A BLOCKCHAIN-BASED LAND TITLES REGISTRY IN NAMIBIA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF MASTER OF SCIENCE

(INFORMATION TECHNOLOGY)

OF

THE UNIVERSITY OF NAMIBIA

BY

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OCTOBER 2024

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ABSTRACT

Land administration systems in many countries are vulnerable and lack transparency, which leads to fraud, delays, and significant costs, especially in developing countries like Namibia. This study aims to address these issues by proposing a blockchain-based land titles registry to preserve land rights in Namibia, drawing inspiration from successful implementations of countries such as Sweden. The study employs a quantitative methodology, using synthetic data to simulate real-world land transactions and scenarios, resulting in a controlled experimental environment. The research findings reveal significant dissatisfaction among Namibians with the existing land administration system as a result of various challenges encountered during land registration. The study proposes a hybrid blockchain network as a promising solution, balancing flexibility, transparency, and privacy, with the potential to reduce bureaucratic delays and improve accessibility for all stakeholders. This network's cryptographic foundation ensures data integrity and increases transparency in land transactions, which may influence land rights protection and stimulate economic growth. Despite its potential, the literature review identifies several challenges, such as contract legality, co-ownership management, and legal framework alignment, that must be addressed before widespread blockchain implementation can occur. This study however lays the groundwork for future investigations into infrastructure scalability, legal framework integration, infrastructure challenges, user adoption strategies, and interoperability issues. These critical areas of research will help understand blockchain's transformative potential for revolutionizing land administration systems.

Keywords – blockchain, land registry, land administration, smart contracts, transparency.

PUBLICATIONS/CONFERENCES PROCEEDINGS

Paavo, J. P., & Puente, R. R. (n.d.). A systematic literature review on blockchain-based title registries for transparent land administration. *International Science and* Technology Journal of Namibia, [Status: Submitted for Publication, 2023].

Paavo, J. P., & Puente, R. R. (n.d.). Leveraging blockchain technology in land administration: a practical approach for Namibia. *International Science and Technology Journal of Namibia*, [Status: Submitted for Publication, 2024].

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ABBREVIATIONS/ACRONYMS

BlockLand – The name of the developed land registry

ETH – Ether

ICT – Information and Communication Technology

LAS – Land Administration System

LTO – Live Contracts, Token, and Organizations

NDP – National Development Plan

SDG – Sustainable Development Goals

UI – User Interface

ACKNOWLEDGEMENT

First and foremost, I want to express my gratitude for the divine guidance and grace that have been with me throughout this academic expedition.

My sincere appreciation goes to my dedicated supervisor, Prof Rafael Rodríguez Puente, for his unwavering support, constructive feedback, and constant invaluable insights.

I am also grateful to all of the participants for generously sharing their knowledge and experiences through discussions and questionnaires. Your contributions were instrumental in shedding light on the subject matter. A special acknowledgment is reserved for my personal lawyer, Ms. Adora Katuuo, whose expertise in land administration were indispensable in shaping this project to suit the Namibian context.

Finally, I would like to extend my heartfelt gratitude to Imperial Managed Solutions Namibia through the UNAM Foundation for their generous bursary support, which significantly eased the financial burden of pursuing this research.

This experience has left me profoundly humble. To God be the glory.

DEDICATION

This thesis is dedicated to my beloved son Jacob Tangeni Paavo, with the hope that it will inspire him to reach for the stars and bravely pursue his dreams; may this academic journey serve as a testament to my love for him and my commitment to creating a better future for us.

DECLARATIONS

I, Johannes Pandeni Paavo, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution.

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CHAPTER 1: INTRODUCTION

This chapter provides an overview of the research topic, stating the problem statement, research objectives, significance, study limitations, and delimitations.

1.1 Background of the Study

A land title is a legally binding document that grants ownership rights to an individual or entity, enabling them to utilize and make alterations to the property as they deem appropriate. Additionally, ownership interests or portions thereof can be transferred to other parties through a deed, which serves as the legal instrument delineating the rights of ownership (Moerkerke, 2017). According to Hendrik et al. (2005), the title system is closely linked to the causal legal system and entails many obligations for both the alienator and the acquirer during the transfer of property ownership. As an illustration, it is necessary to inquire whether the individual performing an action possesses the rightful entitlement to operate as the proprietor and whether they possess the requisite legal authorization to engage in the sale of the property.

Zimmermann (2008) asserts that the implementation of effective public land management is of utmost importance in facilitating sound governance within a country's land administration. This facet is widely recognized as a critical element that underpins both economic advancement and the promotion of sustainable development (Salfarina , 2011). The complex nature of the subject necessitates the involvement of seasoned professionals to undertake a comprehensive procedure that accurately represents the facts, provided that all parties involved maintain honesty. This inevitably highlights the limitations of the traditional titles system in delivering assurances such as transparency, timeliness, and accessibility (Moerkerke, 2017).

1.2 Statement of the Problem

The majority of land in suburban areas of Namibia is undocumented or unregistered primarily due to the inadequate management system for land titles. Furthermore, the high fees and lengthy procedures involved in property registration have resulted in countless contraventions of title administration (Simon , 2022).

1.3 Objectives of the Study

To effectively address the research problem, this thesis established a set of research objectives that acted as the guiding principles. These objectives outlined the primary aims and purpose of the study.

Main Objective:

- Develop a blockchain-based land titles registry to preserve land rights in Namibia.

Sub-objectives:

- Identify the feasible blockchain network type critical to the Namibian context.
- Evaluate the registry's timeliness, accessibility, cost-effectiveness, and sustainability.
- Validate the registry’s security and transaction transparency.

1.4 Justification of the Study

The study developed a blockchain-based land titles registry that aims to complement the existing system for managing titles data. This initiative attempts to mitigate the lengthy process and excessive financial resources associated with land registration. Furthermore, the study addressed the issue of transparency in land ownership, which

is a significant contributing factor to the occurrence of title administration transgressions in Namibia.

1.5 Significant of the Study

The study is significant because it advances both theoretical and practical understanding of blockchain applications in land administration. The study also supports the NDP's 5 pillars of good governance by promoting accountability and transparency, both of which are essential for reducing corruption and enhancing public trust. Furthermore, it contributes to the SDGs by promoting equitable land distribution and strengthening governance systems.

1.6 Limitations of the Study

Future research has the potential to address two fundamental limitations inherent in this study. The legal framework that governs land registries is complex, and the task of complying with regulatory requirements across diverse jurisdictions can pose significant challenges. Furthermore, the utilization of blockchain technology in land registries gives rise to apprehensions regarding the confidentiality and protection of data.

1.7 Delimitations of the Study

This study was limited to Windhoek, and some findings may not have applied to other towns. It excluded all other influencing factors and focused solely on the impact of blockchain on land title registries. The legal and regulatory aspects were based on existing frameworks, which may not have accounted for subsequent changes. While stakeholders were engaged, not all may have been represented. To enhance generalizability to other towns, short-term residents of Windhoek were excluded from the analysis.

1.8 Thesis Organization

The subsequent chapters of this thesis are structured in the following manner: *Chapter 2: Literature Review*, this chapter explores the shortcomings of traditional land administration practices and introduces blockchain technology as a potential solution. It discusses how blockchain can be applied to improve land administration, addressing associated challenges. The chapter emphasizes the benefits and implications of blockchain-based title registries and provides insights for future research and practical implementation.

Chapter 3: Research Methodology, this chapter provides a comprehensive overview of the research procedures and methodologies utilised to achieve the objectives of the study.

Chapter 4: Design and Implementation, this chapter presents a comprehensive examination of the methodologies employed in the design and development of the blockchain-based land registry, which served as the central focus of the research project.

Chapter 5: Results and Discussions, chapter 5 presents the findings and discussions on the blockchain network's suitability for Namibia, registry evaluation (timeliness, access, cost, sustainability), and security and transparency validation.

Chapter 6: Conclusion and Recommendations, the final chapter summarises key findings, contributions to the field, limitations, and future research directions before making conclusive assertions.

1.9 Chapter Summary

This chapter presented the background of the study, and offered an overview of the statement of the problem, research aims, significance of the study, study constraints, and delimitations. The structure of the thesis has also been outlined. Chapter 2 will be dedicated to conducting a comprehensive literature review.

CHAPTER 2: LITERATURE REVIEW

This chapter presents a comprehensive examination of the issues associated with conventional land administration practices. It introduces the concept of blockchain technology and its potential applications in the domain of land administration. Furthermore, it discusses various solutions that utilize blockchain technology to address the challenges faced in land administration. Lastly, it highlights the advantages and consequences of blockchain-based title registries and offers valuable insights for future research and practical application.

2.1 Challenges of the Traditional LAS

According to the Global Land Tool Network (GLTN) in 2023, a training package on transparency in land administration highlighted weak governance as a key determinant of corruption in land occupation and administration across more than sixty-one countries (GLTN, 2013). Multiple studies have also indicated that a significant portion of land in suburban areas of developing countries is undocumented or unregistered. This can be attributed to the frailty of the existing land titling data management system, as well as the lengthy process and excessive expenses associated with property registration (Krishnapriya & Greeshma, 2020; Biraro et al., 2021).

The existing land registration process in many countries exhibits numerous vulnerabilities and loopholes that can be used for fraudulent activities (Krishnapriya & Greeshma, 2020). In their publication in an international journal of information management, Vinay et al. (2020) brought attention to several issues related to land registration. These issues include a lack of transparency and accountability, delays in the registration process, and high charges. Additionally, the authors noted the presence of incoherent data sets due to the involvement of multiple parties in the registration process. Nir and Jeffrey (2018) agree with prior studies by affirming that the alteration

of titles for registered properties by government officials is a prevalent occurrence. Furthermore, instances have been documented where government officials have assigned properties with altered titles to themselves, thereby giving rise to numerous instances of malpractice in title administration.

In another far-reaching study conducted by Nir (2018), it was found that an earthquake in Haiti in 2010 resulted in a situation where farmers were involved in disputes over land due to the destruction of municipal buildings that housed crucial documentation confirming land ownership. In one more study conducted in 2019, the author observed that several initiatives, including the implementation of Blockchain technology, have been pursued in countries such as Ghana, where almost 78 percent of the land remains unregistered. Despite the efforts undertaken by private entities such as Bitland and BenBen since 2014, the tangible outcomes of their endeavour remain undisclosed, and no additional findings have been made available as of yet (GEORG , 2019).

2.2 Overview of Blockchain Technology

According to Tiana (2019), the introduction of blockchain technology can be attributed to Satoshi Nakamoto, who initially presented it in the Bitcoin white paper as a decentralized time-stamp server operating on a peer-to-peer network. Satoshi introduced the concept of "blocks" and "chains" in his scholarly contribution, wherein he proposed a method for organizing and securing records. By employing a shared database, the integrity and authenticity of entries could be confirmed and validated by mathematical verification. According to Müller and Markus (2019), blockchain is characterized as a continuously expanding collection of interconnected records referred to as blocks, which are secured by the utilization of encrypted data exchange. Typically, every block has transactional data, a timestamp, and a reference to the preceding block as displayed in Figure 1. The utilization of the consensus algorithm

within the blockchain network ensures a reliable transaction process within potentially untrustworthy environments. This feature has contributed to the widespread adoption of blockchain technology across various industries, including land administration (Namasudra & Akkaya , 2023).

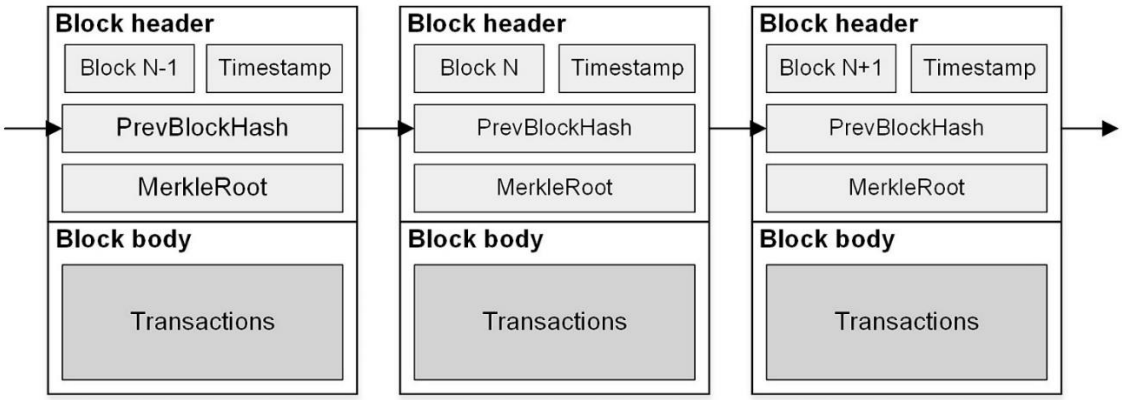


Figure 1 A schematic representation of a blockchain *(Sladić , Milosavljević, Nikolić, Sladić, & Radulović, 2021).*

2.3 Blockchain Solutions for Land Administration

Several countries, according to Sladić et al. (2021), have launched (pilot) projects to investigate the applicability of blockchain technology in land administration. Brazil, Dubai/UAE, Georgia, India, Kenya, Ghana, Ukraine, Sweden, Honduras, and other countries have such projects. Driven by its dedication to augmenting and enhancing the transparency, security, and efficiency of its land registry system, Sweden has emerged as one of the innovators in adopting blockchain-powered land registry systems (Marinos, 2018). According to Proskurovska and Dörry (2022), Sweden's level of digitalization is among the most advanced in the Organization for Economic Co-operation and Development (OECD) countries. Coupled with its high internet penetration, this advanced digital landscape paved the way for the successful implementation of its hybrid public-private blockchain land registry solution. On the

other hand, Namibia's digital divide and limited internet access, particularly in rural areas, might hinder the effective implementation of such a land registry system.

During the mid-2000s, the Republic of Georgia embarked on a mission to combat corruption in its land registry system (Qiuyun & Price, 2019). Through the utilization of Blockchain technology, the Georgian government aspired to take a pioneering role in bolstering governance, ensuring security, and reinstating public confidence in both institutions and government agencies. The pivotal role of Georgia's political stability and proactive approach to enacting legal and administrative reforms is evident in the success of its blockchain-based land titling system. In contrast, the Namibian government's hesitancy in this regard stands as a potential obstacle that could impede the achievement of a comparable solution (Ben & Scoones, 2010).

Similar to the situation in Georgia, where for numerous years, Honduras's public officials with malicious intent could infiltrate the land register and improperly alter property ownership records, the country had to adopt a blockchain-based land registry system (Marinos, 2018). This innovative solution was put in place to eradicate fraudulent land title activities and ensure a secure and streamlined safeguarding of property ownership records. Like in Georgia, the Honduran Government played a crucial part in establishing a strong system for land and property rights. This was achieved through the Land Registry Reform, backed by the World Bank, which introduced a modernized approach to title management (Colindres, Regan, & Panting, 2016). By digitizing titles within a unified registry framework, this initiative laid the foundation for the effective adoption of their blockchain-based land registry solution.

The process of acquiring land in Ghana can be classified into two main categories: Customary land, which accounts for approximately 80% of the total land, and statutory or public land, which makes up the remaining portion (Donkor & de Vries, 2021). This

adoption of a divergent approach to land acquisition leads to the emergence of multiple conflicts within the realm of land administration. In response to the aforementioned issue, Ghana has implemented the utilization of blockchain smart contracts as a means to digitize and protect land records. This implementation serves to enhance transparency and reduce conflicts about land ownership and transactions (Samuel & Tahiru, 2020). The successful implementation of this initiative in Ghana can be attributed to a comprehensive land tenure reform and a high level of commitment from the government. The complexities of land tenure in Namibia, as well as their historical contexts, have been examined by scholars such as Walter and Lewis (2009) as well as John et al. (2012). These studies highlight distinct differences, indicating the need for a tailored approach that extends beyond mere technological implementation.

Similar to Ghana, which shares a colonial history with Britain, Kenya maintains two central registries for all land-related data: the Nairobi land registry, also known as the Inland Registry, and the Coast Registry (Land Layby Kenya, 2018). In Kenya's historical context, the majority of the land was governed by community leaders through customary tenure systems. These systems were retained by the Kenyan government during the post-colonial era. Notably, the Kenyan government, as highlighted by the Land Layby Group, assumed direct control over community lands, resulting in conflicting land claims nationwide. This situation led to political and social unrest, displacing numerous individuals from their land and fostering an environment conducive to corruption and chaotic land registries. In contrast to developed countries like Sweden, where the primary aim of introducing blockchain into real property transactions is to enhance transaction speed, reduce costs, and minimize errors, Kenya has embraced blockchain technology to augment transparency in property dealings and combat corruption, a choice underpinned by the intrinsic immutability of blockchain

technology (Sladić , Milosavljević, Nikolić, Sladić, & Radulović, 2021). Kenya's blockchain-based land registry operates on the Ethereum blockchain network, establishing a single, unmodifiable record of land ownership. Sladić et al. further note that while the ledger is publicly accessible, it incorporates multiple permission levels to safeguard specific transaction details, such as sales prices and sensitive personal information, ensuring their confidentiality.

Dubai, as one of the constituent emirates of the United Arab Emirates (UAE), has experienced significant growth across diverse economic sectors in recent times. This necessitated the regular modernization of conventional procedures to uphold efficiency and expediency, thereby safeguarding the nation's standing among potential investors (Bishr, 2019). The current economic expansion is bolstered by a robust and efficient government sector that has embraced technological advancements and is dedicated to upholding elevated standards of performance. The Dubai Land Administration has initiated various projects, including the "Blockchain in Real Estate Strategic Plan," which was introduced in October 2016 to facilitate real estate transactions by leveraging blockchain technology (Alsuwaidi, 2018). This involves the utilization of blockchain technology to effectively optimize the procedure of buying, selling, and transferring property titles, consequently mitigating the potential for fraudulent activities and conflicts. According to Alsuwaidi, the land administration in Dubai has implemented blockchain technology as a means to decrease the reliance on paperwork, remove intermediaries, enhance transaction efficiency, and establish transparent transaction histories for all stakeholders. The adaptation experience of blockchain for land registry is claimed to be actively working well in Dubai by Graglia and Mellon (2018).

Graglia and Mellon (2018) correspondingly posit the existence of eight distinct theoretical steps that can be identified for the integration of blockchains into society. These steps range from the utilization of public blockchains for document recording to the eventual achievement of interoperability, wherein various blockchain-based registries are merged. Instances of the integration of blockchain technology in land administration can be observed at the primary level. Numerous nations, such as Brazil, have initiated the practice of documenting land transaction-related records and workflow processes by leveraging the Bitcoin blockchain to authenticate property sales and by utilizing smart contracts, to minimize the occurrence of fraudulent activities and errors for all data recorded within the decentralized ledger. Nevertheless, it is worth mentioning that the extensive implementation of blockchain technology in land administration applications within Brazil has not yet materialized, as observed by Krigsholm et al. (2019). The outcomes of ongoing pilot programs, including both existing and yet-to-be-implemented initiatives, will determine the future role of blockchain in land administration.

Some countries, Estonia being one of them, have successfully integrated blockchain technology into their land registers as a component of a broader e-government initiative aimed at running various governmental functions on a blockchain-based platform. Estonia is notable for its pioneering approach to digital governance, wherein blockchain technology has been extensively employed within its governmental infrastructure (Sladić , Milosavljević, Nikolić, Sladić, & Radulović, 2021). The Estonian government has developed an extensive infrastructure based on blockchain technology, encompassing various registries such as the business registry, property registry, health registry, digital court documents, and official announcements. Sladić et al. (2021) argue that this technological framework enables not only the effective

identification of data modifications but also guarantees the utmost level of record integrity. The land administration system in Estonia is a prominent example of the utilization of blockchain technology. This system is effectively incorporated into the broader “e-Residency” initiative, which was initiated in 2014 through a partnership with Bitnation (Sullivan & Burger, 2017). Sullivan and Burger (2017) further stated that the primary objective of this system is to enhance the facilitation of secure and efficient land registration and management. The implementation of blockchain technology in Estonia has resulted in the optimization of its land registration procedure, leading to enhanced levels of transparency, security, and confidence in property-related transactions (Josip & Lenac, 2020). Josip and Lenac (2020) assert that Estonia’s successful integration of blockchain technology into its government infrastructure, particularly in the domain of land administration, exemplifies the potential advantages of digital innovation in governance and the modernization of administrative procedures.

Vinay et al. (2020) as well as Bal (2017) noted that despite the considerable economic growth experienced by India in recent years, the land administration system in the country has traditionally been characterized by complexity and inefficiency. This has been attributed to challenges such as incomplete and damaged records. According to Vinay et al., the implementation of digitization of land records and computerization of property registration offices in most states has been successful. However, the computerized systems currently operate independently, without a reliable ecosystem for managing transactions and updating records. This is because various departments within the land administration system store their copies of records, leading to incomplete records. Andhra Pradesh, an Indian state, has partnered with ChromaWay, a blockchain-based start-up, to address the aforementioned obstacles by establishing a

blockchain-powered land registry, following the examples set by countries like Estonia (Bal, 2017). The integration of blockchain technology as a backend, along with the utilization of a web application as a frontend, has facilitated enhanced data transparency for citizens. This implementation has effectively decentralized land registries to the village level, thereby contributing to the mitigation of corruption. In contrast to the prior centralized digital solution, this decentralized approach has proven advantageous by ensuring that small farmers are not disadvantaged in favour of large- and middle-scale farmers who benefited from the centralized system (Saari, Vimpari, & Junnila, 2022).

In Serbia, the Real Estate Cadastre serves as a vital register for property information, including data on ownership rights and the individuals or entities that hold such rights. Nonetheless, there are flaws in the current system's immutability and tamper-proof capabilities. As a result, data validation is heavily reliant on supporting documents (Stefanović, Pržulj, Ristić, Stefanović, & Vukmanović, 2018). Discrepancies in the land register and cadastre data are resolved in the absence of supporting documents by assuming the accuracy of the data stored in the land register (Sladić , Milosavljević, Nikolić, Sladić, & Radulović, 2021). This land register comprises cadastral records and maps containing two kinds of data: alphanumeric data about property transactions and geospatial data about cadastral changes. Although the presence of numerous blockchain networks and services, according to Sladic et al. (2021), does not currently adhere to a standardized method for encoding geospatial information, blockchain preservation has the potential to provide significant benefits to both types of data. As a result, the Open Geospatial Consortium has launched initiatives to address this shortcoming, and it is confident that exploring the potential of blockchain technology in geospatial data maintenance holds promise for future advancements, especially

given its relatively early stage of development in the non-financial domain, Sladic et al. (2021) concluded.

Based on the evaluation conducted by the United Nations in 2020, Haneem et al. (2020) proclaim that Cyprus is one of the countries that has achieved a notably high E-Government Development Index (EGDI). Consequently, the blockchain initiative undertaken by Cyprus has the potential to enhance understanding and establish standards for other countries. The country has emerged as a prominent hub for academic research, education, training, and practical development of applications focused on fourth-generation technologies, specifically blockchain (Giaglis, 2018). Since 2014, the University of Nicosia has held the distinction of being the pioneering institution to provide a comprehensive academic curriculum centred on Blockchain technology. This program, known as the Master of Science in Blockchain and Digital Currency, has established the University of Nicosia as the global leader in offering such specialized education, Giaglis (2018) affirmed. Based on existing literature, it is evident that numerous pilot projects have been conducted to explore the application of blockchain technology in land registration. However, further advancements are necessary to fully harness the potential of blockchain as a means to document land interests. In this context, Cyprus presents a noteworthy prospect for leveraging blockchain technology to facilitate the establishment of peace on the island (Yapicioglu & Leshinsky, 2020). Yapicioglu and Leshinsky (2020) also assert that further investigation is necessary, specifically regarding the potential applications of side chains in documenting conflicting land interests and contested land ownership assertions.

In 2019, a project based on Distributed Ledger Technology (DLT) was launched in Afghanistan by UN organizations (UNOICT and UN-Habitat) in collaboration with

the LTO Network and the Afghan government. This project was launched after these stakeholders signed a memorandum of understanding (Kaczorowska, 2019). Its primary goal was to promote the development of cities that are inclusive, secure, resilient, and sustainable. By December 2020, the UN announced the creation of a new digital land registry dedicated to informal urban settlements within Afghanistan's Ministry of Urban Development and Land. This registry aimed to address the issue of secure land rights, which is a major source of conflict in the country. The hybrid blockchain platform LTO Network was used for this endeavour, which includes both a public blockchain network and a suite of tools that allow users to create private chains within the network. This platform, known as 'goLandRegistry' was created to manage property records on the blockchain, including at least one million individually registered land parcels, as well as the issuance of occupancy certificates. However, Shah et al. (2023) expressed reservations about the viability of the 'goLandRegistry' solution, citing Afghanistan's formal land administration system's limited capacity. This limitation highlighted the reliance of all such deployments on governance capacity that Afghanistan lacked. Given that approximately 80% of the Afghan population lives in rural areas, Bustamante et al. (2022) expressed similar concerns and argued that simple, community-based information recording using basic technology can often provide greater certainty in land registration within local communities.

In another far-reaching case, both Niloy et al. (2022) and Alam et al. (2022) emphasized the significance of land as a valuable asset in densely populated developing countries like Bangladesh. Consequently, investing in land assets has emerged as the most prudent means of deploying capital. Nonetheless, Niloy et al. (2022) argue that acquiring land is a time-consuming process due to the necessity of

extensive communication among buyers, sellers, and various government agencies to secure the requisite documentation and approvals. On the contrary, Alam et al. (2022) put forward that the primary issue with the current system lies in the fragmentation of information across multiple government offices that lack synchronization, creating opportunities for corrupt bureaucrats to modify legal documents and assert false ownership claims. These authors, along with Islam et al. (2020) and Biswas et al. (2021), have proposed blockchain-based solutions as a remedy to these challenges.

These solutions promise data synchronization, transparency, accessibility, and the management of immutable records, all accomplished swiftly and cost-effectively. Among these proposals, LANDCHAIN stands out, as it automates the land administration process while upholding security and transparency standards. According to Niloy et al. (2022), LANDCHAIN's lightweight nature facilitates effortless deployment and automatic scalability. The model has undergone testing on the Ethereum Virtual Machine (EVM), demonstrating superior reliability, security, efficiency, and scalability compared to conventional database management systems (Shithy, Pipash, Elme, & Mahmud). Consequently, LANDCHAIN not only addresses existing land administration issues but also aids the government in optimizing the processes identified by Niloy et al. (2022).

Over the years, several countries with limited land areas have invested substantial funds in land reclamation projects. However, some countries, like Japan, have undertaken even larger land reclamation undertakings (Stefanović, Pržulj, Ristić, Stefanović, & Vukmanović, 2018). Japan has been at the forefront of blockchain-based developments, including pioneering blockchain assessment methodologies and forms. These innovations mark the first attempts to evaluate blockchain-based systems while considering their compatibility with existing systems and comprehensibility.

Furthermore, Japan has conducted extensive surveys on blockchain technologies, collaborating with universities and research institutes to explore the potential applications of blockchain in various sectors, including land administration (Haneem, et al., 2020). According to Müller and Markus (2019), Japan had plans to migrate its state-owned real estate databases onto a blockchain platform, which would encompass proprietary and sales data. The initial testing phase was scheduled for 2018. In a parallel effort, González (2018) identified Japanese companies that have been actively involved in the creation of a public system for land transactions since 2018, with notable participants being the Nomura Research Institute and Fujitsu. Lastly, Müller and Markus (2019) claim that Japan's long-term goal is to merge all of its local government agencies' property registers and real estate companies' databases into a single blockchain database.

According to Haneem, et al. (2020), South Korea's government is a global leader in providing online services, with the highest EGDI value in Asia. However, Veeramani and Jaganathan (2020) highlight that, despite service modernization, there is still a lack of transparency. To address this issue, e-governance requires a robust underlying technology that ensures record integrity and effectively eliminates corruption. This explains why the central and local governments of South Korea have actively embraced blockchain technology, positioning the country as a potential leader in the blockchain market (Soomin, et al., 2022). For instance, in 2020, the Ministry of Science and ICT and the Korea Internet Security Agency (KISA) selected 24 companies to launch ten blockchain-based pilot projects worth up to 5.3 million US dollars. One of these initiatives, as reported by Soomin, et al. 2022), took place in the Ministry of Land, Infrastructure, and Transport, with a specific focus on documentation and certification processes. This innovation meant that citizens no

longer had to endure the time-consuming bureaucratic procedures of visiting multiple offices and navigating various steps to secure a mortgage for the purchase of a home.

Following the country's independence in 1960, Nigerians, like those in many other African countries, took control of the management and governance of the country's territories and resources (Ibrahim, Daud, Azmi, Noor, & Yusoff, 2021). Land management systems in Nigeria, like those in Kenya, remained largely unchanged from the colonial era during the early years of independence, with the state taking charge of land administration as a public service. This approach, however, has been hampered by a slew of challenges and limitations, exemplified by the country's lack of formal, documented, and registered land titles (Obamehinti & Eguavoen, 2022). As a result, a sizable portion of the population is denied access to secure land titles, as well as the economic opportunities and potential benefits associated with land title utilization and trade. As a result, researchers have been investigating potential solutions, with many pointing to blockchain technology. All of the aforementioned authors have emphasized the benefits of blockchain over the traditional land titling system in Nigeria, which could serve as a solution to the land title issues if adopted. It is also noteworthy that a study conducted by Omole, et al. (2019) using a pragmatic approach to understand the perspectives of Nigeria's professionals regarding their awareness, acceptance, feasibility, and readiness to embrace innovations in land administration revealed that there is an awareness level exceeding 50%, complete acceptance, and a readiness level exceeding 95%. However, the study predicts that the technology will take 5 to 10 years to become mainstream, but this timeline may vary depending on regulatory developments and technological advancements.

Government officials worldwide are progressively adopting blockchain technology to address common challenges in land administration. Ukraine has also embraced this

global trend, incorporating blockchain technology into the State Land Cadastre as the second pilot project in the public sector, starting in September 2017 (Bachynskyy & Radeiko, 2019). This system records all cadastre transactions systematically on the blockchain, following a predefined algorithmic protocol. Government support is vital for the adoption of blockchain technology, as emphasized by Ansah et al. (2023). Christopher et al. (2019 additionally suggest that early adopters of blockchain technology typically have greater political stability, which is crucial for safeguarding the system against potential cyber threats, as explained by Graglia and Mellon (2018). Unfortunately, the blockchain land registry project in Ukraine encountered significant challenges due to political unrest, primarily stemming from Russian interference. These disruptions ultimately led to the project's abandonment during its early stages, as documented by Konashevych (2020). Nevertheless, Graglia and Mellon maintain that a glimmer of hope remains for the Ukraine project, as they speculate that Bitfury's involvement, given its prior experience in implementing blockchain technology for land rights registration in Georgia, could lead to its revival. Moreover, Bitfury's skilled Ukrainian programmers are well-positioned to enhance government operations within the e-government system, potentially paving the way for the project's recovery and future success.

In Germany, Müller and Markus (2019) cite several difficulties in the country's land transfer process, including its complexity and lack of transparency, which can take 5-6 months to complete and result in a 6-8-week delay between intention and transfer. Bureaucratic procedures involving paper documents further slowed the process. Müller and Markus (2019) propose using blockchain technology to upgrade the electronic land registry to address these issues. This could reduce the processing time by 1-2 weeks, improve security with digital signatures, prevent document loss with

decentralized data management, and increase transparency. Similarly, Müller and Markus (2019) note that the British Land Registry is eager to investigate blockchain technology and envisions that implementing blockchain for registration could result in a government-backed property guarantee. Beznosov et al. (2021) also identified the United Kingdom as a global leader in the use of blockchain technology for land management, citing the successful Digital Street project. This initiative allows buyers to acquire properties almost instantly and allows the Land Registry to maintain more comprehensive and detailed data records.

In their publication, Muller and Markus (2019) also shed light on Russia's stance on the integration of blockchain technology into land administration. According to their 2019 report, Russia intends to investigate a Blockchain-based land registry system, with a test planned for later that year. The Ministry of Economic Development and the State Cadastral and Cartographic Organizations are collaborating on this project. According to the Russian government, such a system could significantly reduce the operational costs associated with land registration. The project's administrators plan to evaluate the results of the initial pilot project later that year to determine whether to proceed with the full-scale implementation of the Blockchain-based Land Registry system.

The inaugural IBM Blockchain Innovation Centre, established in partnership with the Singapore Economic Development Board and the Monetary Authority of Singapore (MAS), stands as a pioneering hub for the start-up of blockchain projects spanning diverse sectors such as finance, cross-sector partnerships, education, and supply chain management (Haneem, et al., 2020). In Singapore, the Land Registry serves as the custodian of a comprehensive land register, acting as the primary and authoritative repository of land ownership information. It is critical to understand that registered

land titles take precedence and can only be challenged under certain predefined conditions (Ooi, Peng, & Soh, 2022). The Singaporean government has proactively implemented digital signature legislation, eliminating the need for handwritten signatures in real estate transactions. This legal framework is supported by a transparent ledger that is accessible to all relevant stakeholders (Rohaidi, 2019). It is also worth noting that China has emerged as a major investor in land reclamation projects in Asia, particularly in the use of blockchain technology for e-government. According to Heng (2017), land administration is an integral component of national land policy in China, exerting significant influence on both economic development and societal stability. A proposed conceptual framework has also been put forth in Pakistan for a blockchain-based land registry, which aims to address the inherent vulnerabilities of property records to falsification and corruption, particularly in light of the country's economic challenges (Khalid, et al., 2022).

According to a report on the size of the blockchain market, the United States, specifically North America and Canada, accounts for approximately 40% of the global blockchain market (Grand View Research, 2021). Additionally, in 2018 a survey conducted by PricewaterhouseCoopers (PwC) (2018) identified the United States as the current leader in blockchain technology (see Figure 3). Further research into how the United States is adopting and utilizing blockchain technology revealed that the city of South Burlington, Virginia, has launched a pilot project in partnership with the Propy blockchain start-up. This pilot project is viewed as a possible step toward using blockchain technology to replace the city’s real estate registration system. Similarly, in collaboration with the retailer Overstock, the state of Wyoming is actively incorporating blockchain systems into regional governance, particularly within the land registration mechanism (Beznosov, Skvortsov, & Skvortsova, 2021). Müller and

Markus (2019) reported in 2022 that the Chicago Cook County Recorders of Deeds (CCRD) piloted the use of blockchain registries for real estate. This project investigated the integration of physical properties with digital assets in approximately 2,000 vacant properties in Chicago. Along with the CCRD, the International Blockchain Real Estate Association (IBREA) worked with the start-up company "Velox.RE" on this project.

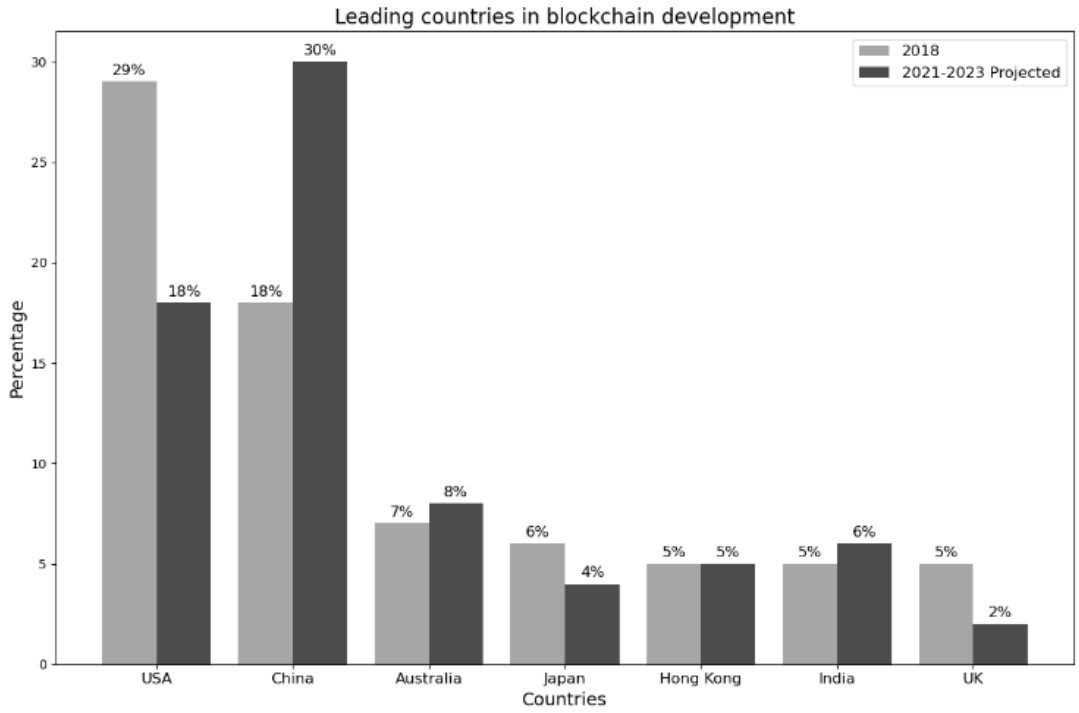


Figure 2 Countries leading in blockchain development *(PricewaterhouseCoopers (PwC), 2018).*

2.4 Advantages of Blockchain-Based Titles Registries

The utilization of blockchain technology has undergone significant development since its inception, and it is now being employed for the storage of records in various systems, such as land administration systems (LAS) (Stefanović, Pržulj, Ristić, Stefanović, & Vukmanović, 2018). While there is ongoing debate regarding the feasibility of implementing the entire LAS on the blockchain, Stefanović et al. (2018) emphasized that specific processes could indeed derive advantages from utilizing

blockchain technology's inherent characteristics, such as its distributed ledger, immutable transaction records, and the efficiency facilitated by smart contracts. Both Kaczorowska (2019) and Borse et al. (2022) concur with Stefanović et al. regarding the transformative potential of blockchain's underlying distributed ledger technology in revolutionizing land registration systems. This potential can be leveraged through the utilization of its secure architecture and cryptographic protocols, which offer several advantages including heightened trust, enhanced processing efficiency, and cost reduction. Shang and Price (2019) conducted a study that specifically discusses the advantages of blockchain-based title registries, including enhanced efficiency, security, and transparency in land administration Georgia is benefiting from the increased reliability of the Ethereum blockchain land register. Based on an estimation provided by project partners affiliated with the Swedish government, Sweden recognized as a leading country in the integration of blockchain technology within land registry systems, is projected to achieve an annual cost reduction of 106 million US dollars. This reduction is attributed to the elimination of paperwork and the expedited processing of transactions facilitated by blockchain technology.

Furthermore, Müller and Markus (2019) emphasized key goals for the implementation of blockchain technology in the domain of land administration. These objectives encompass expediting transaction processes, automating change notifications, enhancing transparency and security measures, and establishing digital archives for contracts.

2.5 Implications of Blockchain-Based Title Registries

The accomplishments of blockchain land registries in countries such as Sweden and Georgia can only serve as a model for other countries, as the effectiveness of implementing such systems is contingent upon the unique ICT infrastructures, legal

frameworks, and land reform policies specific to each country. The release of an open-source land registry system in Central Asia was announced by UN-Habitat, OICT, and LTO Network in 2020, with a scheduled debut in December 2020 (UN-Habitat & OICT and LTO Network , 2020). Despite the commendable effort, similar to the aforementioned solutions, it is imperative to further develop or tailor this solution according to the specific land laws and policies of individual countries.

In a comprehensive study, Rosa (2020) conducted an in-depth investigation of the potential challenges presented by blockchain technology. The study specifically addressed concerns related to the verification of participants' identities, the legal validity of contracts in the absence of independent transaction verification, the complexities surrounding co-ownership and property rights in smart contracts, and the assessment of the practicality of modifying blockchain records. The significance of this matter lies in the fact that legal frameworks have the potential to facilitate alterations or transfers of property ownership and rights without the need for unanimous consent from the existing owners, given specific conditions.

2.6 Literature Findings

Traditional land registration processes in many countries are susceptible to fraud due to inherent vulnerabilities and a lack of transparency. This challenge is exacerbated by the delays, costs, and lack of accountability associated with land registration, particularly in developing countries.

Blockchain initiatives have been launched to address these concerns. Notably, Sweden has emerged as a pioneer in the adoption of blockchain-based land registry systems, owing to its commitment to transparency, security, and efficiency. Sweden's success in implementing a hybrid public-private blockchain solution can be attributed to its advanced digital infrastructure and high internet penetration.

However, countries such as Namibia face challenges due to limited internet access, particularly in rural areas, which could stymie the effective implementation of a public blockchain-based land registry system.

Georgia is a success story in using blockchain to combat corruption in its land registry system. Political stability and a commitment to legal and administrative reforms were critical to its successful implementation.

Similarly, Honduras collaborated with the World Bank to implement blockchain, digitizing titles within a unified registry framework to eliminate fraudulent land title activities.

Ghana's adoption of blockchain technology addresses conflicts in land administration caused by complex land tenure systems. Government support and a commitment to land tenure reform were critical to its success.

Kenya uses blockchain on the Ethereum network to improve transparency and reduce corruption in its land registry, particularly in community-led land governance contexts.

Dubai's initiatives, such as the "Blockchain in Real Estate Strategic Plan," demonstrate the city-state's commitment to modernizing real estate procedures and reducing fraudulent activity.

Estonia stands out for its extensive use of blockchain technology in government infrastructure, including land administration, resulting in increased transparency and confidence in property transactions.

In India, Andhra Pradesh's adoption of blockchain aims to simplify land administration by providing data synchronization, transparency, and immutable records, ultimately reducing corruption and inefficiency.

Afghanistan's project to create a digital land registry using hybrid blockchain technology focuses on securing land rights in informal urban settlements, though challenges remain regarding the capacity and governance of the formal land administration system.

Bangladesh is investigating blockchain-based solutions to address land administration issues such as information fragmentation and corruption, with LANDCHAIN providing a lightweight and efficient solution.

By migrating real estate databases onto a blockchain platform, Japan hopes to modernize processes, improve security, and increase transparency.

South Korea actively embraces blockchain technology in e-governance, reducing bureaucratic procedures and increasing citizen convenience in documentation and certification processes.

Nigerian professionals demonstrate a willingness to embrace blockchain-based solutions for secure land titles and economic opportunities while addressing land administration challenges.

Ukraine's adoption of blockchain in its State Land Cadastre aims to reduce operational costs associated with land registration, with success dependent on political stability and government support.

Germany proposes using blockchain to improve its electronic land registry to address complexity, transparency issues, and document-based delays. Similarly, the UK's Digital Street project aims to create government-backed property guarantees using blockchain.

Russia is investigating blockchain-based land registry systems to reduce operational costs, but political stability and external factors may have an impact on their success.

In the United States, particularly in North America and Canada, various pilot projects in states such as Virginia and Wyoming reflect efforts to investigate blockchain applications in land administration.

Singapore's advanced land registry system, along with digital signature legislation and transparent ledgers, serves as a model for efficient land administration. China invests in land reclamation projects and is researching blockchain technology for e-government.

Blockchain-based title registries provide benefits such as distributed ledgers, immutable records, and smart contract efficiency. However, due to differences in ICT infrastructure, legal systems, and land reforms, Sweden and Georgia's successes cannot be directly replicated.

The challenges include participant identity verification, contract legality, co-ownership management, and adapting blockchain records. Future research should focus on addressing these challenges to develop holistic solutions that can accommodate complex legal frameworks.

In conclusion, blockchain technology has the potential to transform land administration by increasing transparency, efficiency, and security. Different countries have faced distinct challenges in their approaches, necessitating careful consideration of legal, technological, and governmental factors to realize their full potential. The successes of Sweden, Georgia, Honduras, and Ghana highlight both the possibilities and limitations of using blockchain for land registries.

2.7 Chapter Summary

This chapter provided an overview of the challenges in traditional land administration, specifically vulnerabilities and lack of transparency, which have prompted blockchain adoption as a solution. The chapter described blockchain solutions for land

administration, citing examples from Sweden and Georgia that demonstrated blockchain's transparency, security, and efficiency benefits in combating corruption and fraud. These models, however, not only inspire, but also highlight the need for context-specific strategies due to varying ICT infrastructure, legal systems, and land reforms. While the potential of blockchain in land administration is clear, challenges such as participant verification, contract legality, and co-ownership management necessitate focused attention for comprehensive integration.

CHAPTER 3: RESEARCH METHODS

This chapter provides a comprehensive description of the research procedures and methodologies utilized to accomplish the study objectives. The purpose is to allow the reader to evaluate the credibility and soundness of the research findings.

3.1 Research Design

According to Sawsan and Jaradat (2018), the concept of research design can be broadly defined as the strategic blueprint that addresses research questions and aligns with the overall objectives of the study. This study utilized a quantitative methodology and employed the PXP agile software development framework to achieve its main objective. Considering that case studies are seen most suitable for modelling causal processes in controlled settings and prioritizing internal validity over external validity (Paul, Gardner, & Haeffele, 2012), the utilization of case studies was undertaken to validate the developed registry. In addition, the Ethereum Tester was applied to assess the security, transaction transparency, and other functionalities of the system.

3.2 Population of the Study

Individuals interested in purchasing land and landowners who had resided in suburban areas of Windhoek for a minimum of three years were surveyed to draw connections between the land register system in Namibia and the challenges highlighted in the literature review. To ensure the protection of sensitive and personally identifiable information (PII) of land owners present in the actual land records, the developed registry used synthetic land records instead. In response to the significant need for accurate data, these synthetic records were designed to closely replicate the characteristics and patterns found in authentic land records, including property sizes, geographical locations, ownership histories, and other relevant variables.

3.3 Sampling Procedures

Since a significant number of eligible participants were reluctant to complete the questionnaire, a non-probability sampling approach combining convenience and purposive sampling methods was employed to include 24 participants who met the predefined criteria and were readily accessible and willing to participate in the study. Because sampling, as defined by Alvi (2016), is a technique for selecting a subset of a target population to make statistical inferences and estimate the characteristics of the entire population, the generation of synthetic records used in this study rendered sampling inapplicable in this case, but enough synthetic records were generated to make meaningful inferences about a larger population despite the limitations imposed by the lack of real data.

3.4 Research Instruments

A prominent blog focused on postgraduate matters, DISCOVERPHDS (2023), asserted that effective research instruments should facilitate the achievement of research objectives. Throughout the phase of data collection, a diverse range of tools were utilized, including google questionnaires, an online data generator called Mockaroo, and case studies. Truffle, a world class open-source development environment, testing framework and asset pipeline for blockchains using the EVM (Truffle Suite, 2023), was used to facilitate the execution of both white-box/code-based and black-box test cases to evaluate the internal structures and functionalities of the developed registry.

3.5 Data Collection Methods

The process of data collection involves gathering information from various relevant sources to address the research problem and evaluate the resulting outcomes (Dudovskiy, 2022). The primary dataset for this study was generated using an online

data generator to populate the developed land titles registry, considering the objectives of the study as advised by Dudovskiy (2022). The administration of questionnaires was conducted to establish correlations between the traditional LAS in Namibia and the challenges identified in the literature review of this study. During the final phase of the study, a comprehensive analysis was undertaken to extract relevant insights from both prior blockchain-based LASs and the case studies conducted in this research.

3.6 Data Analysis

The first step in data analysis was pre-processing and cleaning the generated primary dataset for the registry. This process addressed outliers, and inconsistencies to ensure the quality and dependability of the synthetic land records, which were designed to closely resemble the actual Ministry of Agriculture, Water, and Land Reform records. Using Google questionnaires with automatic graphical data presentation (graphs, charts, tables), a descriptive analysis was conducted to identify correlations between the Namibian LAS and the challenges identified in the literature review. A thorough comparative analysis of the case studies was conducted to understand their implications and contributions to the research objectives, and insights from the descriptive analysis and case studies were synthesised to draw conclusions, address the research problem, and assess study outcomes.

3.7 Research Ethics

The ethical clearance was obtained from both the Decentralized Ethics Committee (DED) and the University Research Ethics Committee (UREC). The necessary research permission was gained from the Centre for Research Services at the University of Namibia (UNAM). Furthermore, the research period was characterized by the implementation of the following ethical guiding principles:

- The participants in the questionnaires and interviews maintained anonymity throughout the research unless explicitly indicated differently.
- The participants were provided with concise explanations and responses to often-asked questions regarding honesty and integrity. It is important to note that the data was not manipulated or modified in any kind.
- The acknowledgment of intellectual property rights was demonstrated through the thorough referencing of similar systems approaches, including published data, methods, results, and other relevant resources.
- Compliance with legal requirements - the study adhered to all applicable rules and regulations about the research topic.

3.8 Chapter Summary

This chapter provided a detailed explanation of the research procedures and methodologies that were utilized to achieve the objectives of the study. The study was based on a quantitative methodology, and the primary data was generated. To identify eligible participants, a non-probability sampling method was used. The research used numerous tools, including Google questionnaires, Mockaroo, case studies, Truffle, and a systematic extensive literature review. Descriptive and comparative analyses were performed to draw conclusions from the study's findings.

CHAPTER 4: DESIGN AND IMPLEMENTATION

This chapter presents an overview of the procedures employed in the design and implementation of the blockchain-based land titles registry, which serve as the primary focus of this research project.

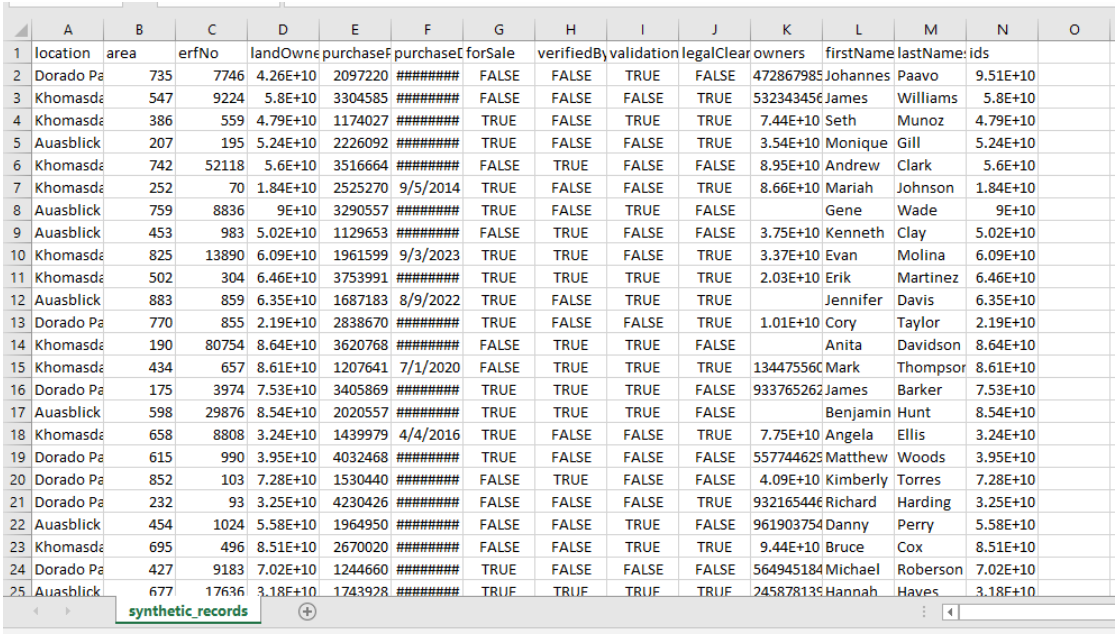
4.1 Primary Data Generation

To address the sensitivity of land ownership information and ethical considerations, this study utilized an online data generation method to create a synthetic dataset that is in line with the research objectives. The process of generating data was divided into three distinct phases.

Initially, the goal was to find an appropriate Online Data Generator with the ability to produce synthetic data that accurately imitate actual land records. Mockaroo, a free test data generator and API mocking tool, was selected after a thorough assessment due to its capacity to accurately imitate real data and offer flexibility in generating data volumes, thereby ensuring alignment with the objectives of the study.

Following that, the second stage focused on identifying the necessary data. This step was decisive in defining the data fields necessary for populating the land titles registry. The extracted data fields originate from the specified data structure in the smart contracts and include important information such as the location of land parcels, Erf No, area measurements, owner details, purchase history, and various status indicators.

The last stage of the process was dedicated to data validation, specifically ensuring that the synthetic data conforms to the schema and constraints outlined in the smart contracts. This was achieved by implementing validation rules on the generated data to guarantee that it satisfies the specified criteria, such as non-negative area values, valid addresses, and correct data formats, as depicted in Figure 4. At this stage, any outliers and inconsistencies in the generated data were also addressed.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	location	area	erfNo	landOwne	purchaseP	purchaseD	forSale	verifiedBy	validation	legalClear	owners	firstName	lastName	ids	
2	Dorado Pa	735	7746	4.26E+10	2097220	########	FALSE	FALSE	TRUE	FALSE	472867985	Johannes	Paavo	9.51E+10	
3	Khomasda	547	9224	5.8E+10	3304585	########	FALSE	FALSE	FALSE	TRUE	53234345(	James	Williams	5.8E+10	
4	Khomasda	386	559	4.79E+10	1174027	########	TRUE	FALSE	TRUE	TRUE	7.44E+10	Seth	Munoz	4.79E+10	
5	Auasblick	207	195	5.24E+10	2226092	########	TRUE	FALSE	FALSE	TRUE	3.54E+10	Monique	Gill	5.24E+10	
6	Khomasda	742	52118	5.6E+10	3516664	########	FALSE	TRUE	FALSE	FALSE	8.95E+10	Andrew	Clark	5.6E+10	
7	Khomasda	252	70	1.84E+10	2525270	9/5/2014	TRUE	FALSE	FALSE	TRUE	8.66E+10	Mariah	Johnson	1.84E+10	
8	Auasblick	759	8836	9E+10	3290557	########	TRUE	FALSE	TRUE	FALSE		Gene	Wade	9E+10	
9	Auasblick	453	983	5.02E+10	1129653	########	FALSE	TRUE	FALSE	FALSE	3.75E+10	Kenneth	Clay	5.02E+10	
10	Khomasda	825	13890	6.09E+10	1961599	9/3/2023	TRUE	TRUE	FALSE	TRUE	3.37E+10	Evan	Molina	6.09E+10	
11	Khomasda	502	304	6.46E+10	3753991	########	TRUE	TRUE	TRUE	TRUE	2.03E+10	Erik	Martinez	6.46E+10	
12	Auasblick	883	859	6.35E+10	1687183	8/9/2022	TRUE	FALSE	TRUE	TRUE		Jennifer	Davis	6.35E+10	
13	Dorado Pa	770	855	2.19E+10	2838670	########	TRUE	FALSE	FALSE	TRUE	1.01E+10	Cory	Taylor	2.19E+10	
14	Khomasda	190	80754	8.64E+10	3620768	########	FALSE	TRUE	TRUE	FALSE		Anita	Davidson	8.64E+10	
15	Khomasda	434	657	8.61E+10	1207641	7/1/2020	FALSE	TRUE	TRUE	TRUE	134475560	Mark	Thompsor	8.61E+10	
16	Dorado Pa	175	3974	7.53E+10	3405869	########	TRUE	TRUE	TRUE	FALSE	933765262	James	Barker	7.53E+10	
17	Auasblick	598	29876	8.54E+10	2020557	########	TRUE	TRUE	TRUE	FALSE		Benjamin	Hunt	8.54E+10	
18	Khomasda	658	8808	3.24E+10	1439979	4/4/2016	TRUE	FALSE	FALSE	TRUE	7.75E+10	Angela	Ellis	3.24E+10	
19	Dorado Pa	615	990	3.95E+10	4032468	########	TRUE	FALSE	FALSE	FALSE	557744625	Matthew	Woods	3.95E+10	
20	Dorado Pa	852	103	7.28E+10	1530440	########	FALSE	TRUE	FALSE	FALSE	4.09E+10	Kimberly	Torres	7.28E+10	
21	Dorado Pa	232	93	3.25E+10	4230426	########	FALSE	FALSE	FALSE	TRUE	932165446	Richard	Harding	3.25E+10	
22	Auasblick	454	1024	5.58E+10	1964950	########	FALSE	FALSE	TRUE	FALSE	961903754	Danny	Perry	5.58E+10	
23	Khomasda	695	496	8.51E+10	2670020	########	FALSE	FALSE	TRUE	TRUE	9.44E+10	Bruce	Cox	8.51E+10	
24	Dorado Pa	427	9183	7.02E+10	1244660	########	TRUE	FALSE	FALSE	FALSE	564945184	Michael	Roberson	7.02E+10	
25	Auasblick	677	17636	3.18E+10	1743928	########	TRUE	TRUE	TRUE	TRUE	245878135	Hannah	Haves	3.18E+10	

synthetic_records

Figure 3 CSV containing information about land records for the developed registry.

In order to ensure the accuracy and consistency of the land registry system and avoid any potential mistakes or discrepancies that may occur from injecting substantial data volumes into the blockchain, the simulated data was manually added to the registry as required, during specific stages such as user registrations and land additions. The study effectively addressed ethical concerns by using only synthetic data, thereby logically eliminating the risk of violating individual privacy and maintaining the highest ethical standards. This approach enabled the implementation of a research methodology that adhered to ethical boundaries while effectively accomplishing the research objectives.

4.2 System Design

System design is a critical process that involves defining the architecture, components, modules, interfaces, and data for a system to satisfy its specified requirements (Albert, 2012). It plays a crucial role in developing complex software and hardware systems, ensuring their scalability, reliability, and performance.

A structured approach was used to develop a profound understanding of the architectural design and functionality of the blockchain-based land registry, which

outlines the essential elements that shape the system's design, performance, and usability.

As the project advanced, the design was revisited and refined, resulting in an iterative process. This section begins by defining both functional and non-functional requirements of the developed registry, which serve as the foundation for the subsequent design phases. Figure 5 shows the registry architecture diagram, which depicts the overall structure and components of the registry system.

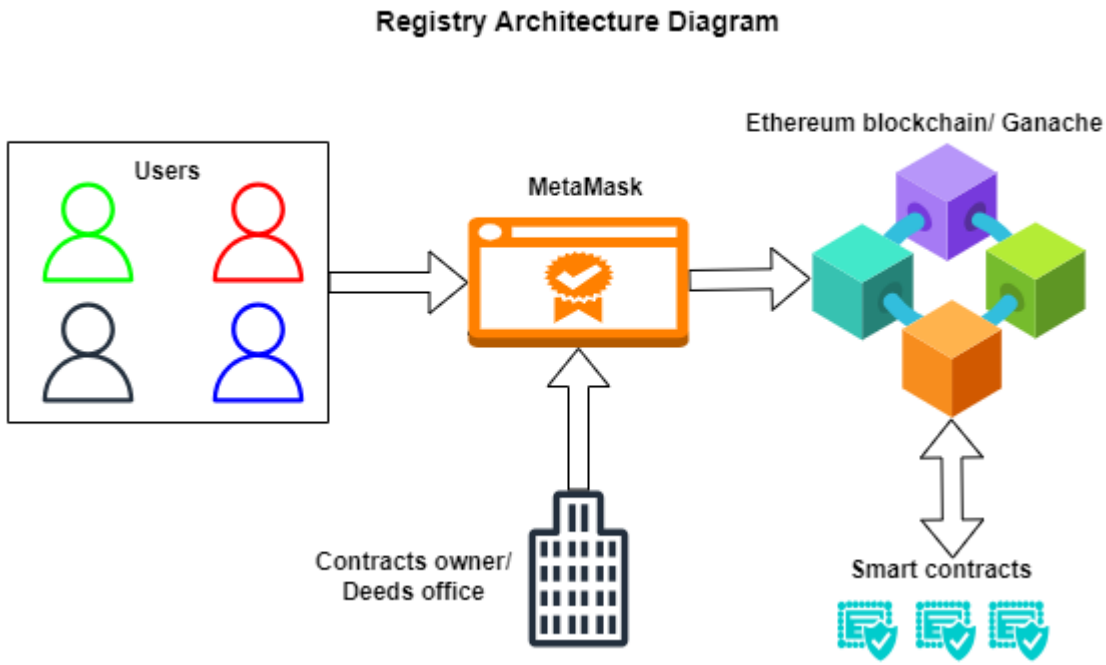


Figure 4 The developed registry architecture diagram.

4.2.1. Functional Requirements

User Roles:

- Landowners should be able to register their land and add a sales transaction to the blockchain.
- Purchasers should be able to initiate a purchase request for any land listed for sale, complete the transaction, and become the owner.

- Lawyers/conveyancers should be able to participate in the verification of legal and financial requirements of land sales initiated by landowners.
- Government entities, such as the Deeds Office and the Municipality, should have the authority to validate and verify lands and user registrations.

Table 1 below provides a precise outline of the roles and responsibilities of the registry users.

Table 1 Registry users' roles and responsibilities.

Users / roles	Verify Users	Add Land	Purchase Land	Verify Land	Validate Land
Landowners	×	✓	✓	×	×
Purchasers	×	×	✓	×	×
Deeds Office	✓	×	×	✓	✓
Municipality	×	×	×	✓	×
Lawyers/conveyancers	×	×	×	✓	×

User Stories

The primary user stories listed below describe various interactions between users and the developed land registry system. Each user story includes a brief description and a priority rating.

- User Story 1

  Priority: High

  Description: Users should be able to register in the land registry. During registration, they will be required to enter their personal information, such as

their name and contact information, as well as their user type (for example, landowner, municipality, lawyer, etc.).

- User Story 2

  Priority: High

  Description: Landowners should be able to add and register their land on the land registry. This process involves submitting information such as the precise location, land area, and Erf number, which ensures complete land records.

- User Story 3

  Priority: Medium

  Description: Access to specific processes for verifying and validating land records should be limited to government entities and authorized lawyers/conveyancers. These privileged users will have the authority to review land ownership, legality, and other requirements.

- User Story 4

  Priority: High

  Description: The land registry system should allow users to initiate land transfers and sales. This feature will simplify the process of transferring land ownership and facilitate secure land sales.

4.2.2. Non-Functional Requirements

- Security: measures should be implemented to ensure users' data and land records are securely stored on the blockchain, with tamper-proof attributes and access control mechanisms to restrict unauthorized access to data.
- Performance: the registry should possess the capability to efficiently process a high volume of transactions while maintaining low latency, and user interaction response times should be within acceptable bounds.

- Scalability: scalability is crucial to handling a growing user base. The registry should be designed to be scalable, and both land records and smart contracts should be optimized for gas efficiency.
- Usability: to ensure a positive user experience, user interfaces should be intuitive and user-friendly, and error messages should be clear and informative throughout the registry.

4.2.3. Data Structures

User Profile Data Structure:

Attributes: first name, last name, email, user type, password, registration date, terms agreed, ID, gender, ID document, ownership history.

Relationships: users can own multiple lands, but lands cannot have multiple owners at the same time.

Land Record Data Structure:

Attributes: location, area, Erf No, current owner, owner's history, purchase price, purchase date, for sale status, verification status, validation status, legal clearance status.

Relationships: while a piece of land can be owned by a single owner, it can have multiple verification or validation records.

4.2.4. Algorithms

In the implementation of the blockchain-based land registry, specific algorithms play a crucial role in maintaining data integrity and security. A set of validation rules is used in the user registration and land registration processes to ensure the accuracy and integrity of the data entered.

During the user login phase, the system uses the Elliptic Curve Digital Signature Algorithm (ECDSA), a key component of the Ethereum protocol that is facilitated by MetaMask. This algorithm is used for signature verification, which confirms a user's identity by comparing the signed message to the public key associated with their Ethereum account. The ECDSA offers a high level of security, making it extremely difficult to forge digital signatures, ensuring that only authenticated users have access to their accounts.

The LandTitleRegistry smart contract uses a set of rules to transfer ownership of land. This rule is divided into several steps: it first verifies the ownership of the land, then checks for any legal or governmental restrictions, and finally executes the transfer of ownership only if all conditions are met. This process is protected by Solidity's smart contract capabilities, which include transactional integrity and atomicity, ensuring that the transfer either completes fully or returns if any step fails. This secure strategy is critical in preventing unauthorized or fraudulent land transfers and maintaining the integrity of the land registry.

4.2.5. Main Processes Flowcharts

User Registration:

Inputs: Personal information, user type selection, email, password, terms agreement.

Outputs: User registration confirmation.

Figure 6 depicts the user registration process, in which user inputs such as personal information, user type, email, password, and terms agreement lead to a user registration confirmation.

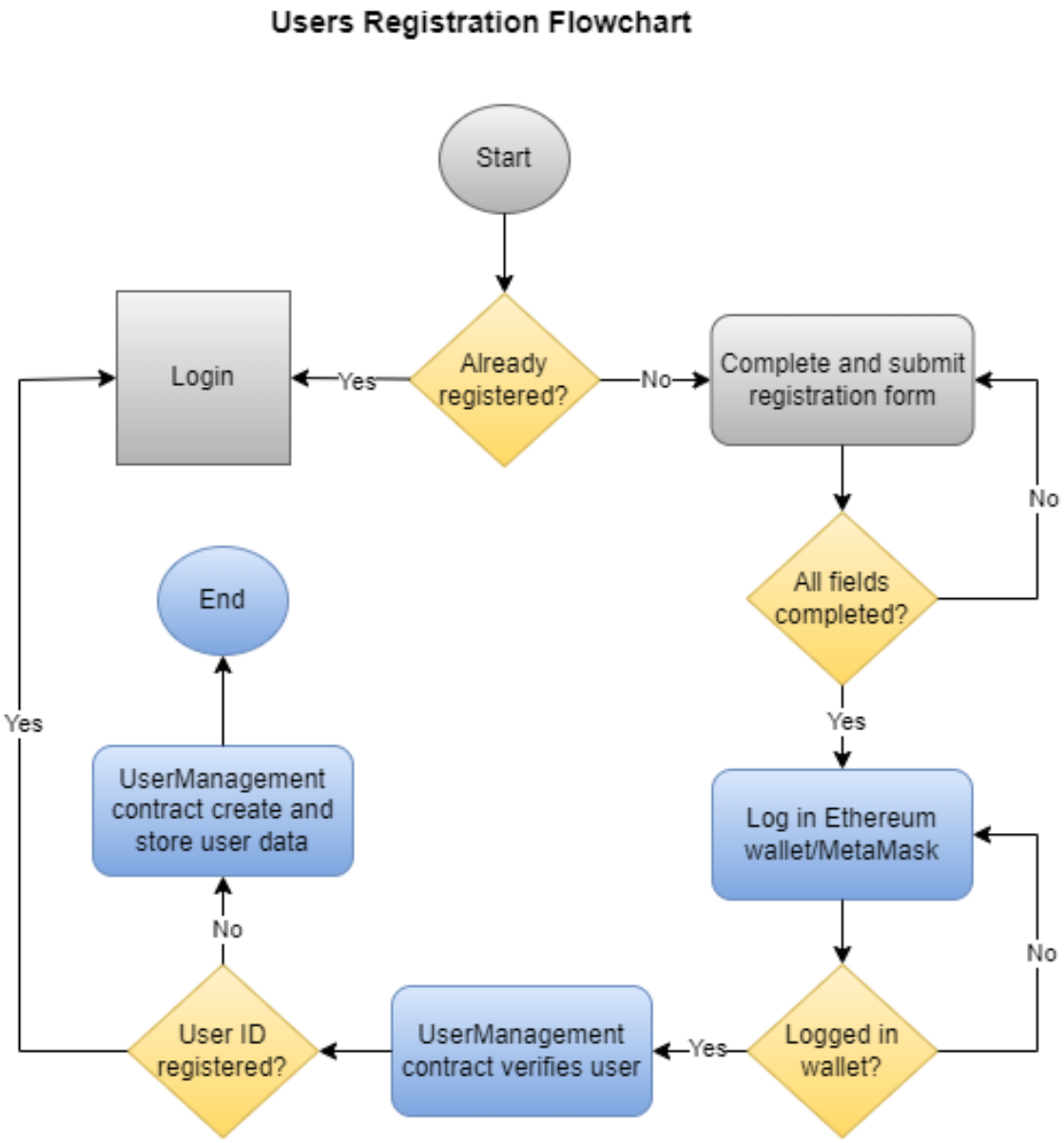


Figure 5 Users Registration Flowchart.

Land Registration/Purchase:

Inputs: Land details (location, area, Erf No or offer), owner/purchaser authentication.

Outputs: Land registration confirmation.

Figure 7 illustrates the Land Registration/Purchase process, which involves inputs such as land details and owner authentication and produces a land registration confirmation as an output.

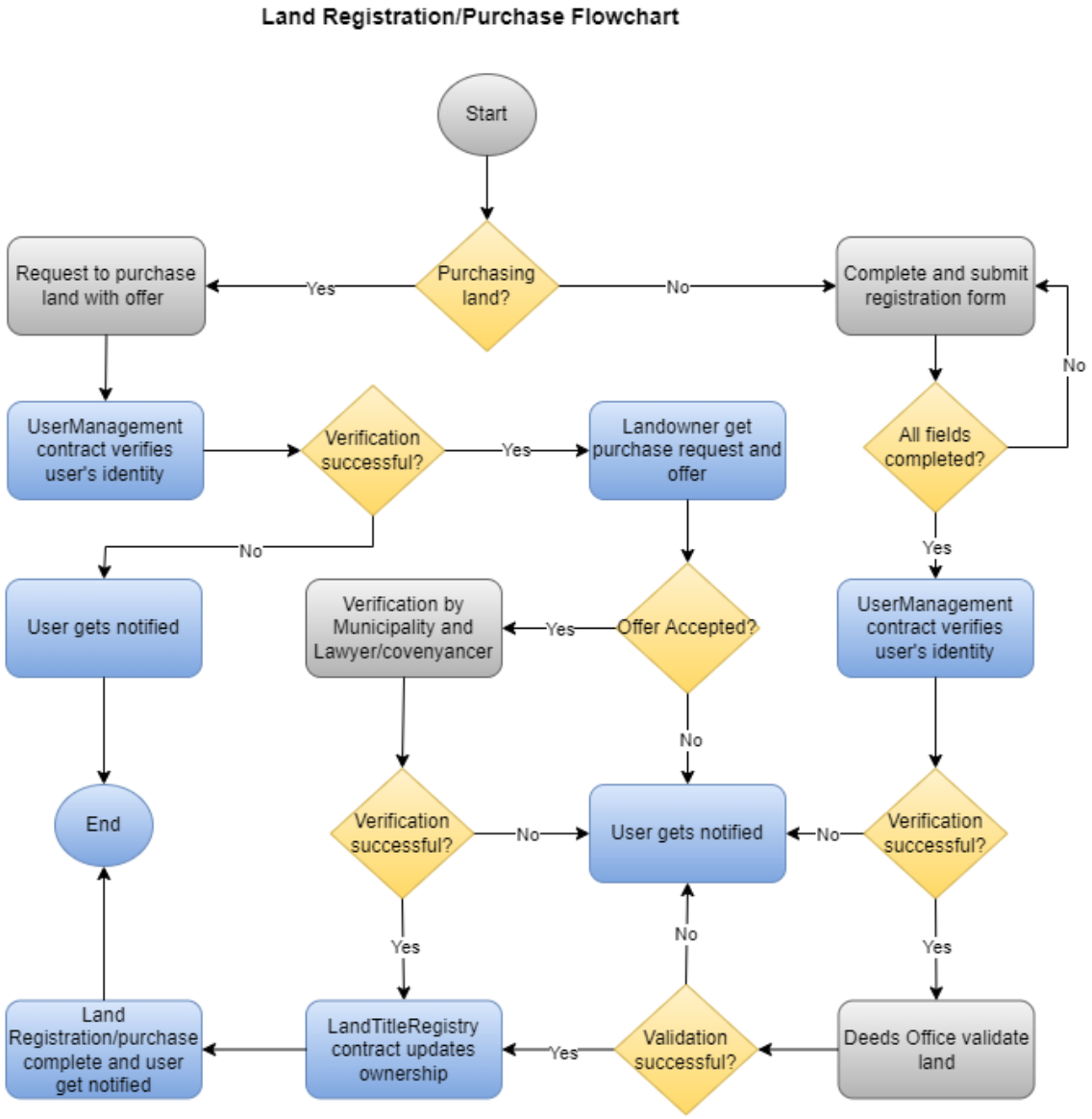


Figure 6 Land Registration/Purchase Flowchart.

4.3 Development and Blockchain Integration

This section delves into the development process and how blockchain technology was integrated into the land registry. The development approach, blockchain technology selection, smart contract development, and UI design are all thoroughly scrutinized.

4.3.1. Development Approach

The development approach for the blockchain-based land registry incorporated the principles of transparency, security, and user-friendliness. The aspects that were taken into consideration include:

- Decentralized Approach: Initially, the project was designed as a decentralized land registry that aimed to transform land administration and ownership verification by leveraging blockchain technology. The primary objective is to establish transparency, minimize the time and financial resources required for land registration, and ultimately reduce land administration contraventions in Namibia.
- Agile Development: The project utilized iterative releases, a key advantage of the agile development methodology, to enhance efficiency by allowing the researcher to accommodate changes, find and fix flaws, and align expectations early on (Tools qa, 2023). This approach, specifically PXP, allowed the developed registry to evolve incrementally, improving functionality and usability as it progressed. The extreme programming method utilized to develop the land registry is depicted in Figure 8.

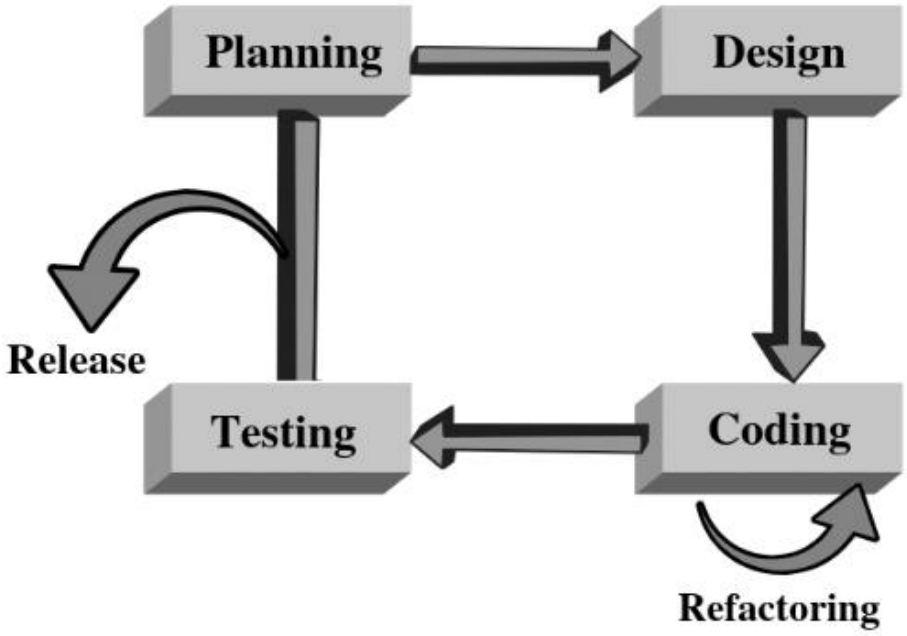


Figure 7 eXtreme Programming (XP) method depicted in diagram form *(Tools qa, 2023).*

- Collaboration: While the registry development process was not a collaborative effort, particularly in terms of technical aspects such as smart contract development and UI design, land management experts such as land administration officers, real estate agents, and a lawyer were engaged throughout the development to ensure that it complements the existing system.
- Version Control: GitLab was utilized as a version control system to effectively handle code modifications and support potential collaborative development in the future. Due to the lack of comprehensive documentation, the descriptions of smart contracts and the rationale behind UI design were kept straightforward and easily manageable.

4.3.2. Blockchain Technology Selection

Choosing the right blockchain technology was a critical decision in the project. To begin, various blockchain types, such as private and public, were assessed to determine the best fit for the developed land registry (BlockLand). The table below compares the key differences between the public and private blockchains considered for the developed registry.

Table 2 Private Blockchain vs Public Blockchain attributes.

Private Blockchain	Public Blockchain
Users must be invited to use the blockchain (permissioned blockchain).	Anyone can use the blockchain (permissionless blockchain).
Owned and controlled by a centralized authority.	Owned by no one.
Tend to be centralized.	Fully decentralized.
Blockchain owners can reverse or delete transactions.	Data is immutable and cannot be changed once added to the blockchain.
Transaction verification and validation.	Transaction verification and validation.
The entire ledger can be modified by the owner.	Data cannot be altered.
The rules to use the blockchain can be changed at any time.	The rules on how the blockchain works are defined in the Bitcoin white paper.
Potentially less secure as fewer nodes could be more easily compromised.	Potentially more secure as many nodes make it hard for malicious actors to gain network control.

While both private and public blockchains have their upsides, a hybrid blockchain was deemed more appropriate because it allows for the combination of the most important qualities that align with the project objectives, providing flexibility, transparency, and privacy advantages.

The next step was to choose a suitable blockchain platform, which was accomplished through careful comparisons of available options. Due to a number of compelling factors, Ethereum emerged as the most favorable option.

Ethereum has a well-established and recognized presence in the blockchain ecosystem, demonstrating its dependability and resilience. Its vibrant developer community, comprising over forty thousand members worldwide, signifies a robust and constantly evolving ecosystem. According to its official website (Ethereum, 2023), Ethereum is fundamentally a global network of interconnected computers that follow a predefined set of rules known as the Ethereum protocol. This network serves as a foundational infrastructure supporting diverse communities, applications, organizations, and digital assets, all of which can be created and used by anyone.

The exceptional ability of Ethereum to execute smart contracts seamlessly aligns with the requirements of BlockLand. These smart contracts make it possible to execute contractual agreements in an automated, reliable, and transparent manner. Moreover, Ethereum's infrastructure is open source, ensuring transparency and accessibility for all. Interactions with Ethereum can be facilitated using established programming languages such as JavaScript, simplifying development for a wider audience. Additionally, Ethereum's open-source nature allows developers to fork existing codebases and reuse functionalities, promoting efficiency and collaboration within the Ethereum ecosystem.

4.3.3. Smart Contract Development

Solidity was the natural choice for smart contract development after choosing Ethereum as the platform for the developed land registry. Solidity is a statically typed curly-braces programming language for developing smart contracts that are compatible with the Ethereum blockchain (Solidity, 2023).

The foundation of BlockLand is built on three smart contracts: UserManagement, LandTitleRegistry and VerificationAndValidation, which are designed with a modular architecture to streamline code organization and accommodate future improvements while ensuring efficient interaction among contract components. Furthermore, the smart contracts were developed in strict accordance with industry best practices recommended by reputable sources such as Ethereum. These practices included implementing measures to prevent common vulnerabilities like re-entrancy attacks, integer overflow/underflow, and gas exhaustion attacks. To mitigate re-entrancy vulnerabilities, the 'checks-effects-interactions' pattern was used, which ensured that external calls were the final step in contract functions, preventing re-entrancy. In addition, the smart contracts underwent rigorous code audits and security assessments to reinforce their security measures.

UserManagement Smart Contract:

The "UserManagement" contract is in charge of managing user registration, login, and user details in a blockchain-based system. It allows users of different types (Landowners, including purchases, Government - the Deeds Office, Municipality, Lawyers/Conveyancers) to register, store their information, and verify their identity using MetaMask signatures. The following are the primary responsibilities of this contract:

- User Registration: The contract allows different types of users to register by providing personal information such as first and last name, email, password, ID, gender, and ID document. The contract requires that each ID be unique for each type of user and the terms and conditions must be accepted by the user.
- User Login: Registered users can log in using their email address as their usernames, password, and a MetaMask signature. The contract compares the provided information to the stored data and validates the MetaMask signature.
- Ownership: The Deeds Office owns all contracts and has special privileges such as the ability to add new user types and verify specific users (Municipality and Lawyers).
- Events: To track user actions and state changes, the contract emits events such as UserRegistered, UserLoggedIn, UserDetailsSentToDeedsOffice, and UserVerified.

In its entirety, the contract manages various categories of users within the title land registry, facilitates user registration and login, and safeguards the confidentiality and integrity of user information.

LandTitleRegistry Smart Contract:

The contract "LandTitleRegistry" is in charge of managing land records and their ownership within the land title registry. For user-related functionality, it interacts with the "UserManagement" contract. The following are the primary responsibilities of this contract:

- Land Registration: Users can register lands by providing the location, area, Erf No and ID in the contract. Each piece of land has a unique owner.
- Ownership History: The contract uses IDs to track each land's ownership history.

- Land Details Retrieval: By entering their unique ID, users can retrieve information about specific lands for sale. This information includes things like location, area, owner, purchase price, and various status flags (for sale, verified by the government, validation status, and legal clearance status).
- User Ownership Information: Users can retrieve their ownership information, which includes their first and last names, as well as the total number of lands they own.
- Listing Land for Sale: Landowners can list their lands for sale by entering the land ID and the purchase price.
- Requesting to Purchase Land: Users can request to purchase land that is listed for sale by submitting an offer.
- Transfer of Land Ownership: Land ownership can be transferred from one user to another by specifying the land's unique ID and the new owner's address. Following contract owner verification, the contract updates ownership information and ownership lists accordingly.

In its entirety, the "LandTitleRegistry" contract functions as a land registry, facilitating land registration, sale, and status updates, and preserving ownership records. It works in conjunction with the "UserManagement" contract to oversee user data and authenticate ownership.

VerificationAndValidation Smart Contract:

The contract "VerificationAndValidation" is in charge of verifying and validating land records within the land title registry system. It communicates with both the "LandTitleRegistry" and "UserManagement" contracts to access land parcel details and verify users. The following are the primary responsibilities of this contract:

- Verify Municipality or Lawyer: Using the "UserManagement" contract, the Deeds Office can confirm the legitimacy of a user as a government entity (Municipality) or a Lawyer/Conveyancer.
- Verify Land: Only verified users have the ability to mark a land as verified. This function determines whether the land exists, has not yet been verified, and is owned by a legitimate user. If all of the conditions are met, the land is verified in the "LandTitleRegistry."
- Validate Land: Only the Deeds Office can mark land as validated. This function determines whether the land exists and can then be validated as belonging to the landowner.
- Clear Land: For contractual purposes, verified lawyers/conveyancers can mark (verify) land as cleared. This function determines whether the land exists, has been validated by the Deeds Office, verified by the Municipality, and is available for purchase. If all of the requirements are met, the land is designated as cleared for contractual purposes in the "LandTitleRegistry."

In its entirety, the "VerificationAndValidation" contract functions as a regulatory overlaid upon the land title registry, enabling clearance, validation, and verification operations to be executed on land parcels by verified users. Additionally, it offers a means by which the contract proprietor can authenticate the credentials of specific users.

4.3.4. User Interface Design

The UI design primary goal was to create a welcoming and friendly user experience. The registry interface integrated HyperText Markup Language (HTML) for content structuring, Cascaded Style Sheet (CSS) with the Font Awesome library for styling elements, and JavaScript for interactive features. It also used user-friendly language

and clear instructions to guide users throughout the registry, reducing confusion and improving overall usability. This combination produced a dynamic interface, effectively presenting blockchain data and functionalities in an accessible manner.

The registry's user interface included registration forms, login screens, land registration forms, and interactive dashboards for users and land verification. All of these components are carefully designed to optimize user interaction.

JavaScript was crucial in creating interactive UI components that allowed users to perform tasks such as user registration, land registration, verification and validation requests. It is also worth noting that Web3.js enabled the seamless integration of HTML, CSS, and JavaScript with blockchain technology. According to its official documentation (Web3.js, 2023), Web3.js is a collection of libraries that enable HTTP, IPC, and WebSocket communication with a local or remote Ethereum node. This integration enabled users to interact securely with smart contracts and the Ethereum network, including seamless integration with Ethereum wallets such as MetaMask, which was a key component of this development, ensuring secure interaction while safeguarding private keys.

Although the diversity of devices used to access the land registry was not initially considered, usability testing sessions were held in a controlled environment to validate UI design choices. Iterative refinements, informed by valuable feedback from three potential registry users, including landowners and a lawyer/conveyancer, improved the UI's usability and user satisfaction which were assessed primarily on the default device, which is the desktop version, as most users navigate important systems like these on desktops. Users expressed high satisfaction, which will translate to positive user experiences and overall system usability.

Furthermore, colour selection was critical in the registry's UI design. The Ministry of Land Reform in Namibia, which is responsible for ensuring equitable and efficient allocation, management, administration, and sustainable use of the country's land resources, colour theme was considered to evoke trust, professionalism, and a sense of familiarity, thereby promoting user engagement and confidence.

Refer to Appendix E for visual representation of the key interface snapshots.

4.4 Testing and Deployment

This section offers an inclusive examination of the deployment, testing and validation procedures of the land registry. The components that have been configured in the development environment to facilitate these tasks are detailed in Table 3, along with their corresponding versions. Each individual element is further elaborated upon in its respective section.

Table 3 Components and their versions in the development environment.

Software	Version
Truffle	5.11.5
Ganache	7.9.1
MetaMask	11.7.3

4.4.1. Deployment and Network Setup

Development Environment:

A local Ethereum-based development environment was established for the development and deployment of BlockLand. The main tools and components of this environment include:

- Truffle: A world-class open-source development environment, testing framework, and asset pipeline for blockchains using the Ethereum Virtual Machine (Truffle Suite, 2023).
- Ganache: A personal blockchain emulator that enables the deployment and testing of smart contracts in a secure and deterministic environment (Truffle Suite, 2023). It also includes a set of pre-funded accounts for development and testing. Figure 9 depicts the three deployed smart contracts of the registry on Ganache UI.

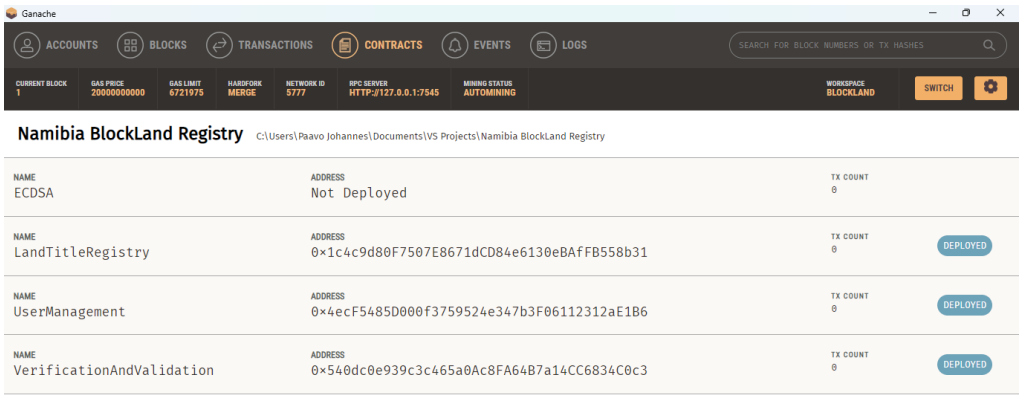


Figure 8 BlockLand deployed (initial) smart contracts on Ganache.

- MetaMask: MetaMask is a browser extension wallet that provides the simplest yet most secure way to connect to blockchain-based applications (MetaMask, 2023). It provides users of the land registry with the key vault, secure login, token wallet, and token exchange required to manage land, as well as acting as a bridge between the browser and the Ethereum network. Figure 10 depicts a user's MetaMask wallet linked to a pre-funded Ganache account.

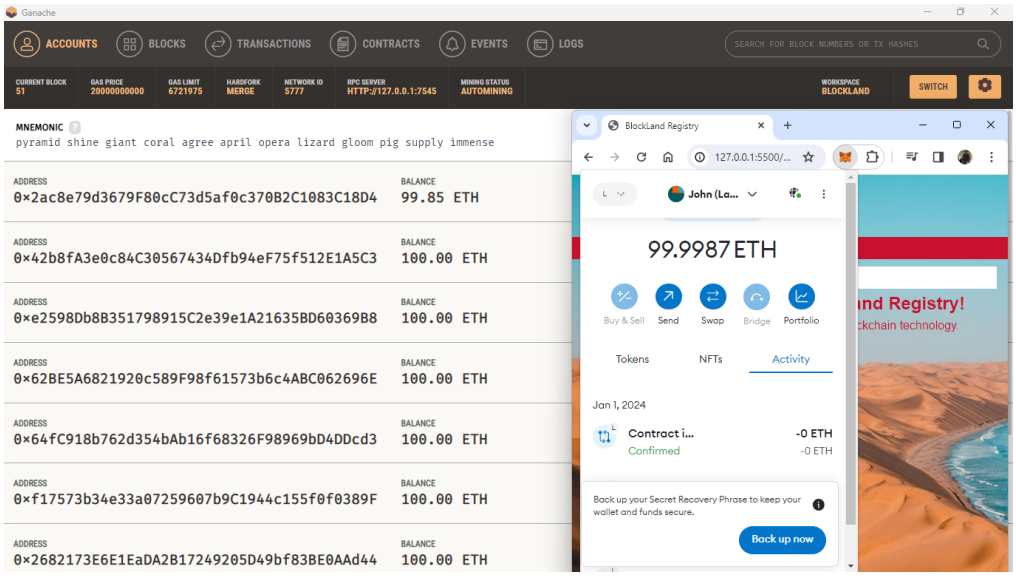


Figure 9 MetaMask wallet next to pre-funded Ganache accounts.

Network Configuration:

The Truffle configuration file specifies the configuration for the developed registry network. This configuration is intended to connect to the Ganache blockchain emulator via MetaMask, which is accessible locally at 127.0.0.1 (localhost) on port 7545 as shown in Figure 11. To make the configuration more versatile, the network ID is set to "*", allowing Truffle to connect to any network. This file also specifies the Solidity compiler version (0.8.11) that is needed for contract compilation. This ensures the compatibility and maintainability of smart contracts throughout their development and deployment to the land registry network.

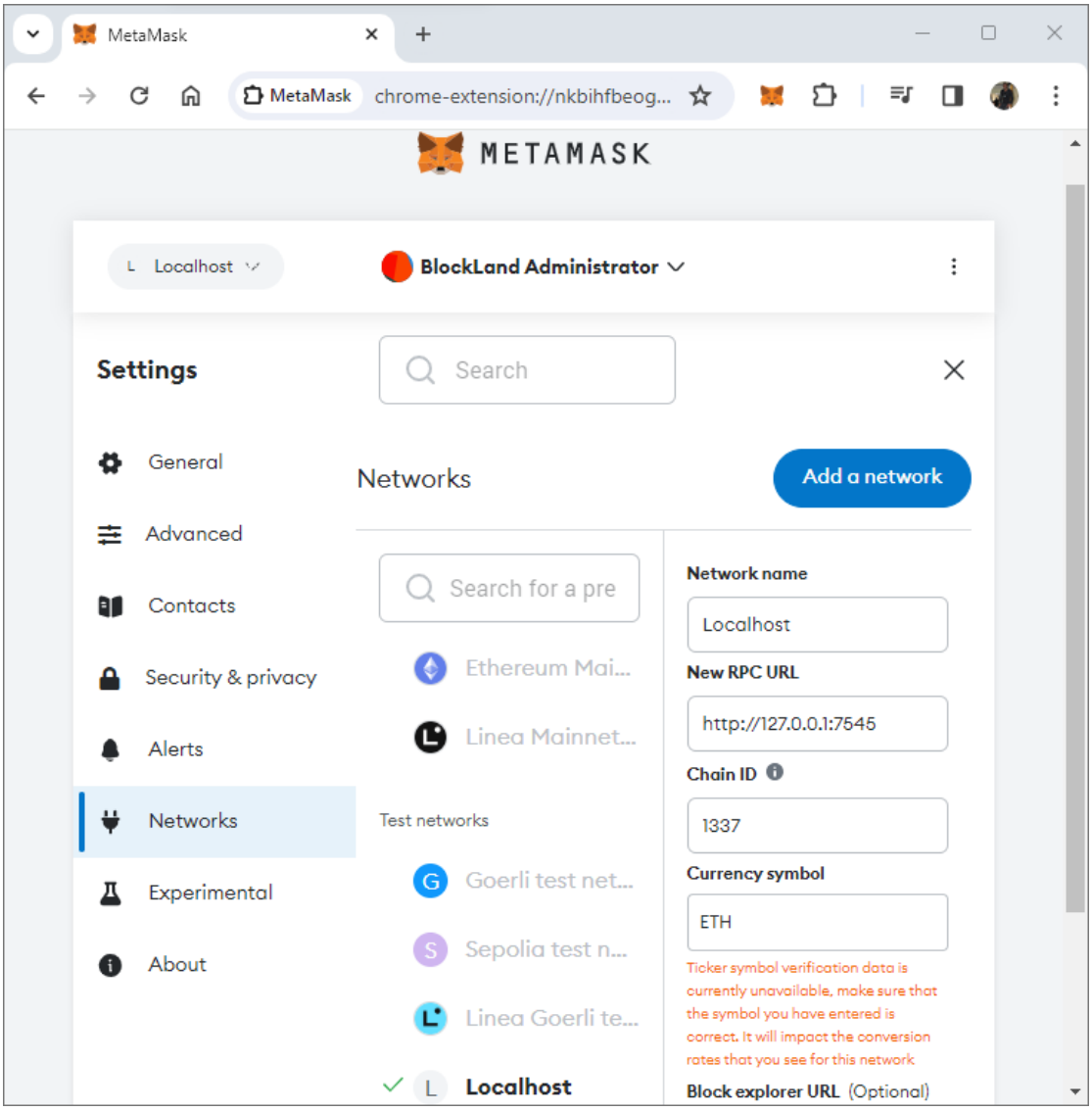


Figure 10 MetaMask network configuration to access Ganache.

4.4.2. Testing and Validation

To thoroughly evaluate the developed land registry's internal structures and functionalities, a two-tiered testing approach was used: white-box and black-box testing. White-box testing, also known as code-based testing, was used to investigate the inner workings and functionalities of the land registry's smart contracts. During this stage, a suite of unit tests was created using the Truffle testing framework. These tests were created to evaluate the behaviour of individual functions and methods within

smart contracts and ensure that they functioned as expected. For instance, the UserManagement contract transaction example depicted in Figure 12.

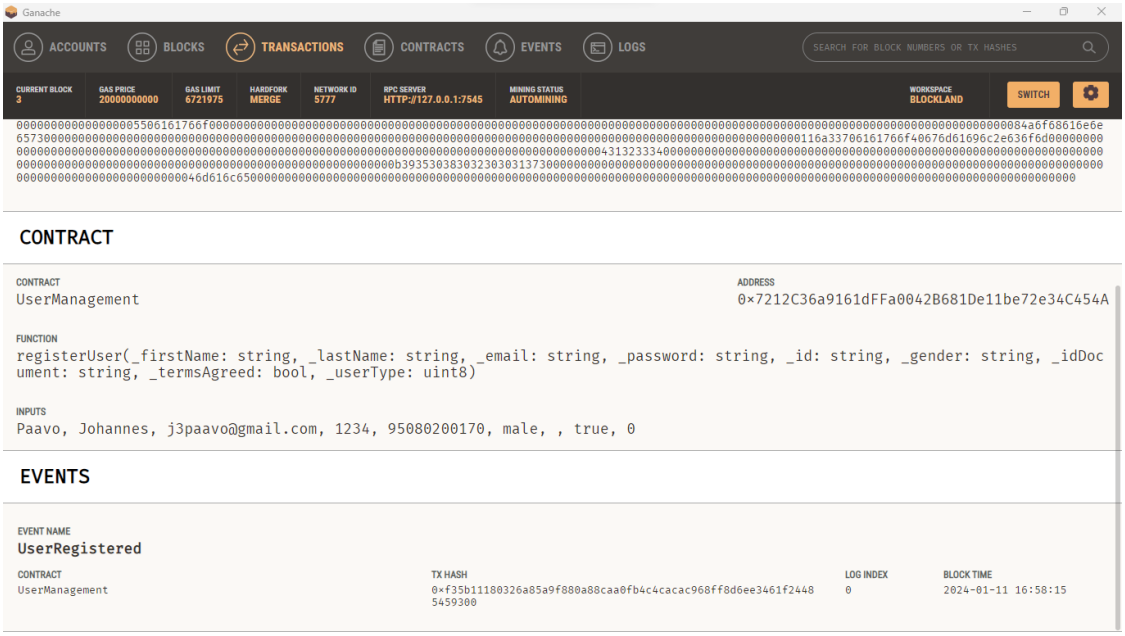


Figure 11 UserManagement contract transaction example when a new user register on BlockLand.

Several scenarios were thoroughly examined, including input validation and contract state changes. After ensuring that the internal code was error-free, functioning as expected, and reliable, the testing focus shifted to black-box testing. This phase was dedicated to assessing the interactions and functional requirements of the land registry as outlined during the system design phase.

To ensure seamless functionality, the black-box testing phase included user interface evaluation. This included inspecting the registry's frontend to ensure that it was functioning properly.

The test scenarios included user registration, land registration, verification processes, and transaction workflows.

By simulating real-world user interactions with the land registry, end-to-end testing was used to adopt a holistic perspective. These tests validated the entire system flow by simulating typical user journeys, beginning with registration and ending with changes in land ownership.

The frontend user interface and backend smart contracts were also tested for seamless integration. This phase of testing confirmed that user actions triggered the necessary smart contract functions.

With the combination of white-box and black-box testing approach, the researcher was able to ensure both code quality and a user-friendly experience, resulting in a robust blockchain-based land title registry that meets its requirements.

4.4.3. Performance Evaluation

The performance of BlockLand was evaluated based on its efficiency and extensibility. Significant performance indicators and factors considered included a deliberate design for smart contract extensibility, as well as a proactive approach to ensuring the system could easily integrate new functionalities and adapt to changes from the start, rather than relying on post-development adjustments. The goal of this strategy was to build a foundation for the seamless integration of new features and updates as the system's user base and number of registered lands grew. To ensure that extensibility features were effectively integrated, the development process involved regular code reviews and design validations. The advantage of this proactive approach is that addressing extensibility concerns early in the development process has laid a solid foundation for BlockLand's future evolution and adaptability. While specific numerical data on extensibility may not be available, design decisions that prioritised extensibility have helped to improve the system's overall efficiency and operational robustness. In addition, gas costs associated with contract interactions were monitored to determine

the registry's economic efficiency. This observation helped the researcher to understand the financial implications of using the registry.

4.4.4. Security Measures

Secure coding practices were used to prioritise transaction correctness and transparency in order to ensure transparent transactions. These practices included several key components.

First, event logging was implemented, making use of Solidity's event logging mechanism to record important transaction events.

Additionally, critical data related to land and ownership history was immutably stored on the blockchain. Once recorded, this data cannot be modified or deleted, resulting in a transparent and tamper-resistant transaction history.

Furthermore, access control mechanisms were critical in maintaining transaction security and transparency.

To assign specific roles and permissions to users, Role-Based Access Control (RBAC) was implemented. This approach enabled the system to grant different levels of access and authority to government entities and lawyers/conveyancers. This ensured that sensitive actions like verification and validation could only be performed by authorised users.

In addition to user security, the user authentication and authorization procedures were created to validate transaction security and transparency. Users were required to verify their identities during registration and login. Finally, the smart contracts that govern the land registry were implemented in an immutable manner. This immutability ensured the contract logic and rules' transparency and resistance to tampering.

4.4.5. Minimum System Requirements

The land registry was designed with user convenience in mind. Users can interact with the platform with just three simple requirements.

A Web3-enabled browser is required, which includes popular browsers such as Google Chrome, Mozilla Firefox, and Microsoft Edge. Users can interact with the platform directly from their browser by incorporating MetaMask or similar browser extensions to ensure a seamless and secure connection to the blockchain.

Secondly, a stable internet connection will ensure that users can access the platform's features without interruption, allowing them to register their lands, verify and validate lands, and conduct secure transactions from anywhere.

Finally, to actively participate in the ecosystem, users must have an Ethereum account. Creating an Ethereum account is simple, and it allows users to manage land records and conduct transparent transactions on the platform. With these minimal requirements in place, the land registry provides a user-friendly and inclusive environment that allows people from all walks of life to navigate land management efficiently and securely.

4.5 Challenges and Solutions

Dealing with the deployment and potential migration of smart contracts on the Ethereum blockchain was one of the major challenges encountered during the implementation of the land registry. Once deployed, Ethereum smart contracts are unchangeable, emphasising the importance of planning for future updates and alterations. To address this issue, a comprehensive contract deployment and migration strategy was developed, which included careful versioning of smart contracts to allow for future improvements. Each contract was designed with modularity in mind, with essential functionalities separated from auxiliary features.

Another significant challenge was ensuring a seamless integration between the front-end user interface and the back-end smart contracts in order to ensure real-time data synchronisation and a consistent user experience. To overcome this barrier, the Web3.js libraries were used to interact with Ethereum smart contracts directly from the front end, allowing for real-time contract function and data retrieval. Furthermore, an event-driven architecture was implemented, allowing the front-end to listen for contract events and react immediately to changes in the blockchain state.

Effective error handling and recovery mechanisms are required for any robust system to be stable. The challenge was efficiently identifying, managing, and recovering from unexpected errors. An error logging mechanism was implemented to record and categorise errors that occurred during user interactions and contract executions.

4.6 Chapter Summary

This chapter examines the complex processes involved in designing and implementing the blockchain-based land registry, which was the central focus of this research project.

To deal with the sensitive nature of land ownership information while maintaining ethical considerations, the first step was to generate primary data. A methodical approach was used, which included defining functional and non-functional requirements, developing data structures and algorithms, and designing user interfaces. This multifaceted process was critical in gaining a thorough understanding of the land registry's architectural design and operational complexities.

The project was purposefully designed to be a decentralised land registry, with iterative releases for the development of smart contracts and user interfaces. Ethereum emerged as the preferred platform for this endeavour, along with Ganache and MetaMask, with Solidity serving as the primary development language.

This chapter also elaborated on the testing and deployment phases, covering critical aspects such as deployment setup, testing procedures, performance assessments, security enhancements, and minimum system requirements. It also explained the difficulties encountered, such as the complexities of deployment and potential smart contract migration, providing valuable insight into overcoming these obstacles throughout the project's lifecycle.

In summary, this chapter provides a comprehensive roadmap for the conceptualization, development, validation, and deployment of the blockchain-based land titles registry.

CHAPTER 5: RESULTS AND DISCUSSIONS

The primary objective of this research was to develop a blockchain-based land titles registry to preserve land rights in Namibia. To achieve this overarching goal, several sub-objectives were identified, assessed, and incorporated into the development process.

This chapter discusses how these sub-objectives were addressed and the resulting findings. In addition to the sub-objectives, an online questionnaire was used to identify and understand issues with Namibia's land administration system. The questionnaire results provided valuable insights into the challenges faced by landowners, revealing that at least 75% of participants encountered difficulties during the land registration process, as illustrated in figure 13.

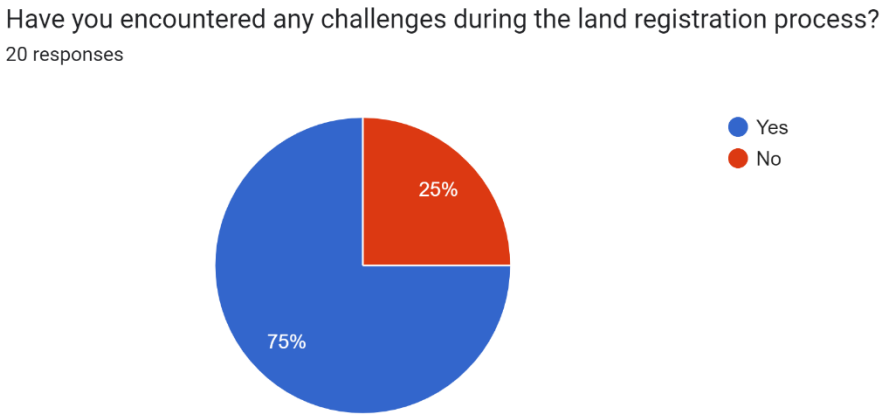


Figure 12 Percentage of participants who encountered difficulties during land registration.

The primary issue raised by participants in the research questionnaire, as shown by Figure 14, was the significant delay in processing land registration documents. This issue is closely followed by landownership disputes, which affect a significant number

of respondents (67%). The high incidence of land disputes can be attributed to an equally prevalent problem: a lack of transparency in land transactions.

While fewer respondents reported issues with difficulty of verifying land ownership, it is worth noting that the inconsistent or outdated land records emerged as a significant challenge in Namibia. This challenge is similar to that of Ghana and Kenya, where divergent approaches to land acquisition have resulted in the emergence of numerous conflicts in the realm of land administration (Donkor & de Vries, 2021).

Blockchain technology's immutable ledger and smart contract functionality will certainly help to maintain accurate records while effectively reducing conflicts and disputes.

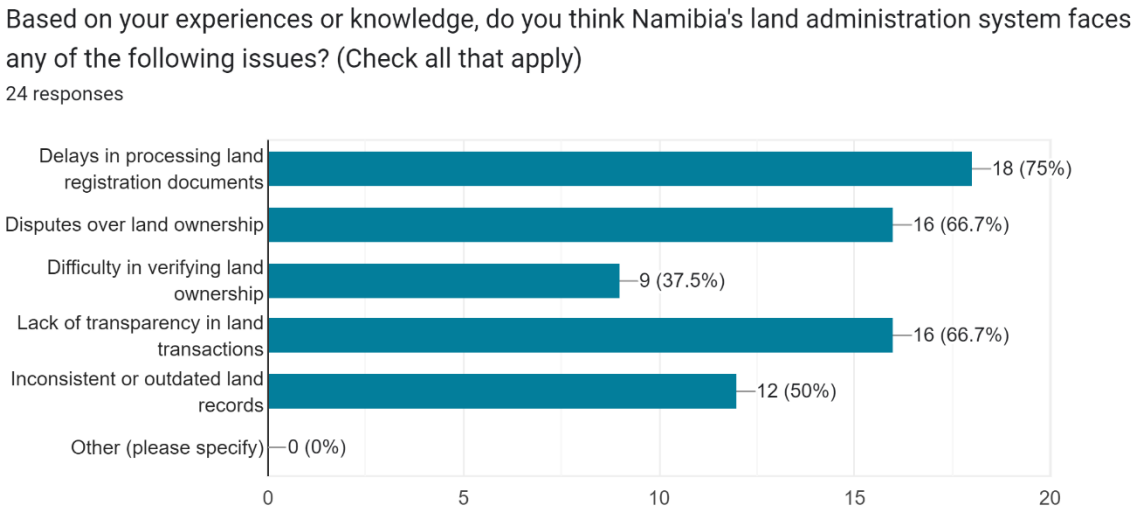


Figure 13 Challenges in Namibia Land administration system.

5.1 Feasible Blockchain Network Type for Namibia

Following a thorough evaluation process that compared the strengths of public and private blockchain networks, the researcher concluded that a hybrid blockchain network was the best option for the Namibian context. This strategic decision was

supported by a thorough assessment of factors such as regulatory compliance, scalability, and controlled access.

A hybrid blockchain network combines the benefits of both public and private blockchains, effectively preserving government oversight while capitalising on blockchain technology's transformative potential.

The hybrid approach integrates key attributes in line with project objectives, resulting in a compelling combination of flexibility, transparency, and privacy benefits. These hybrid public-private blockchain solutions have been successfully implemented by pioneer implementors such as Sweden and Bangladesh (Marinos, 2018), despite the fact that their success is largely due to the countries' advanced digital infrastructure and high internet penetration.

5.2 Registry Evaluation: Timeliness, Access, Cost, Sustainability

Timeliness:

Namibians have expressed dissatisfaction with the country's demanding and time-consuming land title processes, as shown in Figure 15, with ratings ranging from 1 (very satisfied) to 5 (very dissatisfied). This concern aligns with existing literature on land administration challenges in developing countries.

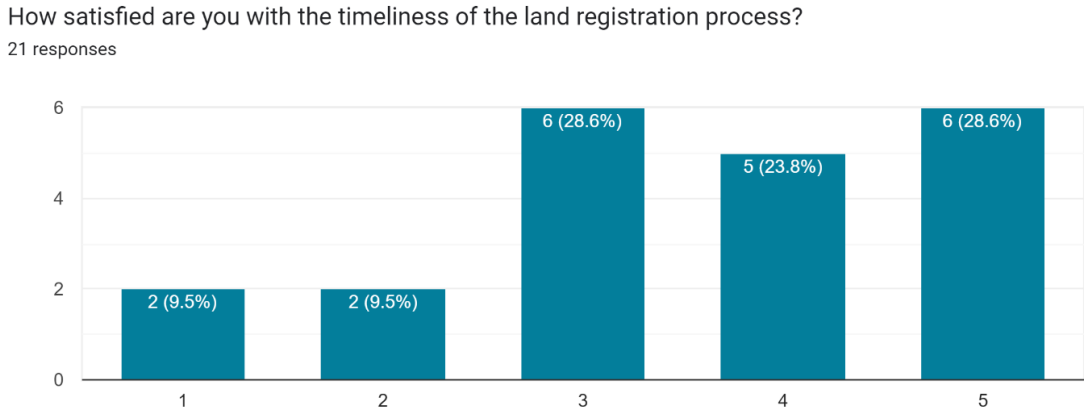


Figure 14 Participants land registration process timeliness satisfactory.

Participants emphasised the presence of too many intermediaries in the land administration process, resulting in delays and unnecessary costs. Such complex procedures have the potential to discourage prospective investors and stifle economic growth, as land administration is an essential component that has a significant impact on both economic development and social stability (Heng, 2017).

One significant advantage of the developed blockchain-based land registry is its ability to speed up the recording and updating of land titles. Unlike traditional paper-based systems, the registry has the potential to significantly reduce processing times, effectively eliminating bureaucratic delays. Its ability to handle a large volume of transactions benefits all stakeholders by increasing operational speed and responsiveness, ensuring that they have streamlined processes and immediate access to critical land title information.

Accessibility:

Previously, doubts were raised about the feasibility of blockchain-based land registry solutions, as demonstrated by projects such as Afghanistan's 'goLandRegistry.' This scepticism stemmed primarily from the country's challenges, such as limited

infrastructure and unstable internet access, as highlighted by Shah et al. (2023). These limitations highlighted the critical role of governance capacity in the success of such deployments, something Afghanistan lacked but Namibia possesses. Nonetheless, it is worth noting that the blockchain-based land registry in this study was designed with accessibility as one of its top priorities. It accomplishes this by providing user-friendly interfaces and cross-platform support, ensuring easy access for its users. This approach not only increases inclusivity, but it also simplifies interactions with the registry. With these minimal requirements in place, the land registry creates a user-friendly and inclusive environment, allowing people of all backgrounds to navigate land management efficiently and securely.

Cost-Effectiveness:

Cost-effectiveness was a key consideration, and the blockchain-based land registry offers clear economic benefits, such as reduced paperwork, which can be costly. Furthermore, the researcher examined the gas costs associated with smart contract interactions, which helped to provide a more complete understanding of the registry's financial efficiency and implications.

Sustainability:

The registry's sustainability was central to its design, which emphasised modularity and flexibility to accommodate evolving technologies and regulations. BlockLand's foundation is built on three smart contracts that were carefully designed to promote code organisation and facilitate future enhancements, all while ensuring seamless interaction between contract components. This strategic approach ensures that the registry's smart contracts are capable of managing a growing user base and number of registered lands while maintaining optimal system performance.

5.3 Security and Transparency Validation

Security:

The blockchain-based land registry required the highest level of security. The cryptographic foundation of blockchain technology ensures the integrity of land title records, significantly lowering the risk of unauthorised access or tampering. The three interlinked registry smart contracts use a variety of cryptographic algorithms and security practices. The UserManagement contract makes use of the Elliptic Curve Digital Signature Algorithm (ECDSA) from OpenZeppelin's cryptography library to ensure secure user authentication by verifying the digital signatures associated with each transaction (OpenZeppelin, 2023). This asymmetric cryptographic algorithm was chosen for its high-security credentials, particularly in terms of verifying user identities and transactions. The LandTitleRegistry contract makes use of Solidity's intrinsic security features, such as mapping and struct, to efficiently and securely manage land records, ensuring data integrity and preventing unauthorized modifications. Additionally, the VerificationAndValidation contract complements these approaches with stringent access controls and validation procedures, which ensure legal compliance and the trustworthiness of land transactions.

Furthermore, the smart contracts were designed in accordance with the industry standards for smart contracts development to strengthen security, effectively addressing common vulnerabilities such as re-entrancy, integer overflow/underflow, and gas exhaustion attacks. This comprehensive security approach protects valuable land-related data and transactions.

Transparency:

The research participants shared valuable insights into potential improvements and reforms to Namibia's land administration system as seen in Figure 17. These findings highlight the current system's challenges, such as a lack of transparency depicted by Figure 16, which have been linked to issues like inequitable land allocation and slow, complex processes.

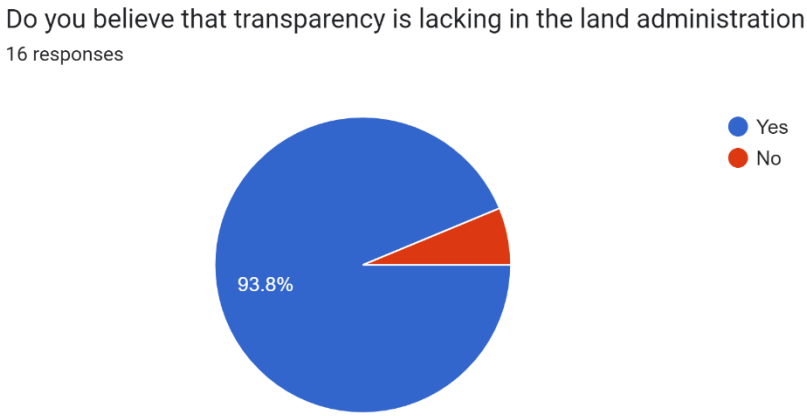


Figure 15 Perceptions of Transparency in Namibia's Land Administration.

These findings support previous research, emphasising the importance of transparency and accountability in land administration. Success stories of blockchain integration, such as the one in Estonia, where optimising land registration procedures resulted in increased transparency, security, and trust in property transactions (Josip & Lenac, 2020), can serve as an inspiring model for Namibia. Blockchain technology's inherent transparency, achieved through the creation of an immutable ledger of land transactions, offers a viable solution to address these concerns and replicate similar successes in Namibia.

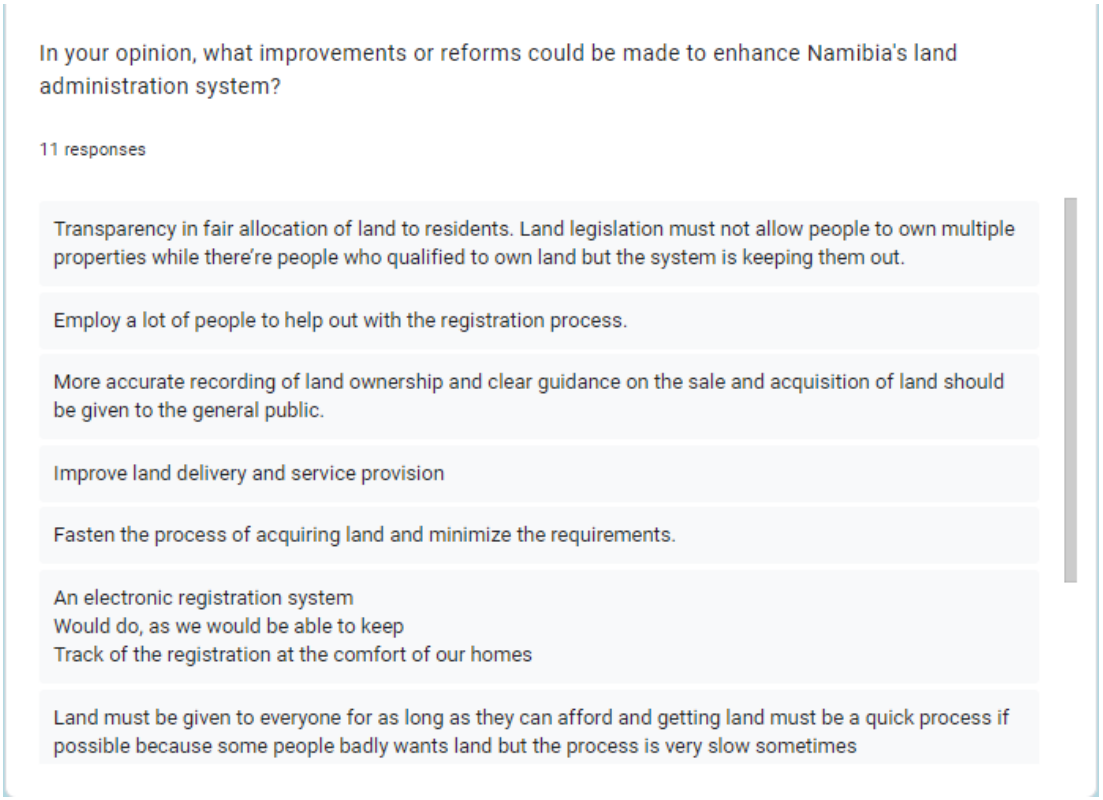


Figure 16 Participants suggestions for Namibia's LAS.

Regarding the developed registry, it has set itself apart by excelling in guaranteeing transparency in every land transaction. All changes to land title records are securely recorded in an immutable ledger, making attempts at manipulation or alteration virtually impossible. Furthermore, the implementation of smart contracts increased transaction transparency. These automated contracts not only enforced predefined rules, but they also reduced the need for intermediaries, ensuring the integrity of the entire land registry system.

5.4 Chapter Summary

This chapter begins by acknowledging Namibia's land administration challenges, which are similar to those faced by other developing countries, as discussed in the literature review.

The results of the online questionnaire are consistent with existing literature on land administration challenges, underlining the potential of a blockchain-based registry in addressing these issues. It then delves into the process of selecting a hybrid blockchain network tailored to Namibia's specific requirements. Following that, a review of the registry's efficiency, security, and accessibility is conducted. Additionally, the cost-effectiveness and sustainability of the blockchain-based land registry are assessed.

Furthermore, the registry's security measures and level of transparency in transactions are examined.

These findings and discussions, taken together, provide a comprehensive view of how the blockchain-based land titles registry effectively achieves its primary objective of developing a secure and transparent system to preserve land rights in Namibia.

The solution developed shows great promise for the long-term development of Namibia's land administration and continued research and implementation efforts are recommended to fully realise the potential of blockchain technology in this context.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

In this final chapter, the study summarises the key research findings and insights in relation to the research objectives and questions, as well as discusses their value and contribution.

The research limitations of this study are briefly reviewed, and recommendations for implementing a blockchain-based land registry, as well as potential future research areas, are presented.

6.1 Summary of Key Findings

The primary objective of this study was to develop a blockchain-based land title registry that would complement the existing system for managing title data, with a particular emphasis on addressing transparency issues in Namibian land ownership. The study found that a sizable proportion of Namibians were dissatisfied with the current land administration system. Their concerns stemmed from a number of challenges encountered during land registration, including a high frequency of land disputes and inconsistent or outdated land records, all of which are consistent with existing literature on land administration challenges in developing countries.

To address these issues, the study found that a hybrid blockchain network, which combines the strengths of both public and private blockchains, was the most effective solution for meeting the research project objectives. This approach provided a compelling balance of flexibility, transparency, and privacy benefits and the developed registry has the potential to significantly reduce processing times, eliminating the bureaucratic delays that currently exist.

Furthermore, the blockchain-based land registry designed in this study prioritised accessibility by offering user-friendly interfaces and cross-platform support, ensuring that all users could easily access it.

The economic benefits, such as reduced paperwork, are clear, and the system's modularity and flexibility accommodated changing technologies and regulations.

The cryptographic foundation of blockchain technology ensures the integrity of land title records, significantly reducing the risk of unauthorized access or altering.

Research participants also provided valuable insights into potential improvements for addressing existing challenges, particularly the current system’s lack of transparency and accountability.

The developed registry's immutable nature distinguishes it by ensuring transparency in all land transactions, which contributes to the resolution of these pressing issues.

6.2 Contributions to the field and implications

This study makes contributions to both blockchain technology and land administration through various avenues.

First, it conducted a thorough examination of the inherent challenges in traditional land administration systems.

Following that, the research provides a tangible demonstration of how blockchain technology can effectively address these challenges.

Furthermore, by developing and implementing a blockchain-based land title registry, the potential to improve transparency, security, and efficiency in land administration is effectively demonstrated.

These improvements have far-reaching consequences for land rights and hold great promise for stimulating the country's economic growth.

The study's implications go beyond academia, resonating across practical and policy domains in land administration.

6.3 Limitations

While the study sheds light on the potential of blockchain technology in land administration, it is crucial to recognise certain limitations.

First, the study used synthetic data to simulate real-world land transactions and scenarios, which, while providing a controlled environment for experimentation, may not fully capture the complexities of actual land administration systems.

Second, the focus was primarily on Windhoek residents, which may limit the findings' generalizability to other towns.

Furthermore, because blockchain technology evolves so quickly, implementation and analysis may not fully reflect the most recent developments or best practices in the field.

Despite these limitations, this study provides a proficient understanding of the subject and paves the way for future research and applications.

6.4 Future Research Directions

When considering future research directions, it is clear that integrating blockchain technology into land administration systems is a rapidly evolving field. There are several options for further investigation. First, it is critical to conduct an additional investigation on scalability of blockchain solutions, with a particular focus on critical infrastructure components like data storage, computing resources, and monitoring systems especially when applied to large-scale land registries. This will facilitate the detection of bottlenecks, monitoring of system performance, and well-informed decision-making, ultimately leading to enhanced scalability.

Secondly, the legal and regulatory frameworks required for widespread adoption must be scrutinised, as successful implementations have demonstrated the importance of good governance.

Furthermore, assessing the long-term viability of blockchain-based systems in areas with limited infrastructure or a lack of a progressive digital environment is critical. Exploring user adoption, acceptance, and the potential socioeconomic impacts of blockchain on land ownership and rights opens up exciting new research opportunities.

Finally, research into the interoperability of various blockchain platforms and their compatibility with existing land administration infrastructure holds promise for furthering the understanding of blockchain's transformative potential in land administration.

6.5 Conclusion

In conclusion, this research study has illuminated the inherent capabilities of blockchain technology to revolutionise land administration systems, specifically in terms of transparency and efficiency in Namibian land ownership.

The hybrid blockchain developed in this study represents a promising solution that balances flexibility, transparency and privacy, potentially minimising bureaucratic delays and improving accessibility for all users.

The cryptographic foundation protects data integrity and enhances transparency in land transactions, potentially influencing land rights and stimulating economic growth.

However, it is crucial to recognise the study's limitations, such as the use of synthetic data and the emphasis on individuals residing in Windhoek.

Nonetheless, this study sets the foundation for future investigations into scalability, legal frameworks, infrastructure challenges, user adoption, and interoperability, all of which can help to advance the understanding of blockchain's transformative potential in land administration.

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APPENDICES

APPENDIX A: ETHICAL CLEARANCE CERTIFICATE

UNAM
UNIVERSITY OF NAMIBIA

ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: SOS-0162 **Date: 23 AUGUST 2023**

This Ethical Clearance Certificate is issued by the University of Namibia Ethics Committee (REC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the ethics committee.

Title of Project: A BLOCKCHAIN-BASED LAND TITLES REGISTRY IN NAMIBIA

Student: JOHANNES PAAVO

Student Number: 201504444

Supervisor(s): Prof. RAFAEL PUENTE

Centre for Research Services

Take note of the following:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the ethics committee.
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee.
4. The ethics committee retains the right to:

i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,

ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.

Dr. Zivayi Chiguvare (Chairperson Ethics Committee)

Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

APPENDIX B: RESEARCH PERMISSION LETTER

CENTRE FOR RESEARCH SERVICES
Office of the Pro-Vice Chancellor: Research, Innovation & Development
University of Namibia, Private Bag 13301, Windhoek, Namibia
340 Mandume Ndemufayo Avenue, Pioneers Park, Office F223 - Fblock, Second Floor
☎ +264 61 206 4673; E-mail:kmbuku@unam.na; URL: http//www.unam.edu.na

UNAM
UNIVERSITY OF NAMIBIA

RESEARCH PERMISSION LETTER

Date: 10/10/2023

Student Name: JOHANNES PAAVO

Student Number: 201504444

Programme: MASTER OF SCIENCE INFORMATION TECHNOLOGY

Approved Research Title: A BLOCKCHAIN-BASED LAND TITLES REGISTRY IN NAMIBIA

TO WHOM IT MAY CONCERN:

I hereby confirm that the above-mentioned student is registered at the University of Namibia for the programme indicated. The proposed study met all the requirements as stipulated in the University guidelines and has been approved by the relevant committees.

The proposal adheres to ethical principles as per attached Ethical Clearance Certificate. Permission is hereby granted to carry out the research as described in the approved proposal.

Best Regards

Dr. AEE Shikongo
Head: Postgraduate Research Support Services
Tel: +264 61 206 3129
E-mail: aeshikongo@unam.na

CENTRE FOR RESEARCH SERVICES
Office of the Director
2023 -10- 10
University of Namibia
UNAM

APPENDIX C: BLOCKLAND INFORMED CONSENT FORM

Informed Consent Form for Survey Participants

This informed consent form is for residents in suburban areas of Windhoek who are invited to participate in this academic research titled "A Blockchain-Based Land Titles Registry in Namibia".

Title of Research Study: A Blockchain-Based Land Titles Registry in Namibia

Researcher: Mr. Johannes Pandeni Paavo

Affiliation: University of Namibia

Contact Information: j3paavo@gmail.com

Sponsor: None

Introduction

You are invited to participate in a research study aimed to develop a Blockchain-Based Land Titles Registry in Namibia. Before you decide whether to participate, you need to understand the purpose, procedures, risks, benefits, and confidentiality involved in this study. Please take the time to read the following information carefully and ask any questions you may have before making your decision.

Purpose of the Study

The study will develop a blockchain-based titles registry that aims to complement the current titles data management system in place, subsequently reducing the lengthy and excessive costs associated with land registration. It will moreover tackle the aspect of transparency in land ownership that is a leading factor in title administration transgressions in Namibia.

Procedures

If you agree to participate, you will be asked to complete an online questionnaire that will inquire about information on your experiences as a resident in a suburban area of Windhoek regarding Namibia's land administration system. The questionnaire will take approximately 20 minutes to complete, your responses will be kept confidential and will only be used for this research.

Risks

There are no known risks to participation and you are free to skip any question that you do not wish to answer.

Benefits

There will be no direct benefit to you, but your participation is likely to help us identify and understand issues that may exist in Namibia's land administration system, how they might align with existing literature, and subsequently contribute to scientific knowledge about concerns associated with land administration systems.

Confidentiality

Your participation in this survey is completely confidential and anonymous. Data will be stored securely and no personal information about participants will be disclosed in a way that could reveal their identity when reporting on the questionnaire's results.

Voluntary Participation

Participation in this study is completely voluntary and you are free to withdraw at any time without any negative consequences. Your decision regarding participation will also not affect your relationship with the researcher or the institution.

Questions and Contact

The University of Namibia's Ethics Review Committee, responsible for safeguarding the well-being of research participants, has thoroughly reviewed and granted approval for this research study. The committee reports to the University's Centre for Research & Services.

If you have any questions about this study before or after participation, please feel free to contact the researcher, Johannes Pandeni Paavo, at j3paavo@gmail.com or the Centre for Research & Services at kmbulu@unam.na.

CONSENT

By continuing with the survey and submitting your responses, you indicate that you have read and understood the information provided above. You voluntarily agree to participate in this study and consent to the use of your data for research purposes.

By providing your consent, you also acknowledge that you are at least 18 years of age.

Please tick in the box below on your participation decision in this study.

[ ] I have read the information provided above, and I voluntarily agree to participate in this study.

[ ] I do not wish to participate in this study.

……	……..	……
Name of Participant (day/month/year)	Signature of Participant	Date

APPENDIX D: BLOCKLAND SURVEY QUESTIONNAIRE

BLOCKLAND QUESTIONNAIRE

Dear participant,

1. Thank you for participating in this survey. My name is Johannes P Paavo student number 201504444 studying towards a Master of Science in Information Technology degree at the University of Namibia. The purpose of this questionnaire is to gather information on the experiences of residents in suburb areas of Windhoek regarding Namibia's land administration system.
2. I aim to identify and understand any issues that may exist in the system, and how they might align with existing literature. You have been selected as a participant in my study due to your specific group inclusion. I invite you to kindly complete this questionnaire as a valuable contributor to the research.

3. I have obtained approval for my research from the UNAM Research Ethics Committee and your participation in completing this questionnaire is highly appreciated. I would like to assure you of the following:

- Completing this questionnaire is optional, and you are under no obligation to do so.
- You are free to stop the questionnaire and participation at any time without any negative consequences.
- Your participation in this survey is completely confidential and anonymous. No personal information about participants will be disclosed in a way that could reveal their identity when reporting on the questionnaire's results.
- After completion, questionnaires and data will be securely stored in a designated location accessible only to authorized University officials, my supervisor, and myself. After five years, all information will be environmentally friendly destroyed.

4. If you have any inquiries regarding this questionnaire or if anything is unclear, please do not hesitate to ask. I would be more than glad to provide explanations and help you understand it better.
5. You are expected to spend approximately 15 minutes to complete the questionnaire.
6. Feel free to inquire further about the research I am conducting via my cell phone at +264 81 879 7347 or by sending an email to j3paavo@gmail.com.I would be delighted to provide you with additional information.
7. I sincerely appreciate your willingness to take part in this research. Thank you very much.

Section 2: Demographic Information

1. How long have you resided in Windhoek?

Mark only one oval.

- 1-3 years
- 4-6 years
- 7-10 years
- More than 10 years

Section 3: Land Ownership and Registration

2. Do you own land in Windhoek?

Mark only one oval.

- Yes
- No

3. If yes, how was the land acquired?

Mark only one oval.

- Inherited
- Purchased from the government
- Purchased from a private seller
- Other (please specify)

4. How satisfied are you with the timeliness of the land registration process?

Mark only one oval.

	1	2	3	4	5	
Very dissatisfied						Very

5. Have you encountered any challenges during the land registration process?

Mark only one oval.

- ◯ Yes
- ◯ No

6. If yes, please specify the challenges you faced:

_____

_____

_____

_____

_____

7. Did you seek assistance or legal advice to resolve these challenges?

Mark only one oval.

- ◯ Yes
- ◯ No

8. How would you rate the effectiveness of the assistance or legal advice you received?

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very ineffective

Section 4: Land Registry System Issues

9. Based on your experiences or knowledge, do you think Namibia's land administration system faces any of the following issues? (Check all that apply)

Check all that apply.

- [ ] Delays in processing land registration documents
- [ ] Disputes over land ownership
- [ ] Difficulty in verifying land ownership
- [ ] Lack of transparency in land transactions
- [ ] Inconsistent or outdated land records
- [ ] Other (please specify)

10. Please provide any additional information or examples related to the issues you mentioned.

Section 5: Conclusion

11. Do you believe that transparency is lacking in the land administration system of Namibia?

Mark only one oval.

- ◯ Yes
- ◯ No

12. In your opinion, what improvements or reforms could be made to enhance Namibia's land administration system?

Thank you for your valuable input! Your participation is greatly appreciated and will contribute to the understanding of Namibia's land registry system issues.

APPENDIX E: BLOCKLAND KEY GRAPHICAL USER INTERFACE

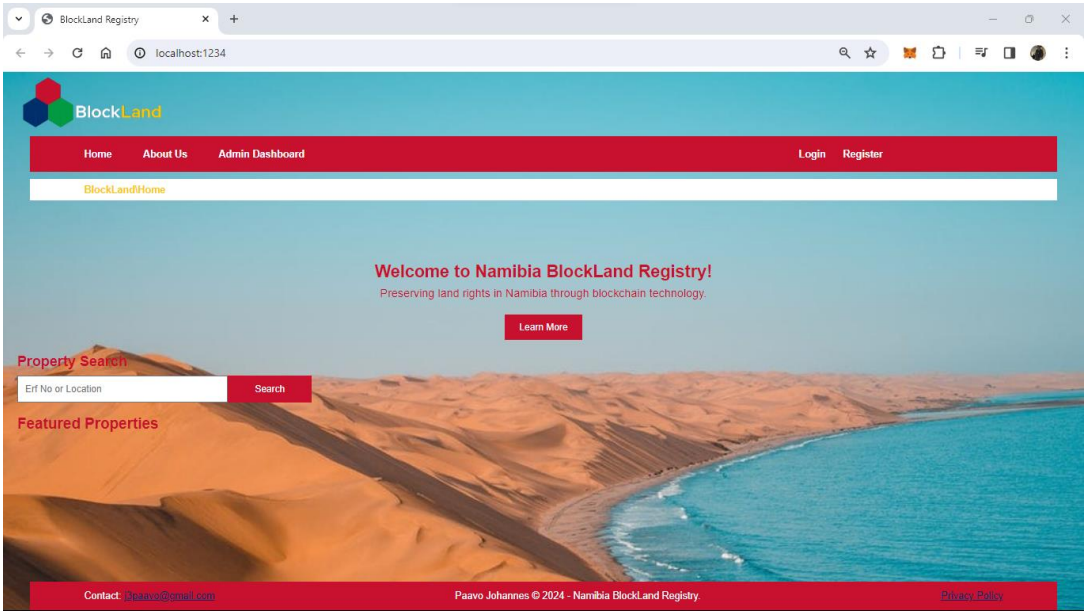

Figure 17 Homepage/landing page.

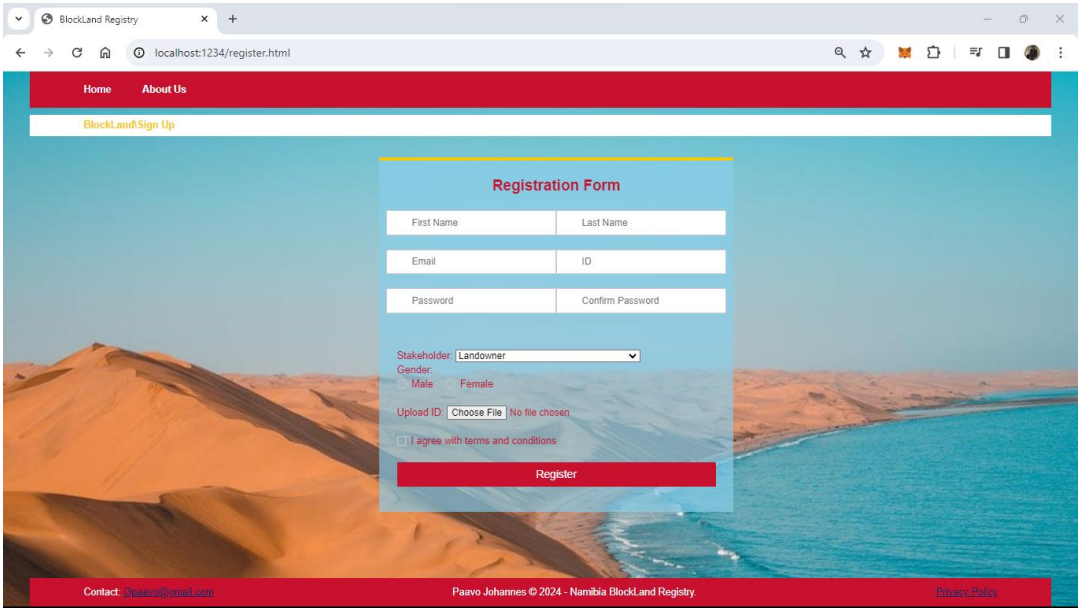

Figure 18 Users registration form.

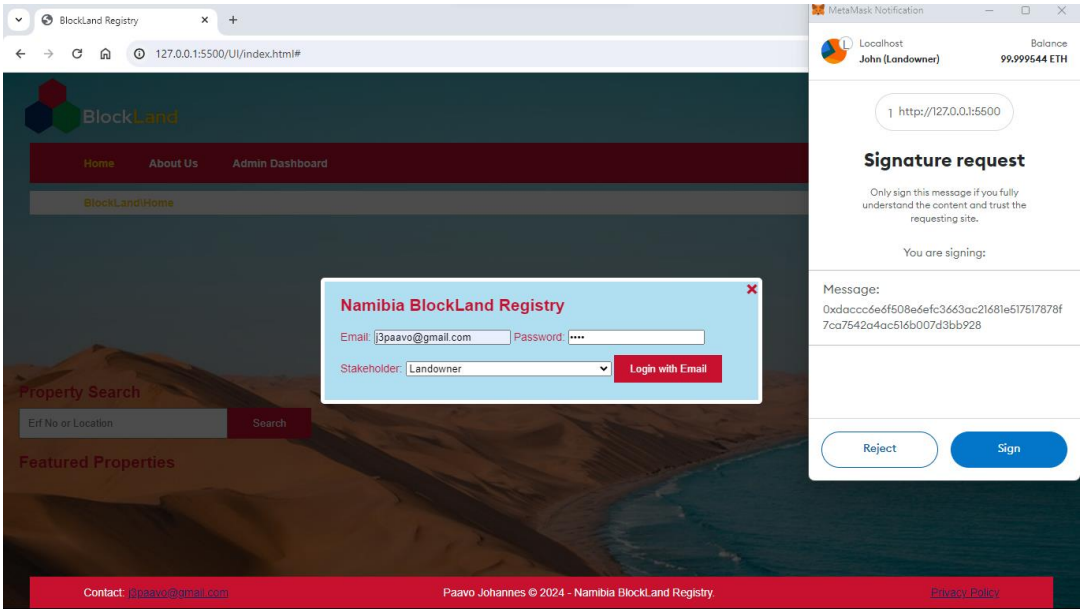

Figure 19 Login form with MetaMask authentication prompt.

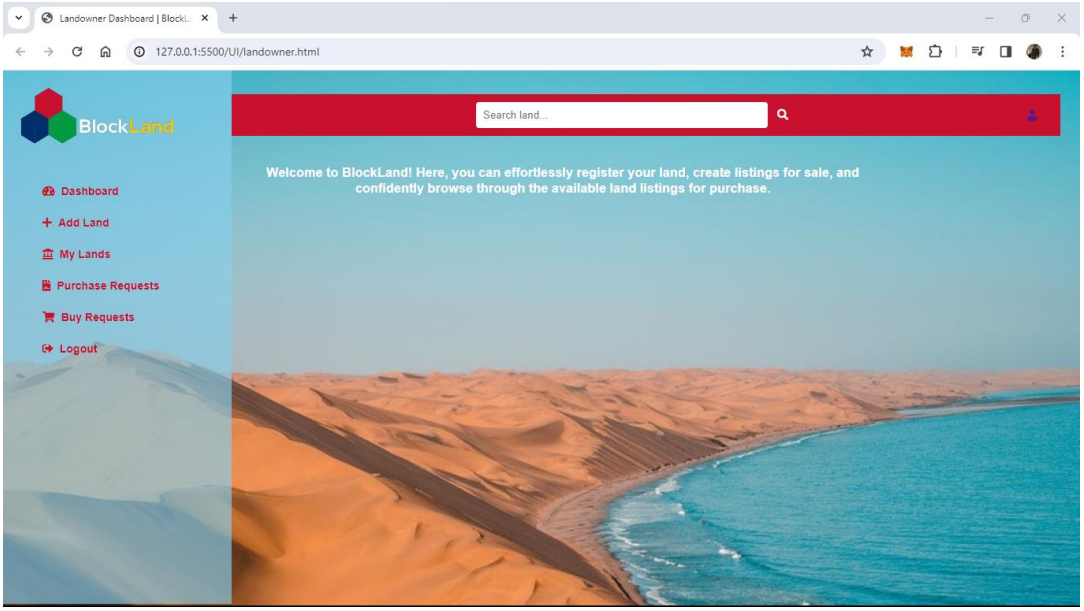

Figure 20 Authenticated landowners and purchasers' dashboard.