This result in higher data quality.
	Reducing human errors	Automatic transactions and controls reduces the making of errors by humans.
	Access to information	Information is stored at multiple place which can enhance the easy the access and speed of access
	Privacy	User can be anonymous by providing encryption keys or access can be ensured to avoid others to view the information.
	Reliability	Data is stored at multiple places. Consensus mechanisms ensures that only information is changed when all relevant parties agrees
Technological	Resilience	Resilient to malicious behavior.
	Security	As data is stored in multiple databases using encryption manipulation is more difficult. Hacking them all at the same time is less likely.
	Persistency and irreversibility (immutable)	Once data has been written to a BC it is hard to change or delete it without noticing. Furthermore the same data is stored in multiple ledgers.

	Reduced energy consumption	Energy consumption of the network is reduced by increased efficiency and transaction mechanisms.

Table 1: Potential benefits and promises of Blockchain (Ølnes et al, 2017)

Table 1 shows a diversity of benefits that are attributed to BCT, from which many of them might not be BC specific and require considerable organizational and institutional practices to let the BC system function in such a way that the benefits outweigh potential risks. From the description it becomes clear that some benefits are attributed to other technologies (like encryption, identity management) and are not BC specific. Some other benefits are not BC specific at all, like reducing fraud and corruption.

Blockchain technology (BCT) can help improve control and auditing, leading to more trust. But this only works if the institutions using it are trustworthy. It's not clear if blockchain really saves energy, as it needs lots of computing power. Whether blockchain benefits actually happen depends on how it's used and adopted (Ølnes et al, 2017).

So, the benefits of blockchain might be exaggerated. Whether they happen depends on how it's used, who's in charge, and the context it's used in. To get the benefits, we need to understand how the government works and be ready to change how things are done. We need a way to manage transactions that's spread out and a set of rules to follow. And we need to think about what people want, like fairness, transparency, and privacy. Also, we could get the same benefits from other tech. So, we need to figure out what benefits only blockchain gives us and when it's the best choice. It is also important to remember that blockchain is still new and could change (Ølnes et al, 2017).

In short, reaping the benefits of blockchain might be harder than we first thought. We might need to change the way we use technology and have rules in place. Studying how blockchain can

help governments requires looking at different areas like technology, rules, and how people use it (Ølnes et al, 2017).

2.4 Critiques of Blockchain

Blockchain technology is often seen as a groundbreaking tool with the power to change many industries, like finance and supply chains. However, it also faces several important challenges. While blockchain is praised for its ability to decentralize control, improve security, and increase transparency, there are some significant issues that need attention (World Economic Forum, 2024). These include the high energy use involved in processes like mining, difficulties in scaling up to handle lots of transactions, and complex legal and regulatory obstacles. Moreover, concerns about security flaws, the risk of widening economic gaps, and the difficulty for everyday people to use this technology also raise questions (World Economic Forum, 2024). Understanding these problems is crucial to get a full picture of what blockchain can and cannot do in today's world. They are some critiques below :

One of the most significant criticisms of blockchain technology, particularly Proof of Work (PoW) blockchains like Bitcoin, is their substantial environmental impact. The process of mining, which requires solving complex mathematical problems to validate transactions, consumes a vast amount of electricity. This energy consumption contributes to carbon emissions, which is a growing concern as the world grapples with climate change. This critique has led to debates about the sustainability of blockchain, especially as the technology scales up (World Economic Forum, 2024).

Moreover, Blockchain networks often struggle with scalability, particularly when it comes to processing a large number of transactions simultaneously. As the number of users and transactions increases, the system can become slower and less efficient, leading to higher transaction costs and delays. This limitation poses a significant challenge for the widespread adoption of blockchain technology in industries that require high transaction throughput, such

as finance and supply chain management (United Nations Conference on Trade and Development [UNCTAD], 2023).

The decentralized and pseudonymous nature of blockchain creates significant regulatory challenges. Governments and regulatory bodies struggle to apply existing legal frameworks to blockchain activities, such as money laundering, fraud prevention, and consumer protection. Moreover, the global nature of blockchain transactions complicates jurisdictional issues, making it difficult to enforce laws across borders. These challenges are particularly acute in sectors like finance, where regulatory compliance is critical (United Nations Conference on Trade and Development [UNCTAD], 2023).

While blockchain is often touted for its security features, it is not entirely immune to vulnerabilities. For example, 51% attacks, where a single entity gains majority control of the network's hashing power, can allow that entity to double-spend or reverse transactions. Additionally, smart contracts, which are a critical component of many blockchain systems, can contain bugs or exploits that can be difficult to patch once deployed due to the immutable nature of blockchain (World Economic Forum, 2024).

There is a growing concern that blockchain technology could exacerbate economic and social inequalities. The concentration of mining power and wealth in the hands of a few individuals or entities contradicts the decentralized ethos that blockchain advocates promote. Additionally, access to the technology and its benefits can be uneven, further widening the gap between those who have the resources to engage with blockchain and those who do not (World Economic Forum, 2024).

Despite the potential benefits of blockchain, the technology remains complex and difficult for the average user to understand and utilize effectively. The learning curve for interacting with blockchain applications, understanding smart contracts, and managing digital wallets is steep. This complexity limits its adoption among the general population and creates barriers to entry for businesses and individuals who may benefit from its use (World Economic Forum, 2024).

These critiques highlight the challenges and limitations of blockchain technology, which must

be addressed to realize its full potential in various sectors. Including these points in your thesis will provide a balanced view of blockchain's capabilities and its current drawbacks.

2.5 Token Standards

Tokenization unlocks liquidity by enabling fractional ownership and lowering the barriers to entry for investment in illiquid assets.

Two core components of tokenization are blockchain technology and smart contracts. Blockchain technology helps to streamline processes by allowing separate stakeholders to have secure access to the same copy of data, which cannot be altered without validation from other stakeholders. The data central to tokenization is a digital ROM (a tamper-proof digital record or representation of the asset), which is uploaded to a blockchain as a complete record of ownership (Colliers International et al., 2020).

Although fractional ownership itself is not a novel concept, maintaining the ROM on a blockchain makes the management of fractional ownership drastically more efficient because the digital ROM can be updated almost instantly, and it is resistant to unauthorized alterations by unverified actors. Each transaction is encrypted and recorded on the blockchain, making sensitive data traceable but protectable by smart contracts (Colliers International et al., 2020).

Smart contracts form the building blocks of programmable actions, which is the key to unlocking liquidity. Smart contracts are coded to execute compliance protocols, due diligence, KYC, and anti money laundering (AML) procedures, as defined by regulatory requirements and further specified by the terms set by individual issuers. Smart contracts also play a role in facilitating near-instant settlement of transactions (Colliers International et al., 2020).

Immutable transaction records on blockchain and a high degree of automation enabled by smart contracts bring much-needed process optimization and efficiency to investment. Other actions that are programmable throughout the investment lifecycle include investor and

corporate action management, such as distributing dividends and holding shareholder votes (Colliers International et al., 2020).

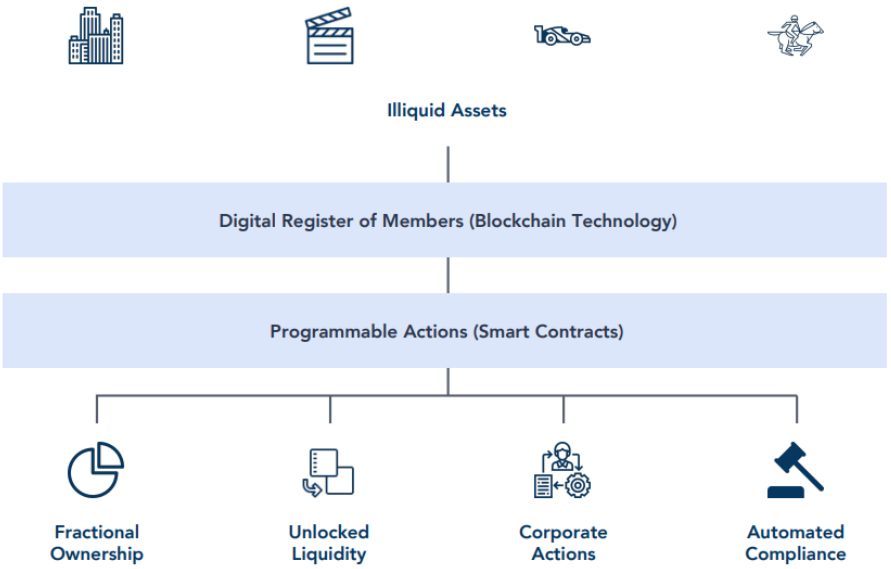

Figure 3. Digitalization (Colliers International et al., 2020)

A token is defined as a blockchain-based digital share of an asset. In real estate tokenizing, the underlying asset of the token is a property. The property is held by a holding company through which property managers, valuers, auditors etc. are hired. Furthermore, the net operating income is managed through the holding company. The holding company is controlled by a special purpose vehicle, that in turn was established by the company who originally acquired the property. The special purpose vehicle is the tokenized underlying asset. The special purpose vehicle is tokenized and divided into tokens through a tokenization platform. Thereafter, the property is indirectly liquidated through divestments of the tokens at the secondary market. If the tokenized asset is issued on an exchange, the tokens are publicly traded. The dividend and ownership of the tokens are distributed, transferred and recorded in a read-only memory (ROM) with means of smart contracts and blockchain (Colliers International et al., 2020).

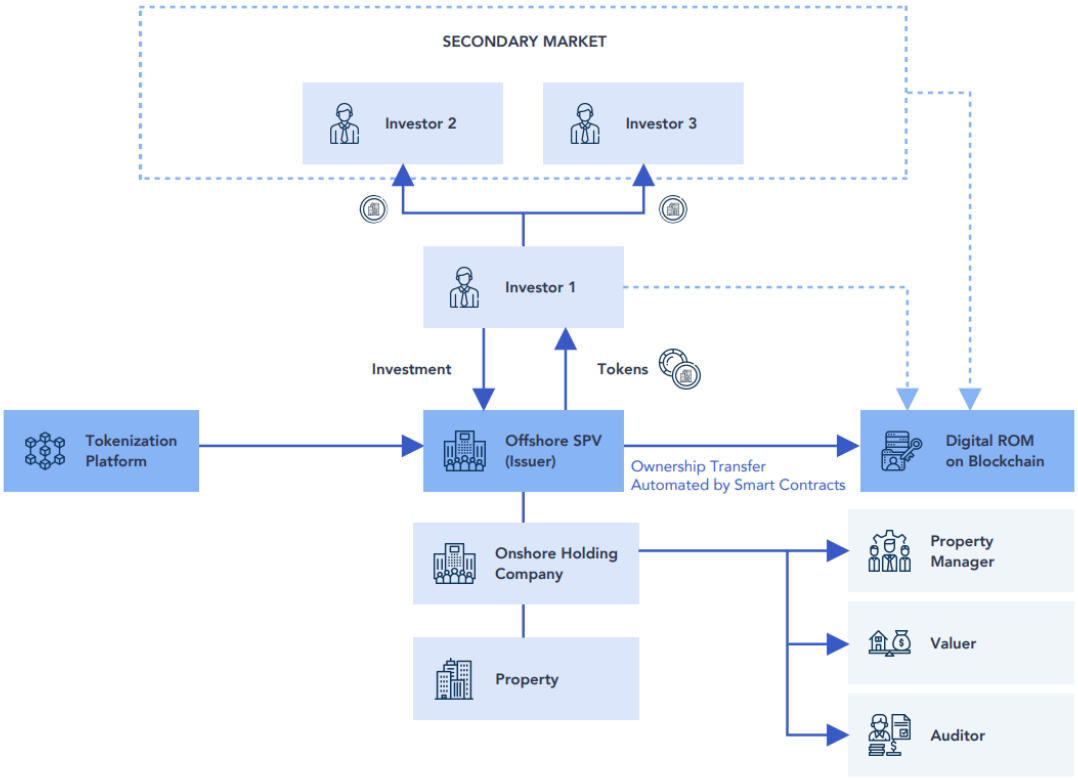

Figure 4. Lifecycle of a tokenized property (Colliers International et al., 2020).

2.6 Post-Tokenization Management

In post-tokenization management, smart contracts enforce automated corporate action management processes, including dividend distribution and shareholding voting. Smart contracts also facilitate the swift settlement of token transfers. Issuers retain control over the final approval or rejection of investors who pass automated restrictions before token transfers are finalized. Every transaction throughout the life of a security token is recorded immutably on blockchain, for example Bonds secured by real estate are fixed-income investments or loans, and generally offer a relatively stable yield (Colliers International et al., 2020).

Tokenization can significantly reduce the cost of bond issuance by streamlining and lowering the multitude of costs that are incurred throughout the lifecycle of a bond, by using blockchain

technology for the digital issuance, trading and management of the bond.After company information is recorded on blockchain, smart contracts are coded with the terms of the bond issuance. Investors are issued with tokens which are a digital representation of the bond . Settlement, trading, and post-issuance coupon payments can be executed by smart contracts (Colliers International et al., 2020).

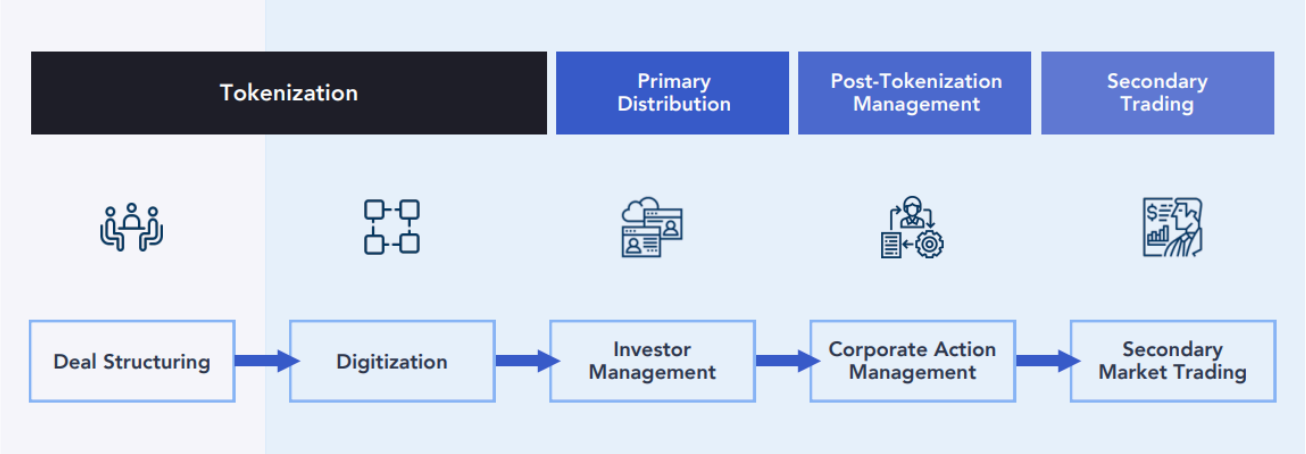

Figure 5. Lifecycle of a tokenization (Colliers International et al., 2020).

As we have seen so far, a blockchain is a database that has a digital ledger, otherwise called the smart contract that stores the details of all the transactions and information exchanged in blocks. While a majority of researchers and practitioners argue about its abundant potential benefits and application areas in government, the literature also presents various challenges that need to be addressed.

In 2018, in a report on cryptocurrencies and blockchain in Europe and central Asia, the World Bank stated that "policymakers should strike a balance between curbing the hype surrounding these new technologies and exploring the essence of these new opportunities". The European Commission summarized the technical and legal challenges to the government's use of blockchain technology as lack of policy framework for cryptocurrencies, integration with existing systems, scalability issues, blockchain to blockchain interoperability, and enforceability of smart contracts. The lack of infrastructure is also identified as one of the important obstacles

to implementing this technology across the globe by governments. In this section, we review adoption challenges and how governments have faced them to encourage innovation, considering the benefits reaped out of this technology (Khan et al., 2022).

The Study Found in Literature/Use cases: Govt. Adoption of Blockchain	**Opportunities**	**Challenges**
Adoption of blockchain for identity management, with a focus on the Korean Government	Data integrity and Reliability; reduce the cost of service delivery; A user-centric personal data management without a central authority. Allows for quicker data access	Educating the public sectors on the blockchain, privacy, and, regulatory concerns
Key regulatory challenges of blockchain adoption in the EU and US. It discusses the hands-off approach initiated by both countries, and how this has leveraged the adoption of blockchain	Promotes a clear understanding between cryptocurrency and blockchain	Lack of adequate knowledge and blockchain expertise from regulators
Automating the process of regulatory reporting using blockchain technology in the UK	Reduces duplication, efficient regulatory reporting system; Creates a better understanding of blockchain for regulators by making them use the technology in regulatory	Educating regulators and other stakeholders, on confidentiality issues

	reporting.	
e-Estonia Application of blockchain in healthcare innovation in Estonia	Promotes better understanding of regulators, governments, and healthcare providers	Storage problems and end-user are responsible for data
Use of blockchain to boost tourism among small economies	Commercial opportunities for small countries and improved stakeholder knowledge	Educating stakeholders on blockchain and regulatory gaps
Adoption of blockchain technology in Tourism and the implications for tourism development in the Caribbean economy .	Boosting tourism revenue; Launching the first digital legal tender in the Caribbean	Lack of IT infrastructure and government support for new technologies

Table 2: Benefits and challenges faced by governments in blockchain adoption (Khan et al., 2022)

As already discussed, leading countries of the world and their governments are experimenting with the benefits provided by blockchain technology.Therefore, this study found it necessary to further probe the benefits of this technology in addition to the ones discussed above.

Saudi-based company Aramco has implemented a blockchain-based system for handling payments within peer-to-peer networks and has projected to bring about a cost efficiency of about 5%. Maurya highlights the fact that both artificial intelligence (AI) and blockchain have contradictory properties, but when combined can lead to improved efficiency and enhanced security (Khan et al., 2022). The combination of these two technologies can lead to a faster and better decision-making process . A blockchain is entitled to be completely reliable when it comes to safety and identity management. The reliability of the available current data is important for

governments to make any decision, however, the data collected from different sources may or may not be reliable at all definite time intervals (Khan et al., 2022). With decentralized data on blockchains, all the active nodes within the network would maintain a copy of the distributed ledger . Hence, the reliability of the system is achieved and makes the network dependable for all nodes. There is a necessity for the public verifiable contracts with an increased level of transparency in data utility (Khan et al., 2022).

The literature review reveals that several opportunities are available for utilizing blockchain in various government and private sectors; however, there are still some challenges to be addressed to achieve better utilization of this technology. The topic of privacy in blockchain has been debated vigorously by practitioners and researchers. In the public blockchain system, the data on the network is made available to all authorized users. This becomes a point of concern in safeguarding the privacy factors of individuals in the network and the data as a whole. Private blockchain ledgers, on the other hand, would ensure restricted data access by authorized personnel (Khan et al., 2022). Blockchain is much more secure when compared to central databases for safeguarding the data . However, several security risks exist, which must be examined and analyzed before the actual data transaction takes place. The infamous Decentralized Autonomous Organization (DAO) attack surprised the cryptocurrency world, as the hacker managed to scrape around 3.6 M Ether (Ether is essential to the network's operation, as it incentivizes miners or validators to process transactions and maintain the integrity of the system) from the network, leaving the developers and crypto experts in shock. The peer review of smart contract code and independent testing of the code can avoid such incidents in the near future. When it comes to implementing and adopting blockchain by organizations or government institutions, the major hurdle that remains seems to be the lack of standards and regulations . As with any emerging technology, it takes a while to be accepted and adopted by individuals as well as a wide range of industries. As reported by Forbes, the regulation authorities lack complete knowledge of any technological advancement, which becomes the same case with blockchain as well (Forbes, 2023). The launch of new services, applications, or

products based on a decentralized blockchain, needs to be governed under regulatory acts which are lacking currently (Khan et al., 2022). Blockchain promises transparency and verifiability of all the events; however, the organizations need to build robust laws and industry standards to ensure smooth functioning of the overall process which will eventually enhance the trust that an organization will have in the blockchain network. Such an integrated approach will not only facilitate the financial functioning and transaction monitoring, but also will guide the companies' auditing process . Laws and regulations need to be introduced to govern the smart contract information transaction and also to facilitate the interaction among system participants (Khan et al., 2022).

Benefits	Practical Example	Challenges	Practical Example
Reduced cost and improved efficiency	In Dubai's smart city initiative, blockchain is used to streamline government operations such as document processing and citizen services, reducing paperwork, manual intervention, and administrative costs. The government estimates savings of $1.5 billion annually by digitizing transactions through blockchain (World Economic Forum, 2020).	Lack of IT infrastructure	In many developing countries, urban planners struggle to implement blockchain technology due to a lack of internet connectivity and basic IT infrastructure, particularly in rural or underdeveloped urban areas (UNCTAD, 2023).
Data integrity and reliability	Estonia has implemented blockchain technology in its national e-residency program,	Lack of government support	In some countries, such as India, government hesitation to adopt blockchain technology

	where citizens can access and use various government services securely. The blockchain ensures that all citizen data, such as medical records and legal documents, are tamper-proof, leading to high data reliability and integrity (UNCTAD, 2023).		has delayed its integration into public services like land registry and taxation, limiting the technology's benefits to society (World Economic Forum, 2020).
Improved accountability	In Chile, the government implemented blockchain to track energy data. By recording the data transparently, stakeholders in the energy sector can verify that resources are used effectively, improving accountability in energy usage and distribution (UNCTAD, 2023).	Lack of awareness among stakeholders	In the construction industry, many contractors and project managers are unaware of blockchain's potential to track supply chain logistics, leading to slow adoption despite the technology's ability to prevent fraud and enhance transparency (UNCTAD, 2023).
Enhanced trust and understanding	The city of Zug in Switzerland adopted blockchain for e-voting, allowing citizens to vote securely and anonymously. This blockchain-based system has increased trust in the voting process because it is transparent,	Lack of expertise	Municipalities in many regions, including parts of Latin America, face challenges in adopting blockchain for smart city initiatives because there are not enough trained professionals who can develop,

	verifiable, and tamper-proof (World Economic Forum, 2020).		implement, and maintain blockchain solutions (World Economic Forum, 2024).
Reduced regulatory reporting	In Singapore, blockchain is being used in trade finance to reduce the need for manual documentation, providing real-time information to regulators and reducing the time and effort required for regulatory reporting in financial transactions (World Economic Forum, 2024).	Privacy and security	In healthcare, the adoption of blockchain is slow due to concerns about the privacy of patient data. For example, the European Union's GDPR regulations pose challenges in using blockchain for medical records because the technology makes it difficult to delete or modify data (UNCTAD, 2023).
		Lack of standards ,interoperability and regulations	In the global supply chain sector, many companies struggle with blockchain adoption due to a lack of industry standards. Different blockchain platforms often do not communicate with each other, making it hard for companies to implement interoperable solutions across borders (World Economic

			Forum, 2024).

Table 3: Benefits and challenges of blockchain for governments

2.7 Definition and Purpose of Urban Testbeds

Urban testbeds are designated areas within urban environments or governance systems where new technologies, policies, and innovative solutions are tested under real-world conditions. These testbeds act as controlled environments that enable the practical application and evaluation of emerging solutions to urban challenges. They are crucial for understanding how new approaches perform in a real-life setting and involve extensive collaboration among multiple stakeholders, including government agencies, private sector companies, research institutions, and local communities (Marres & Stark, 2020). Urban testbeds are thus essential for modern urban planning and development, offering a practical approach to integrating innovative technologies and solutions into the urban fabric. They help cities navigate the complexities of urban challenges while fostering a culture of innovation and collaboration (Marres & Stark, 2020). According to Orit Halpern and her colleagues (2013), a "test bed" is not an experiment as conventionally conceived in ideals of science. The term does not denote the unearthing of a truth about the world. The phrase test bed emerges in the engineering literature to describe a controlled and often isolated development environment in which to test the operability of new technologies, processes, or theories for large systems. Test beds can include practices such as beta-testing software, testing control systems in manufacturing, stress testing in financial regulation, and so forth (Halpern et al, 2013).

In the same paper, Halpern and colleagues argue that test beds calculate uncertainty not risk. The absence of a perfect model is not just something that concerns design experts. Instead, it serves as a tool for exploring new ideas. This approach to imagining a utopia relies on statistical and probabilistic methods that evolve through constant feedback. For planners there is a great

deal of uncertainty in the outcomes of their experiments, but what has increased is a faith in techniques of calculability (Halpern et al, 2013). This faith, which takes mystical and magical undertones, embeds itself in the sensory environments and business models that largely bank on fantasized data sets that can be used to direct every aspect of life from the medical status of bodies to education to entertainment. These data are considered valuable because of an armament of new techniques for excavating results without ever knowing the objective endpoint or baseline. The language of ubiquity as the definition of smartness is revelatory in this case. Its lack of a definite endpoint or image of the city is indicative of the new calculations that take into account uncertainty but cannot think from within their internal logic about absolute failure, loss, or termination, if only because there is no base point from which to start. Repeatedly, both government officials and engineers argued that this was a prototype whose failings would be fodder for the next generation of city (Halpern et al, 2013).

Marres also discusses the role of testbeds in urban governance, similar to Orit Halpern's concept of testbed urbanism. She suggests that cities are increasingly being used as testbeds for smart technologies, which has significant implications for how urban spaces are managed and regulated. This practice raises critical questions about the ethics and governance of using urban populations as subjects in large-scale technological experiments. Marres conceptualizes testbeds as "sociotechnical laboratories" where the social implications of new technologies are as important as their technical performance. In these settings, new technologies are tested in real-world conditions, which allows researchers and developers to observe how these technologies interact with social practices, public policies, and environmental factors. Marres and Stark argue that this approach is crucial for understanding the broader impact of technological innovation on public life (Marres & Stark, 2020).

Testbeds often become arenas for sociotechnical controversies, where the interactions between technology, society, and the environment lead to public debates or ethical dilemmas. For instance, the deployment of smart city technologies in urban testbeds can raise issues related to

privacy, data ownership, and surveillance. Marres and Stark' work highlights the importance of addressing these controversies during the testing phase, rather than after technologies have been widely implemented. They view testbeds as key instruments for innovation, allowing new technologies to be tested and refined in controlled yet realistic environments. However, they caution that the focus on technical innovation in these settings can sometimes overshadow important social considerations, leading to outcomes that may not benefit all members of society equally (Marres & Stark, 2020).

2.8 Role of Testbeds in Blockchain Experimentation

Urban testbeds play a crucial role in the experimentation and development of blockchain technologies. These designated areas within cities provide a controlled environment where new blockchain applications can be tested in real-world conditions, allowing for practical evaluation and refinement before broader implementation (McKinsey & Company, n.d.). One of the primary functions of testbeds is facilitating innovation. They offer a platform for innovators to develop and demonstrate cutting-edge blockchain solutions, addressing urban challenges such as traffic management, energy distribution, and public services (Deloitte Insights, n.d.). By simulating real-life scenarios, these environments help identify potential improvements and adapt technologies to meet the needs of urban populations. Another key advantage is reducing risk. Implementing new technologies at scale can be risky and costly, but testbeds mitigate these risks by enabling controlled experimentation. Issues can be identified and resolved in a smaller, contained setting before full-scale deployment, ensuring that only well-tested solutions are expanded and reducing the likelihood of costly failures (McKinsey & Company, n.d.). Testbeds also support data collection and analysis. They enable the gathering of valuable data on the performance and impact of blockchain technologies, which is crucial for assessing effectiveness, understanding user interactions, and making data-driven decisions for future urban planning and governance (SIPMM Publications, 2021).

Public engagement and acceptance is another essential aspect. Testbeds provide opportunities

for residents to interact with blockchain applications, offer feedback, and gain familiarity with these innovations. This fosters greater public trust and acceptance, which is critical for the successful adoption of blockchain-based solutions (Deloitte Insights, n.d.).

Additionally, testbeds contribute to policy and regulation development. Insights gained from these experiments help shape regulatory frameworks and policies that support the safe and effective implementation of blockchain technologies. This ensures that regulations keep pace with technological advancements while addressing potential legal and ethical concerns (McKinsey & Company, n.d.).

In conclusion, urban testbeds are instrumental in advancing blockchain experimentation by providing a safe, controlled, and collaborative environment for testing and refining new technologies. They help cities harness the full potential of blockchain, ensuring innovations are effective, efficient, and widely accepted. At the same time, testbeds are artificial environments that operate based on certain assumptions about society, governance, and urban settings. While they serve as controlled spaces for testing blockchain applications, they do not fully capture the complexity, unpredictability, and socio-political realities of real cities. Many testbeds are designed with a technocratic perspective, assuming that urban challenges can be solved through technical fixes. However, cities are not neutral spaces; they are shaped by political decisions, economic disparities, and social dynamics. Testbeds do not always account for conflicting interests between governments, private companies, and citizens (Marres & Stark, 2020). Testbed environments often treat blockchain as an inherently beneficial tool, assuming that features like decentralization and transparency will automatically improve governance. However, blockchain also comes with power imbalances, such as the centralization of mining power, high entry costs, and potential misuse for financial speculation, which may not be visible in controlled test environments. The policy insights gained from testbeds may not translate seamlessly into real-world implementation. Testbeds do not fully test large-scale governance issues, such as cross-border legal conflicts, tax regulations, and privacy concerns in blockchain-based services.

While testbeds experiment with blockchain within a confined legal structure, they often fail to anticipate jurisdictional challenges when blockchain operates beyond national boundaries. Many blockchain testbeds assume digital readiness among urban populations, overlooking barriers such as digital illiteracy, lack of internet access, and financial exclusion (Marres & Stark, 2020).

While testbeds accelerate innovation and regulatory exploration, they must be analyzed critically to avoid creating overly optimistic expectations about blockchain's impact on cities. Policymakers must ensure that regulatory frameworks built from testbed insights are adaptable, inclusive, and context-aware, taking into account the diverse realities of urban governance rather than just the controlled conditions of experimental environments (World Economic Forum, 2024).

2.9 Blockchain and digital Governance

There is a multitude of motivations for organizations to adopt blockchain technology in comparison to the traditional databases. The contents of centralized databases are stored in the centralized servers or databases in an organization to which any malicious user will be able to gain access to the system and may corrupt or destroy the information (Khan, et al., 2022). From the moment data or information is stored on a centralized database, a dependency on a central database and administrator is created which leads to security breaches. For instance, the UK National Health Service (NHS) suffered coding errors for 150,000 patients in England when it was involved in a data breach, exposing sensitive medical data without patients' permission or knowledge . A problem with the software used by physicians to record medical treatment details was identified (Khan, et al., 2022) Patients had only agreed for the data to be used for individual care; however, the data were exposed to external auditors and for research . Several other targeted attacks, such as ransomware, botnets, and Distributed Denial of Service (DDoS) have become rampant, causing great damage to the e-services (Khan, et al., 2022) With blockchain, the scenario is different, as it enables us to keep information that is not just relevant at a given time

but also stores details of all the transactions and information that have taken place in history . When hospitals and banks which deal with sensitive information store their data on a central database, in case of a data breach, the data become corrupted or locked, which leads to detrimental effects. With blockchain, all the nodes within the network are notified about the activity in the network, ensuring the integrity of the data (Khan, et al., 2022).

Over the last two decades, there has been a persistent trend towards higher levels of e-government developments globally. Governments around the world have been proactively initiating widespread innovation and digital transformations across multiple levels and platforms. Governments have realized its far-reaching potential, not just for greater efficacy and effectiveness of the public service delivery, but also for ensuring inclusion, participation, and accountability (Khan, et al., 2022). The government of India is aiming to launch a smart warfare solution by adopting the Distributed Ledger Technology (DLT) to safeguard the safety and security of the critical infrastructure. The central bank of India has shown immense interest in developing digital rupees and implementing blockchain technology for land registry systems. The Government of Canada (GC) has been experimenting with utilizing blockchain innovation to give venture-based representatives a sort of advanced CV, giving "a changeless, self-possessed and secure record of their abilities and experiences (Khan, et al., 2022).

Sweden's government's land-ownership authority, "the Lantmäteriet", is aiming to launch its first blockchain technology property transaction for land registrations. The case submitted by McMurren et al. for addressing transaction costs through blockchain and identity in Swedish land transfers states that processing a land deal right from signing a contract until the completion of land transfer approximately takes four months. Signing a contract might take 2 hours as verifying documents and identity management is performed manually. Moreover, this land transfer process not being completely digital leads to missing, incomplete, or wrong entries in the land registry . Furthermore, the security structure of legacy systems prevents digitization because of the firewalls or limitations on network connections where organizations, such as

government regulatory agencies, banks, and realtors, could gain access to the system, but not the sellers, and consumers (Khan, et al., 2022).

Malta has established three cryptocurrency and blockchain related laws, Liechtenstein has proposed a blockchain act enabling a "token economy". The UK is automating the process of regulatory reporting using blockchain technology. The USA has no federal legislation, but some states are passing legislation enabling blockchain technology. Dubai and the UAE are leading the way with their robust data protection laws and classification standards (Khan, et al., 2022).

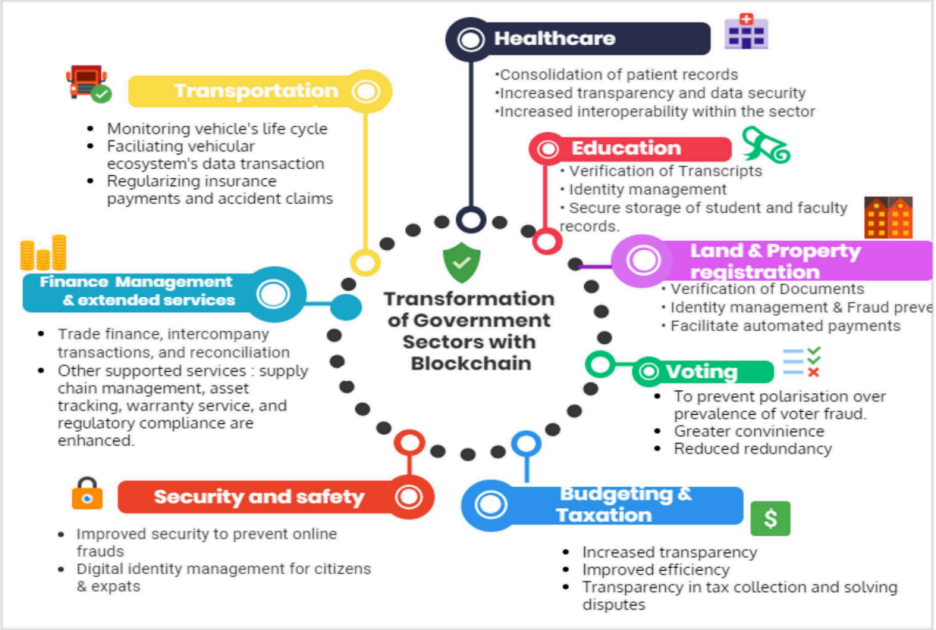

Figure 6. Utilizing Blockchain for Government sector services (Khan, et al., 2022).

Governments across the globe have taken different approaches to developing their blockchain ecosystems, with Malta creating a Digital Innovation Authority to enforce a blockchain technology approval process certifying platforms to enhance trust. The Korean government has adopted blockchain for identity management , and e-Estonia has its application in healthcare innovation. The Caribbean has adopted blockchain technology in tourism, for the development of their economy. A report by the Joint Research Centre (JRC) was submitted by the European Commission which discusses a few use cases, including citizen's identity management, taxation

reporting, development, and management, facilitating new decentralized business models without intermediaries, and e-voting, in which blockchain can play a major role in assisting governmental decisions. The implementations were divided and aimed at two governmental levels: national and local (Khan, et al., 2022).

The Gulf state's positive ranking on eGovernment Readiness (EGDI) reflects major ongoing efforts that regional governments have made to improve the overall ICT infrastructure across ministries and government agencies. Among the Gulf Cooperation Council (GCC) countries, the United Arab Emirates (UAE) has the highest e-government development index, followed by Bahrain, Saudi Arabia, Kuwait, and Oman (Khan, et al., 2022). Among the worldwide top 40 countries leading in e-government development, the UAE is grouped with countries with a very high online service index (OSI), at a rank of 21, jumping eight positions up from the 2016 rankings . Dubai, a significant emirate in the UAE ranks at four (on a scale of ten) in terms of e-government participation initiatives and lies within a 'high' category in terms of e-government development . In the Middle East, the Bahrain government's General Directorate of Traffic, as a part of the Smart Government initiative, has let out a tender to instigate the implementation of distributed ledger technology for monitoring and streamlining the vehicle registration process. The proposal mainly focuses on reducing cost, improving transparency and data integrity, and improving data management. The forecasted developments in the public services when explored show that blockchain can reduce bureaucracy, increase transparency and efficiency of administrative processes, and increase trust in the system (Khan, et al., 2022).

Project Name	**Country of Implementation**	**Field of Implementation**	**Level of Government Involved**
Exonum land title	Georgia	Land title registry;	National

registry		property transactions	
Blockcerts academic credentials	Malta	Academic certificates verification; personal documents storage and sharing	National
Chromaway property transactions	Sweden	Property transactions; transfer of land titles	National
uPort decentralized identity	Switzerland	Digital identity for proof of residency, eVoting, payments for bike rental and parking	Local (Municipality of Zug)
Infrachain governance framework	Luxemburg	Blockchain governance	National
Pension infrastructure	The Netherlands	Pension system management	National
Stadjerspas smart vouchers	The Netherlands	Benefit management for low-income residents	Local (Municipality of Groningen)
Fourth industrial revolution and smart	South Korea	Maritime Export Logistics; Import and	National and International

customs		Export clearance at customs department; Cross-Border Data Exchange	
blockchain-city-Melaka Straits City	Malaysia	Tourism	National
Tradelens	KSA	Supply chain and logistics	National

Table 4: Proposed blockchain-based projects (Khan, et al., 2022)

3. Methodology

3.1 Research Approach

This study adopts a qualitative research approach to investigate the emerging role of smart contracts and non-fungible tokens (NFTs) in urban governance. A qualitative methodology is particularly appropriate for exploring the complex socio-technical and governance dynamics that influence the adoption of blockchain technologies, factors that are not easily captured through quantitative methods.

The research is structured around the urban testbed model, which conceptualizes cities as controlled environments for the experimentation and refinement of emerging technologies. This framework enables an in-depth focus on how blockchain applications are piloted in real-world settings, allowing cities to assess operational feasibility, manage risks, and adapt solutions before full-scale implementation. To explore these dynamics, the study employs a multiple case strategy, drawing on documented initiatives in global cities such as Dubai, Singapore, Barcelona, Tokyo, Zug, and Toronto.

Data collection relies on document analysis of secondary sources, including academic literature, policy reports, government publications, and reputable media. These materials reflect the perspectives of key stakeholders such as public officials, technology providers, and civic organizations. By focusing exclusively on qualitative methods, the research captures rich, contextualized insights and offers a nuanced evaluation of the social, institutional, and policy dimensions of blockchain experimentation in urban contexts.

3.2 Case Selection Criteria

The selection of cases was guided by a set of rigorous criteria designed to ensure that the research

covers a diverse and representative sample of cities engaged in blockchain experimentation.

One of the primary criteria was geographical diversity. Cities from different regions of the world were selected to ensure a global perspective on the implementation of blockchain technologies. This approach captures the varying impacts of cultural, economic, and regulatory contexts on the adoption and effectiveness of blockchain solutions in urban governance.

Another important factor was blockchain application diversity. The research focuses on cities that have applied blockchain technology across a wide range of domains, including real estate, public services, digital identity, financial transactions, and urban governance. This diversity allows the study to examine the full spectrum of blockchain's potential in transforming urban processes and services.

The maturity of blockchain initiatives was also a key consideration. Cities with well-established and mature blockchain initiatives were prioritized to ensure that the research could analyze not only the initial experimentation but also the outcomes and long-term impacts of these initiatives. This criterion helps in identifying successful strategies and lessons learned that can be applied to other urban contexts.

Additionally, availability of data and documentation played a crucial role in the selection process. Cities were chosen based on the availability of comprehensive and reliable data sources, including academic studies, government reports, technical white papers, and case studies. The presence of detailed documentation ensures that the case studies are well-informed and that the analysis can be conducted with a high degree of accuracy and depth.

Examples of cities selected based on these criteria include Dubai, known for its pioneering blockchain-based governance models; Singapore, which has implemented blockchain in digital identity and financial services; New York, recognized for its blockchain applications in real estate; and Barcelona, a leader in smart city innovations.

3.3 Data Collection Methods

To gather the necessary data for this research, a combined approach of documentary analysis and case review was employed, combining various data collection techniques to ensure a comprehensive and robust understanding of the topic:

- Documentary Research: The primary data collection method involved an extensive review of existing literature, including academic articles, government reports, industry white papers, and cases. This documentary research provided a solid theoretical foundation and contextual background for understanding the current state of blockchain technology in urban environments. The documents were analyzed to extract key themes, patterns, and insights related to the implementation and impact of blockchain technologies.
- Case Analysis: The selected cities were analyzed as cases to provide a detailed examination of specific blockchain applications. Each case study was approached with a focus on understanding the contextual factors that influenced the implementation of blockchain technologies, the roles of different stakeholders, and the outcomes of the initiatives. The case method was chosen for its ability to provide a rich, context-specific understanding of the phenomena being studied, which is essential for drawing meaningful conclusions about the impact of blockchain technology on urban governance.

3.4 Analysis Framework

This section presents the conceptual framework for analyzing blockchain-based urban testbeds, focusing on how blockchain experiments are structured, compared, and assessed. The framework evaluates governance, technological feasibility, public engagement, policy adaptation, and economic impact, enabling a comparative analysis of blockchain implementation across cities. The research categorizes blockchain experiments based on five key dimensions, each addressing critical aspects of blockchain adoption and impact in urban

environments.

The first dimension, governance and institutional adoption, examines how governments integrate blockchain into public administration. It explores the involvement of stakeholders, including public, private, and civic entities, in blockchain experiments and assesses how urban testbeds influence policymaking and administrative efficiency. An example of this is Dubai's blockchain strategy, which aims to digitize government transactions (Khan et al., 2022).

The second dimension, technological feasibility and scalability, focuses on how cities test blockchain's efficiency and scalability before widespread adoption. It also investigates technical barriers such as interoperability, transaction speed, and security risks. A relevant case is Tokyo's blockchain testbed, which has faced challenges in scaling transaction volumes (Halpern, 2013).

The third dimension, public engagement and social impact, evaluates how blockchain testbeds involve citizens and businesses in decision-making processes. It considers whether these testbeds enhance transparency, trust, and participation in urban governance. For instance, Seoul has implemented blockchain-based e-voting initiatives to increase civic trust (Marres & Stark, 2020).

The fourth dimension, regulatory and policy adaptation, analyzes how blockchain testbeds influence policy development and regulatory compliance. It examines whether testbed results are used to shape blockchain-related laws and governance frameworks. A notable example is the European Union's challenges with GDPR compliance in blockchain identity systems (Halpern et al., 2013).

The fifth and final dimension, economic and operational efficiency, assesses whether blockchain reduces costs and improves efficiency in urban management. It looks at blockchain's impact on public procurement, land registry, and taxation. An example of this is Barcelona's blockchain-based public procurement model, which has been implemented as an anti-corruption measure (Khan et al., 2022). To assess such impacts effectively, cities often rely on urban testbeds as controlled environments that enable the evaluation of blockchain

applications before full-scale deployment. These testbeds allow for several key benefits. One major advantage is risk mitigation, as testing blockchain solutions in a limited setting helps reduce failure risks (Khan et al., 2022). Additionally, testbeds support data-driven decision-making, enabling governments to collect performance data and refine blockchain applications based on empirical insights (Halpern et al., 2013). Another crucial function is public engagement, as testbeds provide an opportunity for citizens to experience blockchain services firsthand, increasing awareness and potential adoption (Marres & Stark, 2020).

However, testbeds are not neutral spaces; they operate based on certain assumptions about technology and society. They assume controlled environments, which may not fully represent the complexities of real-world urban dynamics (Khan et al., 2022). Moreover, blockchain testbeds often presume that technology alone can resolve urban inefficiencies, overlooking the broader social, political, and economic dimensions that influence urban governance and infrastructure (Marres & Stark, 2020).

By applying the conceptual categories outlined earlier, this research compares blockchain testbeds across different cities to identify key patterns and variations. One focus is on identifying similarities, such as blockchain adoption in public services and governance. Additionally, the study seeks to highlight differences, particularly in regulatory variations across jurisdictions, which impact the pace and scope of blockchain implementation. Another crucial aspect is evaluating success factors, including scalability, public acceptance, and regulatory flexibility. Through this comparative approach, the study aims to provide a structured analysis of blockchain experimentation in urban testbeds, offering insights into both the potential and limitations of blockchain integration in urban governance (Khan et al., 2022).

4. Urban Testbeds in Blockchain Experimentation

Urban testbeds serve as structured and controlled environments where emerging technologies like blockchain can be piloted before large-scale implementation. In the context of this research, testbeds are viewed as critical instruments for understanding how smart contracts and non-fungible tokens (NFTs) are integrated into urban governance frameworks. These environments allow city governments, technology providers, and other stakeholders to experiment with blockchain-based solutions in real-world conditions, while minimizing risk and ensuring operational control.

This chapter explores how blockchain testbeds function across different city contexts, highlighting how they contribute to policy development, citizen engagement, and institutional innovation. Drawing on case studies from cities such as Dubai, Singapore, New York, and Barcelona, the chapter examines how blockchain applications are tested for feasibility, scalability, and public trust. The section also discusses the strengths and limitations of testbeds in shaping urban governance strategies and outlines key insights for future implementations.

4.1 Cases of Blockchain application

Urban planning and governance have continuously evolved to integrate emerging technologies that enhance efficiency, transparency, and security in public administration. Among these innovations, blockchain technology has gained significant attention due to its decentralized, immutable, and trustless nature. Initially introduced through Bitcoin as a digital ledger system, blockchain has now expanded beyond financial applications into various domains, including urban governance, public services, and smart city infrastructure (Ølnes et al., 2017).

Governments and municipalities worldwide are exploring blockchain as a tool to streamline bureaucratic processes, improve data integrity, and foster public trust. By eliminating intermediaries and enabling secure, real-time transactions, blockchain has the potential to revolutionize land registries, identity management, supply chain monitoring, and digital governance (Christidis & Devetsikiotis, 2016). However, despite its promise, blockchain adoption in urban settings is accompanied by scalability challenges, regulatory barriers, and interoperability concerns (UNCTAD, 2023).

To better understand its real-world applications, cities have established urban testbeds controlled environments where blockchain-based initiatives are piloted before large-scale deployment. These testbeds provide valuable insights into policy adaptation, citizen engagement, and technical feasibility, allowing for continuous improvement before full-scale implementation (Halpern et al., 2013). This study examines the cases of Dubai, Estonia, Singapore, Toronto, Zug (Switzerland), and Barcelona, analyzing their blockchain experiments and key takeaways for urban governance.

Not all of these cases are strictly "urban" or directly related to urban governance; some deal with broader governance issues that have implications for urban contexts. Nevertheless, they are included here because they offer valuable insights into governance dynamics that are often relevant in urban settings.

City/Country	Use case	Key Benefit
Dubai	Smart city and digital governance	Cost savings, efficiency
Estonia	E-Residency and Data Security	Data integrity, security
Singapore	Trade Finance and Logistics	Regulatory transparency

Toronto	Digital identity and public services	Citizen engagement
Zug	E-voting and crypto regulations	Trust in governance
Barcelona	Smart contracts in public Admin	Process automation

Table 5: key blockchain use cases in six global cities

The previous table presents a summary of key blockchain use cases in six global cities, highlighting their primary applications and benefits. Dubai leverages blockchain for smart city and digital governance initiatives, achieving cost savings and efficiency. Estonia focuses on e-residency and data security, ensuring data integrity. Singapore applies blockchain to trade finance and logistics, promoting regulatory transparency. Toronto emphasizes digital identity and public services to enhance citizen engagement. Zug (Switzerland) integrates blockchain in e-voting and cryptocurrency regulation, fostering trust in governance. Barcelona employs smart contracts in public administration, streamlining processes through automation. This showcases the diverse potential of blockchain in transforming urban governance worldwide.Three primary themes: Governance, Citizen Engagement, and Process Efficiency emerge as critical areas where blockchain technology is being utilized.

1. Governance: Cities and Countries such as Dubai and Estonia are leveraging blockchain to improve transparency and accountability in public administration. For example, Dubai aims to digitize all government documents using blockchain by 2025, ensuring secure and immutable record-keeping (UNCTAD, 2023). Estonia has similarly employed blockchain in its e-residency program to provide secure access to government services while ensuring data integrity (Christidis & Devetsikiotis, 2016).
2. Citizen Engagement: Barcelona has been a pioneer in integrating blockchain with citizen participation platforms like Decidim. Blockchain ensures secure and transparent voting processes, enhancing public trust and encouraging greater participation in

municipal decision-making (Halpern, 2013). Additionally, Zug in Switzerland uses blockchain-based e-voting to increase transparency and trust in governance (Ølnes, et al., 2017).

3. Process Efficiency: Singapore exemplifies the use of blockchain for trade documentation and supply chain management. By ensuring traceability and compliance with regulations, blockchain has significantly improved operational efficiency in sectors like logistics and finance (Khan, et al., 2022). Toronto has similarly implemented blockchain to streamline digital identity management and public service delivery (Colliers International, 2020).

The overlapping themes reveal how blockchain not only addresses isolated challenges but also creates synergies across multiple domains, such as enhancing trust in governance while simultaneously optimizing operational processes. These case studies provide valuable lessons for cities exploring blockchain as a transformative tool for urban development.

4.2.1 Case number 1) Dubai

This study begins with an in-depth look at Dubai because it stands out as a global leader in adopting blockchain technology within its government operations. Dubai has implemented blockchain in various sectors, making it an ideal starting point for understanding the practical applications and impacts of this technology in urban governance. The study collected empirical evidence from a blockchain project deployed in the Department of Economic Development (DED), one of the seventy government departments in Dubai. Given the specificity of the data sources, a case analysis was chosen as the methodological approach due to the limited research on emerging blockchain technology. This method is suitable for exploratory research, which is the focus of this study.

There are fifteen government departments across Dubai offering nearly 1875 services, out of which 309 services are intra and interdependent. The DED is one of these government departments, which is responsible for developing economic plans and policies and provides

services to domestic and international investors and businesses. The DED and its agencies develop, promote, and support foreign direct investment opportunities to facilitate investors. It also facilitates trade by creating an enabling environment for Dubai's exporters. Dubai launched a blockchain strategy to deliver more seamless, safe, efficient, and impactful city experiences and it plans to achieve efficiency by using blockchain in 100% of applicable government services. As per the recent reports , financial regulators in Dubai are working on crypto regulations and cryptocurrency laws (Khan, et al., 2022). The Dubai Ministry of Economy identified that crypto and asset tokenization was the fundamental support for doubling the size of the economy within the next decade. Growing experimentation with blockchain technology and pilot projects that have already reached the production phase provides an opportunity to analyze the potential of blockchain technology, based on the empirical evidence. Accordingly, our study adopts an empirical approach to analyze the potential of blockchain in the public sector. Researchers proposed a framework in a Joint Research Centre report, to support the European policy making process. This framework was developed for the generalization of collected data, and it consists of several elements covering institutional, functional, technical, and economic aspects of the cases (Khan, et al., 2022).

1. Case Study General Features					
Level of government involved	**Public services provided/enabled**	**Cross-border aspects**	**Cross-sector aspects**	**Location value creation**	**Openness of software**
National	Issuing or modification of a commercial license to domestic and international investors and businesses	None	Other license issuing authorities, other government entities, and private entities, such as banks, telecom, real estate, and other financial institutions.	Across mainland and free zones	Propriety

2. Functionalities		3. Governance				4. Usage			
Institutions disintermediated	**Functionalities provided**	**Roles Included**	**Blockchain governance architecture**	**Consortium governance**	**Current usage**	**capacity**	**Throughput**	**scalability**	**Maturity**
Automation of internal approvals within the government entities.	– Issue, renew, modify, or cancellation of trade name – Issue, renew, modify, or cancellation of trade license – Issue, renew, modify, or cancellation of commerce registry – Integration with other license issuing authorities 1. Integration with information consumer organizations 2. Integrated with Know Your Customer (KYC) registry	– Data Publishers: government license issuing authorities – Data Subscribers: government, private – Registry Service Provider	A hybrid permission-less governance model	Decentralized	Six to seven government entities transacting in this project	400–500 tps	– Hyperledger supports 40 tps, – CORDA supports up to 500 tps – Hyperledger Besu	500 tps	Production stage, following the successful execution of proof-of-concept

5. Technical Architecture				
Blockchain Interface	**Corporate Registry Back-Office Portal**	**Blockchain peer node**	**CA Node**	**Orderer Node**
Encapsulates all blockchain logic for Dubai Business Ledger. Encapsulates interfacing with its corresponding blockchain node.	Provide portal screens for the back-office operations of Corporate Registry, such check/audit exchange of trade license	Host Blockchain software and corresponding smart contracts of corporate registry	Authenticates all transactions	Broadcasts validated transactions for all organizations' peers.
Underlying Software Technologies: – Hyperledger Fabric 1.1 SDK – Node.JS PostgreSql (RDBMS)	**Underlying software technologies:** REACT (client-side development framework) Node.JS	**Underlying software technologies:** Hyperledger fabric Software V 1.1 CouchDB	**Underlying software technologies:** Hyperledger fabricSoftware V 1.1	**Underlying software technologies:** Hyperledger Fabric Software v1.1

6. Challenges	7. Benefits
– Low utilization – Technical immaturity – Lack of skills – Lack of awareness and trust – Governance – Migration challenges	– Improved trust – Standardization of regulatory checks – Reduced operational costs – Increased customer satisfaction – Authenticity of documents – Improved accountability – Positive environmental impact

Table 6. Dubai Blockchain Strategy (Khan, et al., 2022)

The DED's e-government evolution started by having a website to be used for listing business activities. E-services allowed customers to search the activities provided by the DED as well as to find "terms and conditions". In the next stage, the DED enhanced its web services by providing two-way communication for instant license partner approval services. Next, the government of Dubai made a strategic decision in 2012 to achieve a transactional stage of e-government through the provision of high-quality customer-focused e-services (Dubai. ae). Following the directions, all fifteen departments of the Dubai government re-designed their governance, policies, and technology platforms to provide e-service to their customers (Khan, et al., 2022).

During the transactional services stage of e-government, it required the DED take at least 7 days to issue a license for a commercial representative office. As shown in Figure 3, from an investor's perspective, this journey meant accessing various government department online services for taking approval, the contract development, registration, gaining utility connections, and then civil defense. It required the investors to repeat the business registration process at each of these departments. Moreover, each of these departments required similar documents, such as passport copies, ID copies, labor cards, etc., resulting in repetitions of documents. Furthermore, the DED lacked a unified business registry, across mainland and free zones, making it difficult to enforce common business rules, as required by law (Khan, et al., 2022). It was possible to reserve duplicate trade names across different entities due to the process in compliance. Modifications were not synchronized and service providers (such as financial institutions, government agencies, etc.) had to integrate with many different systems/authorities to complete their daily processes. Investors starting a new business were not only facing a long processing time of around three months to open a commercial bank account, but they were also unable to transfer goods from the free zones to mainland, without a local representative. Moreover, free zone firms were unauthorized to provide services to the mainland. Siloed, disorganized and paper-based practices negatively affect customer experience. For financial institutes, such as banks, there was a high operational cost involved in collecting investors' data and their continuous updates. Moreover, there was difficulty in complying with regulatory requirements, leading to penalties

in cases of non-compliance, e.g., money laundering, fraud, and terrorist financing. This resulted in low customer satisfaction with banks due to lengthy procedures. In addition, non-unified standards and lack of governance on business licenses from different authorities were other challenges faced by licensing authorities. It was realized that these existing governance structures, laws, and models were not enough to achieve the goal of creating a global business hub and therefore it required significant changes (Khan, et al., 2022).

4.2.2 Case number 2) Estonia

Estonia is a global leader in digital governance, largely due to its pioneering use of blockchain technology across multiple public sectors. The country began exploring blockchain as early as 2008, integrating it into its national systems to enhance security, transparency, and efficiency. Estonia's approach to digital governance has made it a model for other countries looking to implement similar technologies.

One of Estonia's most notable initiatives is the e-Residency program, launched in 2014. This program allows individuals worldwide to obtain a digital identity issued by the Estonian government. It enables global citizens to access Estonia's online services, such as starting and managing a company, accessing banking services, and digitally signing documents, all without needing to physically reside in Estonia. Blockchain technology ensures that these digital identities are secure, immutable, and trustworthy. The program has seen significant global reach, with over 95,000 e-residents from more than 170 countries establishing over 20,000 companies as of 2024. The security of blockchain ensures that identity data remains tamper-proof, building trust among international users (e-Estonia, 2022).

Blockchain also plays a crucial role in Estonia's healthcare system. Since 2012, all healthcare records in Estonia have been securely stored and managed using blockchain. This system allows patients and doctors to access and update medical records securely and transparently. Blockchain ensures data integrity by logging any changes to a patient's health records, preventing alterations

without detection. Additionally, citizens can access their health records at any time and see who has viewed their data, ensuring transparency (e-Estonia, 2022).

Another key application of blockchain in Estonia is in digital identity and e-government services. Every Estonian citizen and resident possesses a digital identity card, which is central to the country's e-governance system. Introduced in 2002, this digital ID is integrated with blockchain technology to secure and authenticate a wide range of services, including voting, tax filings, and banking. Estonia is the first country to allow online voting in general elections using blockchain technology, ensuring a transparent and secure voting process. The digital ID also grants citizens access to nearly 99% of government services online, from anywhere in the world (e-Estonia, 2022).

The X-Road platform serves as Estonia's backbone for e-services. Launched in 2001, it is a decentralized data exchange system that connects various databases and enables secure internet-based data exchange. Blockchain enhances the security and traceability of data transactions on this platform. X-Road improves interoperability by allowing different public and private sector entities to securely exchange data, reducing redundancy and increasing efficiency. Furthermore, blockchain provides an audit trail, ensuring that all data exchanges are traceable and recorded immutably, which is essential for transparency and accountability (X-Road, 2021).

Estonia's success in integrating blockchain into its governance structure has not only transformed its public services but also positioned it as a global leader in digital innovation. The country's model has inspired other nations to explore similar digital strategies, particularly in the realms of data security, transparency, and efficient service delivery. Estonia's digital infrastructure, supported by blockchain, has gained international recognition as one of the most advanced in the world. The Estonian model demonstrates how blockchain can be effectively scaled across an entire nation, influencing sectors ranging from healthcare to digital identity. By leveraging blockchain technology, Estonia has revolutionized how governments can operate in

the digital age. The country's success story offers valuable lessons for other nations seeking to enhance their digital infrastructure with secure, efficient, and transparent systems. Through its pioneering efforts, Estonia continues to lead the way in global digital transformation (e-Estonia, 2022).

4.2.3 Case number 3) Singapore

Singapore is a leading global hub for blockchain technology, particularly in the financial sector. The country's forward-thinking regulatory environment and strategic government initiatives have positioned it as a center for blockchain innovation and adoption.

One of Singapore's flagship blockchain projects is Project Ubin, a collaborative initiative led by the Monetary Authority of Singapore (MAS) to explore the use of blockchain for clearing and settlement of payments and securities. The project aims to develop a more efficient and secure financial system by leveraging distributed ledger technology (DLT). Since its inception in 2016, Project Ubin has gone through multiple phases, exploring different aspects of blockchain's application in inter-bank payments and cross-border transactions (Monetary Authority of Singapore, 2021).

Another major initiative is TradeTrust, which seeks to develop a framework for digital trade documentation using blockchain technology. By creating a standardized and legally recognized system for managing trade documents, Singapore aims to enhance the efficiency and security of global trade. This initiative supports the country's role as a major global trade hub and aligns with its broader strategy to become a Smart Nation (TradeTrust, 2021).

Blockchain is also being integrated into supply chain management to improve transparency and efficiency. The Singapore Government has supported various pilot projects that use blockchain to track goods, verify origins, and ensure compliance with trade regulations. This is particularly relevant in sectors such as food and pharmaceuticals, where traceability is critical (Infocomm Media Development Authority, 2021).

In the area of digital identity initiatives, Singapore has been exploring the use of blockchain to create secure, verifiable, and portable digital identities that citizens can use across various government and private sector services. This initiative is part of the country's broader digital transformation strategy (Smart Nation Singapore, 2021).

Singapore has also positioned itself as a global leader in financial regulation and innovation. The Monetary Authority of Singapore (MAS) has established a regulatory sandbox that allows fintech companies to experiment with blockchain technology in a controlled environment. This approach encourages innovation while managing risks, making Singapore an attractive destination for blockchain startups (Smart Nation Singapore, 2021).

4.2.4 Case number 4) Toronto (Canada)

Toronto is a significant player in the global blockchain ecosystem, particularly through its involvement in the development and adoption of blockchain technology in various sectors.

One of the key areas where blockchain is making an impact is financial services and innovation. Toronto is home to a thriving fintech scene, with numerous startups and financial institutions exploring blockchain for secure and transparent financial transactions. The city has become a hub for blockchain innovation, particularly in areas such as digital payments, cryptocurrency exchanges, and decentralized finance (DeFi) (Toronto Finance International, 2021).

Blockchain is also being applied in real estate and property management. Toronto has seen the implementation of blockchain in real estate to streamline property transactions. The technology is used to record property titles, track ownership, and facilitate transactions, making the process more transparent and reducing the risk of fraud (Canadian Real Estate Association, 2021).

While less prominent than its financial applications, blockchain is also being explored in public services and governance. Toronto has introduced pilot projects for identity management and transparent voting systems. These initiatives aim to enhance trust in public services by ensuring

data integrity and security (City of Toronto, 2021).

Toronto's blockchain initiatives are contributing to its reputation as a leader in digital innovation, particularly in financial services. The city's involvement in real estate and public service applications of blockchain also positions it as a forward-thinking urban center.

4.2.5 Case number 5) Zug, Switzerland

Zug is famously known as "Crypto Valley" due to its favorable regulatory environment, which has attracted numerous blockchain startups and established companies. This small town has become a global hub for blockchain innovation, fostering a vibrant ecosystem of blockchain companies, including the Ethereum Foundation and Bitcoin Suisse (Crypto Valley Association, 2021).

One of the key applications of blockchain in Zug is digital identity and voting. The local government has implemented blockchain for digital identity verification, allowing residents to use blockchain-based digital IDs for accessing services. In 2018, Zug conducted a pioneering blockchain-based municipal voting trial, showcasing the technology's potential in secure and transparent voting processes (Crypto Valley Association, 2021).

Blockchain has also been integrated into business registration. Zug was one of the first places to accept cryptocurrency for government services, such as business registration fees, further cementing its role as a leader in blockchain adoption (Canton of Zug, 2021).

The impact and global influence of Zug’s successful integration of blockchain into public services and its thriving blockchain ecosystem have made it a model for other regions aiming to embrace blockchain technology.

4.2.6 Case number 6) Barcelona, Spain

Barcelona is known for its innovative Smart City projects, and blockchain technology plays a

role in enhancing transparency and efficiency in public services. The city has implemented blockchain to improve the management of public resources, such as energy and water, by providing a transparent ledger of resource use (City of Barcelona, 2020).

One significant application of blockchain in Barcelona is in citizen participation. The city's Decidim platform, which allows residents to participate in municipal decision-making, is exploring blockchain to ensure transparency and security in voting and public consultations (City of Barcelona, 2020).

Another important area of blockchain application is public procurement. Barcelona is experimenting with blockchain in public procurement processes to ensure transparency, reduce corruption, and enhance efficiency. Blockchain provides an immutable record of all transactions, ensuring that public funds are managed responsibly (Decidim Barcelona, 2020). Barcelona's integration of blockchain into its Smart City framework demonstrates how the technology can be used to create more transparent, efficient, and participatory urban environments (Decidim Barcelona, 2020).

The analysis of blockchain cases across global cities reveals a transformative potential in urban governance, citizen engagement, and process efficiency. Cities like Dubai and Estonia showcase blockchain's ability to enhance transparency and accountability in governance, while Zug and Barcelona demonstrate its effectiveness in fostering trust and participation through secure, decentralized voting systems. Additionally, Singapore and Toronto highlight the operational efficiency blockchain brings to trade logistics and digital identity management, respectively. These examples underscore the versatility of blockchain in addressing urban challenges, offering scalable, secure, and innovative solutions for smart city development. By integrating blockchain into diverse sectors, these cities set a precedent for leveraging technology to create more efficient, transparent, and inclusive urban environments.

4.3 Table Map

The Table Map in Section 4.3 offers an in-depth exploration of blockchain adoption across various global cities, serving as a valuable reference for understanding how this technology is reshaping urban governance and services. By organizing key details such as city and country, smart contract applications, tokenization initiatives, implementation status, primary stakeholders, challenges, and opportunities, the table provides a holistic view of blockchain's impact on urban ecosystems.

For instance, Singapore's entry showcases its leadership in leveraging blockchain for public procurement, digital identity management, real estate tokenization, and loyalty reward programs. With full implementation achieved, the role of Singaporean government agencies and blockchain startups emerges as pivotal. At the same time, challenges such as regulatory compliance and interoperability highlight the complexity of integrating blockchain at scale. Despite these hurdles, significant opportunities are evident, including enhanced efficiency in government processes and innovative customer loyalty programs.

This format not only highlights the technological advancements but also sheds light on the socio-economic and governance implications of blockchain adoption. The inclusion of stakeholders and challenges provides a realistic assessment of what it takes to successfully implement blockchain initiatives, while the opportunities column underscores the potential for urban transformation. By presenting this information in a comparative structure, the Table Map allows us to identify trends, draw parallels, and recognize unique applications of blockchain.

Country / City	Smart Contract Applications	Tokenization Initiatives	Implementation Stage	Key Stakeholders	Challenges	Opportunities
Singapore	Public procurement, digital identity management (Monetary Authority of Singapore, 2021)	Real estate tokenization, loyalty reward tokens (Colliers International et al., 2020)	Full implementation (TradeTrust, 2021)	Singapore government agencies, blockchain startups (Smart Nation Singapore, 2021)	Regulatory compliance, interoperability (Infocomm Media Development Authority, 2021)	Increased efficiency in government procurement, enhanced customer loyalty programs (Smart Nation Singapore, 2021)
Dubai	Land registry, government services (Khan, 2022)	Asset tokenization, utility tokens for government services (Khan, 2022; UNCTAD, 2023)	Pilot phase (UNCTAD, 2023)	Dubai Land Department, government entities, blockchain companies (Khan l, 2022; UNCTAD, 2023)	Legal complexities, technical scalability (Khan, 2022)	Improved transparency in property transactions, enhanced accessibility of government services (UNCTAD, 2023)

New York	Public-private partnerships, financial services (UNCTAD, 2023	Equity crowdfunding tokens, municipal bonds (McKinsey & Company	Planning stage (World Economic Forum, 2024)	NYC government agencies, financial institutions, blockchain startups (Deloitte Insights)	Regulatory compliance, user adoption (UNCTAD, 2023)	Increased investment opportunities for startups, improved efficiency in public-private collaborations (World Economic Forum, 2024)
Seoul	Citizen services, urban planning (Seoul Metropolitan Government, 2023)	Voting tokens, community reward tokens (Ledger Insights, 2023)	Development phase (CommonsHood Research, 2022)	Seoul Metropolitan Government, civic tech organizations, blockchain developers (MDPI, 2020	Security concerns, user education (MDPI, 2020)	Enhanced citizen participation in governance, improved urban planning processes (CommonsHood Research, 2022)
Barcelona	Energy management, mobility solutions (City of Barcelona, 2020)	Public transportation tokens, carbon offset tokens (Decidim Barcelona, 2020)	Experimental phase (Decidim Barcelona, 2020)	Barcelona City Council, energy companies, transportation providers (City of Barcelona, 2020	Interoperability, regulatory compliance (City of Barcelona, 2020)	Optimized energy usage, reduced carbon footprint in transportation (City of Barcelona, 2020)

Eindhoven	Energy trading, waste management (Municipality of Eindhoven, 2021)	Tokenized incentives for sustainable behaviors, citizen participation tokens (Smart Cities World, 2019)	Pilot phase	Eindhoven municipality, energy companies, environmental organizations (Blockchain Innovation Netherlands, 2020)	Regulatory compliance, scalability (EU Blockchain Observatory, 2020)	Increased energy efficiency, enhanced community engagement in sustainability efforts (Smart Cities World, 2019)
Zurich	Insurance, supply chain management (UNCTAD, 2023)	Insurance policy tokens, supply chain tracking tokens (Crypto Valley Association, 2021)	Full implementation (Crypto Valley Association, 2021)	Zurich city government, insurance companies, logistics firms (Crypto Valley Association, 2021)	Data privacy, legal framework (Crypto Valley Association, 2021)	Streamlined insurance processes, improved supply chain transparency and efficiency (Crypto Valley Association, 2021)
Toronto	Healthcare, real estate (Toronto Finance International, 2021)	Healthcare record tokens, fractional ownership tokens for real estate (Canadian Real Estate Association, 2021)	Planning stage (Toronto Finance International, 2021)	Toronto Health Authority, real estate developers, blockchain startups (City of Toronto, 2021)	Data security, regulatory compliance (UNCTAD, 2023)	Enhanced patient privacy and data accessibility, increased liquidity in real estate markets (Toronto Finance International, 2021)

Tokyo	Digital identity management, transportation (Nikkei Asia, 2022)	Digital identity tokens, transportation fare tokens (Ledger Insights, 2021)	Development phase (Ledger Insights, 2021)	Tokyo Metropolitan Government, transportation agencies, tech companies (Tokyo Metropolitan Government, 2023)	Interoperability, public acceptance (Nikkei Asia, 2022)	Improved identity verification processes, seamless integration of transportation systems (Ledger Insights, 2021)
Copenhagen	Public procurement, social services (ITU, 2020)	Procurement contract tokens, social welfare tokens (Luma, 2024)	Experimental phase (ITU, 2020)	Copenhagen city council, government agencies, social service providers (Clutch, 2023)	Regulatory compliance, stakeholder coordination (ITU, 2020)	Increased transparency in procurement processes, efficient distribution of social welfare benefits (Codora, 2023)

Table 7. Table map

4.4 Key Insights

In analyzing global testbeds for blockchain, this section presents the major findings from various experimental implementations worldwide. By examining shared motivations, critical applications, and recurring challenges, it highlights how blockchain is being used to transform urban governance in areas like transparency, digital identity, and land registry. Cities such as Dubai, Singapore, and Zurich exemplify both the potential of blockchain in public administration and the hurdles faced, such as scalability and regulatory constraints. These insights reveal the essential elements driving blockchain's role in cities and the diverse factors influencing its effectiveness and adoption across different urban landscapes.

Commonalities in Blockchain Applications Across Cities

Across cities such as Dubai, New York, and Barcelona, blockchain initiatives are primarily driven by a shared ambition to enhance transparency, security, and process efficiency in public administration. In Dubai, the government has set a goal to transition all official documents and transactions to blockchain by 2025, aiming to eliminate fraud and significantly reduce processing times (World Economic Forum, 2020; UNCTAD, 2023). Similarly, New York has explored the use of blockchain to secure public records and protect them from tampering, reinforcing the technology's value in safeguarding institutional data (Khan et al., 2022).

Barcelona's blockchain experiments in public procurement also align with this focus, seeking to ensure traceability and integrity in government contracts (Decidim Barcelona, 2020). This widespread pursuit of transparency underscores blockchain's appeal as a foundational technology for creating immutable, verifiable records, thereby fostering public trust and institutional accountability in urban governance.

Key Areas of Importance: Digital Identity, Land Registry, and Public Procurement

The analysis reveals that digital identity management, land registry systems, and public

procurement are among the most critical applications of blockchain in urban governance. Cities such as Zurich and Singapore are at the forefront of implementing blockchain in these domains. In Zurich, blockchain is being used to secure digital identities, thereby enhancing the safety and efficiency of interactions between citizens and government services (Khan et al., 2022). Similarly, Singapore's blockchain-based land registry pilot illustrates the technology's potential to prevent fraud, ensure transparency, and streamline property transactions (UNCTAD, 2023; Smart Nation Singapore, 2021).

Public procurement has also emerged as a key area of innovation. In Barcelona, blockchain is being piloted to increase accountability and traceability in government contracting processes, ultimately aiming to reduce corruption risks and improve transparency (Decidim Barcelona, 2020; Halpern, 2013).

These focus areas highlight blockchain's capacity to deliver verifiable, tamper-resistant records that reduce administrative inefficiencies and increase public trust in governance, a cornerstone for smart city initiatives.

Shared Challenges in Scalability and Regulatory Compliance

Cities and regions globally face persistent challenges related to scalability and regulatory compliance when integrating blockchain technologies into urban systems. In Tokyo, the application of blockchain in managing city-wide infrastructure has been constrained by technological scalability issues particularly the difficulty of processing high transaction volumes securely and efficiently (Tokyo Metropolitan Government, 2023; Ledger Insights, 2021).

Regulatory compliance also remains a significant obstacle across jurisdictions. In both Seoul and Toronto, policymakers have expressed concerns over blockchain's implications for data privacy, leading to restricted adoption in sensitive sectors such as healthcare and finance (World Economic Forum, 2024; Khan et al., 2022). These limitations reflect broader tensions between technological innovation and the evolving legal frameworks that govern digital systems.

These shared challenges underscore the need for coordinated international standards and regulatory harmonization. Such frameworks could enable the broader, compliant application of blockchain technologies while still respecting jurisdiction-specific requirements for data protection and public accountability.

Public Engagement and Cultural Acceptance as Success Factors

The success of blockchain initiatives is closely tied to public engagement and cultural acceptance, as demonstrated by Seoul and Toronto's proactive strategies for education and outreach. In Seoul, public seminars and online resources have been introduced to demystify blockchain and encourage citizen participation in services such as e-voting and public documentation (World Economic Forum, 2024). Toronto has similarly invested in educational efforts aimed at both the public and private sectors to raise awareness of blockchain's potential, creating a more receptive environment for its integration into public services (Khan et al., 2022).

These examples underscore the critical role of public support and understanding in the successful deployment of blockchain in urban contexts. They highlight the importance of citizen education, transparent communication, and ongoing dialogue in fostering public trust and technological adoption.

In summary, these insights illustrate how blockchain is reshaping urban governance across diverse cities, with shared goals of transparency, security, and efficiency. While blockchain shows significant promise in critical domains such as digital identity, land registry, and public procurement, persistent challenges including regulatory hurdles and scalability limitations underscore the need for context-specific strategies. By analyzing both the similarities and differences across global blockchain testbeds, urban planners and policymakers can better assess blockchain's transformative potential and address the practical considerations necessary for its successful implementation.

4.5 Blockchain and urban governance

The analysis of blockchain applications across cities reveals several recurring themes and unique insights, which are synthesized below. These themes highlight the transformative potential of blockchain technology in urban governance, as well as the challenges and opportunities specific to each city. Furthermore, the role of urban test beds, as introduced in the conceptual framework (Section 2.8), is revisited to provide a more comprehensive understanding of how blockchain experiments inform broader urban policies and strategies. By integrating data from the case studies, test bed outcomes, and theoretical models, this section aims to provide a holistic understanding of the role blockchain plays in urban governance.

Applications of Blockchain Technology

The diversity of blockchain applications across cities reflects the adaptability of this technology in addressing urban challenges. Urban test beds have been instrumental in piloting these applications, allowing cities to test, refine, and adapt blockchain solutions before wider adoption.

One major application is digital identity management. In Tokyo, digital identity tokens were tested to streamline public service access while ensuring data security and user control. This test bed revealed significant improvements in identity verification processes, with potential applications in healthcare, education, and financial services (Nikkei Asia, 2022). Similarly, Singapore's experiments with digital identity solutions have highlighted blockchain's ability to create secure, tamper-proof identity systems (Monetary Authority of Singapore, 2021).

Another key application is in public procurement and governance. Copenhagen's urban test beds focused on blockchain-based procurement systems to improve transparency and accountability in public spending (ITU, 2020). Early results indicate reduced fraud and enhanced supplier trust. In Singapore, blockchain-enabled procurement platforms were scaled from test beds to full implementation, showcasing efficiency in contracting processes and cost

savings.

Blockchain has also been utilized in tokenization initiatives. Barcelona's carbon offset token pilot project aims to incentivize sustainable behaviors by linking tokens to measurable environmental actions (Decidim Barcelona, 2020). The test bed demonstrated blockchain's potential for engaging citizens in climate action. Dubai's asset tokenization experiments focused on fractional real estate ownership, making property investments accessible to a wider audience while ensuring transparency in transactions (Khan, 2022).

In the realm of energy and waste management, Eindhoven leveraged urban test beds to explore peer-to-peer energy trading platforms. Blockchain facilitated real-time transactions and optimized energy distribution among participants. Waste management systems in Eindhoven also utilized blockchain to track recycling efforts, offering tokenized rewards to encourage citizen participation (EU Blockchain Observatory, 2020).

Role of Urban Test Beds

Urban testbeds are experimental environments where blockchain technologies are deployed and evaluated under real-world conditions. As discussed in Section 2.8 of the conceptual framework, testbeds align with theories of technological experimentation and urban innovation, serving as critical instruments for evaluating feasibility, identifying implementation challenges, and fostering collaborative development (Evans & Karvonen, 2014; Marvin et al., 2018).

One key function of urban testbeds is evaluating feasibility. Testbeds in Copenhagen and Singapore provided important insights into the operational viability of blockchain applications in public procurement and governance systems (ITU, 2020; Smart Nation Singapore, 2021).

Another crucial role is identifying technical and institutional challenges. Testbeds in Dubai and Barcelona revealed significant concerns related to interoperability and scalability that must be addressed before broader implementation can occur (World Economic Forum, 2020; Decidim

Barcelona, 2020).

Urban testbeds also serve to measure impact. In Tokyo, testbeds demonstrated how blockchain could reduce administrative overhead in identity verification systems (Tokyo Metropolitan Government, 2023; Ledger Insights, 2021).

Finally, stakeholder collaboration is a core aspect of testbed success. In Eindhoven, testbeds brought together municipalities, local energy providers, and citizens to co-develop blockchain-based solutions, emphasizing the importance of participatory and multi-stakeholder engagement in urban innovation (Municipality of Eindhoven, 2021; EU Blockchain Observatory, 2020).

Stakeholder Engagement

Blockchain implementation relies heavily on the active participation of diverse stakeholders, and urban testbeds serve as platforms to foster collaboration. Across the case studies, government leadership has played a significant role. For example, the Dubai government led testbed initiatives exploring blockchain applications in real estate and public administration (UNCTAD, 2023; World Economic Forum, 2020). Similarly, the Tokyo Metropolitan Government coordinated experiments in blockchain-based transportation and digital identity systems (Tokyo Metropolitan Government, 2023; Ledger Insights, 2021).

Private sector involvement has also been critical in advancing blockchain applications. Startups and technology firms contributed technical expertise and innovation to public-sector testbeds. In Barcelona, collaboration with local energy companies supported the development of tokenized incentives to encourage sustainable energy consumption (Decidim Barcelona, 2020; Halpern, 2013).

Community participation emerged as a crucial factor for the success of blockchain integration. Seoul's citizen-centered testbeds such as voting token initiatives highlight the importance of civic

engagement in governance innovation (World Economic Forum, 2024). Likewise, Eindhoven's pilots in energy trading and waste management demonstrated that active public involvement is essential to the viability of blockchain-based urban solutions (Municipality of Eindhoven, 2021; EU Blockchain Observatory, 2020).

Challenges in Implementation

While blockchain offers numerous benefits, the testbeds also reveal significant challenges that must be addressed for successful implementation. One major issue is regulatory compliance. In Singapore, navigating legal frameworks posed challenges in scaling blockchain-enabled procurement systems (UNCTAD, 2023; Smart Nation Singapore, 2021). Similarly, Copenhagen's testbeds exposed gaps in existing regulations related to blockchain-based social welfare distribution (ITU, 2020).

Interoperability is another critical challenge. Testbeds in Tokyo and Seoul faced technical difficulties in integrating blockchain with legacy government systems, emphasizing the need for standardized protocols and interoperable infrastructure (Ledger Insights, 2021; World Economic Forum, 2024).

Public awareness and trust also remain significant obstacles. In Eindhoven, limited citizen knowledge of blockchain's potential slowed adoption rates, highlighting the need for education and outreach to support broader civic engagement (Municipality of Eindhoven, 2021; EU Blockchain Observatory, 2020).

Finally, scalability presents notable technical limitations. Barcelona's experiments with tokenization struggled to maintain adequate performance as transaction volumes increased, revealing the current constraints of blockchain platforms in supporting high-throughput applications (Decidim Barcelona, 2020; Halpern, 2013).

Opportunities for Urban Transformation

Despite the challenges, urban testbeds underscore blockchain's transformative potential in city governance. One significant opportunity lies in enhanced transparency. Blockchain's immutability supports transparency in public procurement processes, fostering trust and reducing corruption risks, as demonstrated in Singapore and Copenhagen (Smart Nation Singapore, 2021; ITU, 2020).

Another key opportunity relates to sustainability goals. Tokenization initiatives in Barcelona and Eindhoven promote environmentally sustainable practices, aligning with global climate targets and encouraging resource-efficient urban solutions (Decidim Barcelona, 2020; EU Blockchain Observatory, 2020; Municipality of Eindhoven, 2021).

Citizen empowerment is also a notable benefit. Testbeds in Seoul and Tokyo illustrate how blockchain can strengthen participatory governance and support secure digital identity systems, thereby enhancing both public engagement and digital security (Ledger Insights, 2021; World Economic Forum, 2024).

Furthermore, blockchain contributes to economic efficiency. Dubai's real estate tokenization and Tokyo's digital identity infrastructure have reduced operational costs and streamlined services, demonstrating blockchain's economic benefits and improving financial sustainability in urban development (UNCTAD, 2023; Tokyo Metropolitan Government, 2023; World Economic Forum, 2020).

Comparison of Cases

A comparative analysis of the case studies reveals both shared trends and unique approaches:

In terms of commonalities, all cities leverage test beds to pilot blockchain technologies, emphasizing the importance of experimentation before scaling. Challenges such as regulatory hurdles and scalability issues are universal, and stakeholder collaboration is a critical success factor (Khan et al., 2022; World Economic Forum, 2024). Regarding differences, the scale of

implementation varies, with Singapore and Dubai achieving full implementation (Smart Nation Singapore, 2021; UNCTAD, 2023; World Economic Forum, 2020; Khan et al., 2022), while Copenhagen and Eindhoven remain in experimental phases (ITU, 2020; Smart Cities World, 2019; EU Blockchain Observatory, 2020). Additionally, the focus of blockchain applications differs, with some cities prioritizing governance and efficiency, such as Singapore and Tokyo (Tokyo Metropolitan Government, 2023; Ledger Insights, 2021), while others focus on sustainability and community engagement, as seen in Barcelona and Eindhoven (Decidim Barcelona, 2020; Municipality of Eindhoven, 2021; Halpern, 2013).

5. Conclusion

This dissertation explored the emerging role of smart contracts and non-fungible tokens (NFTs) in urban governance through the lens of blockchain experimentation in global cities. Using a qualitative, case-based approach and structured around the urban testbed model, the research examined how blockchain technologies are being piloted to address administrative inefficiencies, promote transparency, and reshape citizen engagement.

Examples such as Dubai's blockchain-based public service transformation, which targets a paperless government by 2025 (World Economic Forum, 2020), and Singapore's integration of blockchain in trade finance and digital identity systems (UNCTAD, 2023), demonstrate significant progress in deploying these technologies at scale. Similarly, Barcelona's use of blockchain for public procurement and Zug's (Switzerland) blockchain-based e-voting pilot highlight how decentralized systems can improve accountability, efficiency, and citizen trust (Khan et al., 2022).

Testbed urbanism is fundamental to the piloting of blockchain beyond fintech and into urban governance because it provides a structured, low-risk environment where complex socio-technical innovations can be safely introduced, tested, and refined (Evans & Karvonen, 2014; Marvin et al., 2018). Unlike the financial sector where blockchain found early adoption due to its alignment with decentralized value exchange, urban governance presents unique challenges involving regulatory compliance, institutional inertia, and public trust (Ølnes et al., 2017; Atzori, 2015). Urban testbeds bridge this gap by enabling city governments to prototype blockchain applications in real-world settings while maintaining operational control (Marres & Stark, 2020). They also foster cross-sector collaboration and citizen participation, making them uniquely suited to test how blockchain can support public services, infrastructure management,

and democratic processes (Marres & Stark, 2020). As such, testbed urbanism plays a critical mediating role, transforming blockchain from a niche fintech tool into a flexible governance technology (Khan et al., 2022; World Economic Forum, 2020).

Blockchain applications, when implemented through urban testbeds, offer strategic advantages such as risk mitigation, iterative development, and increased public engagement (Marres & Stark, 2020). Testbeds enable cities to evaluate blockchain's operational feasibility in a controlled setting, addressing both technical and institutional readiness.

Yet, the study also brings attention to the challenges that persist: scalability concerns in Tokyo, regulatory barriers in Seoul and the EU (particularly with GDPR compliance), low public awareness, and technical interoperability issues (Halpern, 2013; Ølnes et al., 2017; World Economic Forum, 2024). Moreover, the ideological framing of blockchain particularly in libertarian-leaning applications such as politically charged meme tokens raises important ethical concerns, as such uses often prioritize market freedom and minimal regulation, which can conflict with public governance goals of equity, accountability, and inclusive civic oversight in urban systems. It is the very nature of the testbed as a controlled environment that limits the possibility of more broadly engaging with exterior complexities.

This study demonstrates that the implementation of blockchain technologies in urban governance remains a complex and evolving process. The ways in which smart contracts and NFTs are tested through urban testbeds highlight not only technical and institutional innovations, but also the uncertainties, assumptions, and constraints embedded in these experiments. Rather than offering definitive outcomes, the cases examined in this research underscore the importance of ongoing observation, iterative learning, and context-specific adaptation.

As cities continue to experiment with blockchain applications, questions about scalability, regulatory frameworks, and public engagement persist. These issues highlight the need for

continuous adaptation and close monitoring as blockchain technologies are integrated into urban governance. Blockchain should be approached not as a fixed solution, but as a dynamic and negotiated tool within broader socio-technical systems. This perspective allows for a deeper understanding of its evolving role in shaping the governance of contemporary cities.

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