Master

# Implementation of a blockchain-based on land registration and control management system. Case of North Kivu province in DRC.


YASSIN NDAYE CHIKWANINE NTWALI

SUPERVISOR
Assistant Professor Christian Robero Simonsen
Associate Professor Ghislain Maurice Norbert Isabwe



**University of Agder, 2022**
Faculty of Engineering and Science
Department of Information and Communication Technology

## Obligatorisk gruppeerklæring

Den enkelte student er selv ansvarlig for å sette seg inn i hva som er lovlige hjelpemidler, retningslinjer for bruk av disse og regler om kildebruk. Erklæringen skal bevisstgjøre studentene på deres ansvar og hvilke konsekvenser fusk kan medføre. Manglende erklæring fritar ikke studentene fra sitt ansvar.

| | | |
|---|---|---|
| 1. | Vi erklærer herved at vår besvarelse er vårt eget arbeid, og at vi ikke har brukt andre kilder eller har mottatt annen hjelp enn det som er nevnt i besvarelsen. | Ja / Nei |
| 2. | **Vi erklærer videre at denne besvarelsen:**<br>• Ikke har vært brukt til annen eksamen ved annen avdeling/universitet/høgskole innenlands eller utenlands.<br>• Ikke refererer til andres arbeid uten at det er oppgitt.<br>• Ikke refererer til eget tidligere arbeid uten at det er oppgitt.<br>• Har alle referansene oppgitt i litteraturlisten.<br>• Ikke er en kopi, duplikat eller avskrift av andres arbeid eller besvarelse. | Ja / Nei |
| 3. | Vi er kjent med at brudd på ovennevnte er å betrakte som fusk og kan medføre annullering av eksamen og utestengelse fra universiteter og høgskoler i Norge, jf. Universitets- og høgskoleloven §§4-7 og 4-8 og Forskrift om eksamen §§ 31. | Ja / Nei |
| 4. | Vi er kjent med at alle innleverte oppgaver kan bli plagiatkontrollert. | Ja / Nei |
| 5. | Vi er kjent med at Universitetet i Agder vil behandle alle saker hvor det forligger mistanke om fusk etter høgskolens retningslinjer for behandling av saker om fusk. | Ja / Nei |
| 6. | Vi har satt oss inn i regler og retningslinjer i bruk av kilder og referanser på biblioteket sine nettsider. | Ja / Nei |
| 7. | Vi har i flertall blitt enige om at innsatsen innad i gruppen er merkbart forskjellig og ønsker dermed å vurderes individuelt. Ordinært vurderes alle deltakere i prosjektet samlet. | Ja / Nei |

## Publiseringsavtale

Fullmakt til elektronisk publisering av oppgaven Forfatter(ne) har opphavsrett til oppgaven. Det betyr blant annet enerett til å gjøre verket tilgjengelig for allmennheten (Åndsverkloven. §2).
Oppgaver som er unntatt offentlighet eller taushetsbelagt/konfidensiell vil ikke bli publisert.

| | |
|---|---|
| Vi gir herved Universitetet i Agder en vederlagsfri rett til å gjøre oppgaven tilgjengelig for elektronisk publisering: | Ja / Nei |
| Er oppgaven båndlagt (konfidensiell)? | Ja / Nei |
| Er oppgaven unntatt offentlighet? | Ja / Nei |

# Acknowledgements

Allah, Lord of the universe. Master of the day of retribution, the Almighty Creator and the Great Protector; director of all scientific works, thanks to Him. Thanks to Him, we have been confronted with this exercise, ultimately useful in society as well as in professional life and for which we are coming to the end.

We would like to express our deep gratitude to all the authorities of the University of Agder in general and those of the University of Rwanda, Department of Science and Engineering through its coordination, as well as to all the teaching staff for having contributed to our training despite your multiple occupations and duties that you exercise.

Our thanks go to the Associate Professors Christian Robero Simonsen and Ghislain Maurice Norbert Isabwe, respectively Senior Supervisor and Co-supervisor, who gave up their preoccupations to lend us a hand in finalizing our research, we thank them sincerely. To all our living biological family members and/or those who have already preceded us into the afterlife, we will always keep in our hearts what you have done for us, and our gratitude will never cease to manifest itself to all of you.

To all our colleagues in the Department of Science and Engineering, especially those in the Master of Software Engineering, may you find in these words our thanks and our attachment to a strong family that we have formed together by helping and supporting each other.

To our colleagues in the computer science department of the Institut Supérieur d'Informatique et Gestion ISIG-Goma, we say thank you for your encouragement. To all those whose names we have omitted, may they not think that we have forgotten them, but we still carry them in our hearts.

# Abstract

This project proposes the feasibility of a blockchain-based registration and control management system within the cadastral service in the province of North Kivu in the Democratic Republic of Congo. Given that blockchain has attracted considerable attention because of its ability to be decentralized, and immutable, a new and experimental technology applicable in all fields. It has helped us within this service to provide a solution for the problems that plague the management and control of the registration of land files, the sale and purchase of land, as well as the transfer after sales or purchases.

This research focused on how blockchain can be used to facilitate management to enable system users to be at the center of management by being the manager of their own land information. The solution proposed in this research supports all aspects related to the security, transparency, availability, access, sharing consent or validation of information that the user deems useful to validate.

# Contents

# List of Figures

# List of Tables

# Chapter 1

# Introduction

## 1.1 Background

The land registration process in a country is known to be a multi-stage process, as it involves the engagement of all stakeholders who will have a direct or indirect interest in the registration. The current land title storage system in use raises major issues regarding data fraud, security of highly sensitive data and the risk of system failure due to natural disasters, such as the failure of the server used to store the data (Razali & Mammi, 2021).

Compared to current approaches and procedures for land title management and data storage, blockchain is a state-of-the-art technology and database that could completely solve the problems that plague current systems. The fundamental and most important aspect of blockchain technology is that it is a decentralized network in which all data provided by a single node is confirmed by all other available nodes, and only once a consensus is reached can the shared data be recorded on the blockchain (Mangnani & Achhra, 2021). Various platforms are being used to create reliable, decentralized, transparent, immutable, and secure blockchain-based land registration and management systems. Smart contracts based on the Ethereum blockchain are gaining popularity among these systems. As it is a public blockchain platform, it allows anyone to participate in the blockchain ecosystem (Irfan et al., 2022).

Many attempts have been made to adapt land registries to this emerging blockchain technology to secure and store land data. In this regard, several developed countries around the world have taken the initiative and developed strategies to integrate blockchain into their projects. The Dubai Land Record Authority was one of the first government agencies to put its land titles on blockchain (government launches blockchain strategy 2021 — coin telegraph", n.d.).

However, in developing countries such as the Democratic Republic of Congo, access to land registry and data management is almost non-existent and has become a serious problem. Nationwide, land data is still typically stored and managed by a central person known as the " Property title custodian ", who records this crucial data on large paper registers.

In this regard, the proposal to build or make available an information system for the management and recording of the land registry process will simplify the complex process of storing and managing land registries. Although the digitization of documents and other related data has accelerated the process, security, resilience, and traceability remain important concerns. Due to a lack of infrastructure for the land registry system, land registries are particularly vulnerable to inconsistent, inaccurate, and altered data. Blockchain technology offers a decentralized, reliable, and secure environment.

The land management and title system process are used to store facts about land titles and execute transactions that are related to land titles. As these documents are sensitive, land management and title registration systems must be robust to prevent falsification, to always make these documents available and, most importantly, to perform these transactions in a timely manner (Pranteda & Santamaria, 2018).

Blockchain is no longer limited to simple principles; it has evolved into a hybrid of several replicas, including mathematics, networks, cryptography, and a distributed consensus algorithm (Lin & Liao, 2017). The blockchain was developed from the bitcoin paper published by Nakamoto in 2008. It is a peer-to-peer network where all participants (peers) serve as nodes and all nodes hold the same information (Gatteschi et al., 2018). The blockchain is a publicly dispersed ledger on top of a network that records associated transactions bordered by other network requester (Szabo, 2018). Instead of relying on a single authority such as administrators who can tamper with the database, blockchain technology provides a decentralized environment that also offers robustness and security. Untrustworthy administrators can abuse this power. A normal database suffers from the problem of single-point failure, and this forces them to rely heavily on backups if a failure occurs. Furthermore, due to this failure, if both, i.e., backups and an operating database, are abused, the situation is catastrophic (Suryanarayana et al., 2006).

The Land Management and Titles System process is used to store facts about land titles and to execute transactions that are related to land titles. As these documents are sensitive, the land management and title registration processes need to be robust to avoid falsification, to make these documents permanently available and most importantly, to carry out these processes in a very short period of time. The functionality of the blockchain is also considered a digital registry. Blockchain-based land registry systems use the same functionality as sound land registry systems. At the same time, the blockchain knows that these assets belong to that person and knows when a particular transaction took place.

## 1.2 Motivation

Based on the limitations of paper-based land registry data management systems in the Democratic Republic of Congo, we proposed the development of a blockchain-based solution that will be able to handle the problems of the existing land registry data storage system. The digitization of real-world land registers requires the construction of systems that are robust and able to withstand hacking attempts. These systems must be built on frameworks that can guarantee integrity and longevity.

No such frameworks exist for the implementation of a blockchain-based land registry system in North Kivu province in the Democratic Republic of Congo, which can be used for a real-world implementation of a decentralized land registry. The systematic contribution is to offer a meaningful and authenticated conceptual framework for blockchain-based land registration systems where transparency, security and rights can be ensured without the need for a trusted third party. If a centralized server for land registration data faces many problems, namely data loss due to any natural hazard and data loss due to a powerful adversary who can falsify all available data, then how will the management of land records on a paper be?

In this respect, the Democratic Republic of Congo is one of the most densely populated African countries, with a total area of 2,345,409 km2 and a population of 77,433,744 in 2016. Consequently, it is one of the most sparsely populated countries in Africa. This statistic means that there is enough land for all Congolese to use peacefully and according to their needs (Mugangu, 2009), (Mathijs & van der Haar Gemma, 2014).

However, the reality is that the land sector is a source of concern and difficulty for the country. Indeed, it is estimated that 80% of land disputes brought before courts and tribunals are directly or indirectly related to land and property. Take the example of the province of North Kivu in the Democratic Republic of Congo, where the Nyiragongo volcano erupted on 17 January 2002, causing three lava flows on the western, eastern and southern flanks, as well as a river of lava that reached the town in the evening, cutting it in two before flowing into Lake Kivu, and the eventual lava flow to the northeast of the town of Goma on 22 May 2021. Thousands of plots of land were turned into stone fields and other merged land as a result of this natural disaster, and their rightful owners have not been able to identify them because of the lack of a registration system.

Among all these concerns, the most important and pragmatic problem is that land registrars who process the data may also forge it, and many stakeholders who are the true owners of a piece of land may not be able to find their authentic rights. In this contribution, our main concerns are to make government officials aware of the potential of one of the most disruptive technologies, namely the blockchain, and at the same time to reflect the problems that current land handling systems face. Our motivation and goal is to provide a solution to the shortcomings of the centralized manual land management system by using the distributed and decentralized technology of the blockchain.

To do so, we will first propose a conceptual framework based on blockchain and then validate this framework with the blockchain-based proof-of-concept system. We first used blockchain to validate our framework, and then we will discuss and do some experiments on the idea of moving cadastral data to blockchain technology. In the research, we will contribute to the research community in the following ways:

- We observed the obvious flaws in the current land registry systems in the Democratic Republic of Congo in general and in North Kivu province and presented a study that gives a significant insight into the adoption of blockchain technology
- We discussed and disseminated the required information to the relevant stakeholders, i.e., the sellers or buyers of the plots (owners of the plots) when they register, sell, buy, or transfer.

- From now on, through this technology, the plot owners will be their own managers to avoid all the mischief associated with the current system.
- We have demonstrated the effectiveness of our study and the potential of one of the disruptive technologies, namely the blockchain
- Our study will prove to be the first drop in the bucket to bring transparency and security to sensitive land registry data and handling procedures.

## 1.3 Potential use of Blockchain Technology in Land management

As land management is a quasi general problem, we will limit our research to the management of land titles, especially with regard to registration, sale and/or purchase, transfer of ownership to individuals, securing all information as well as the transparency of each movement through the system.
The field of blockchain being vast and varied, we will just use some of its tools that can offer us the facility to integrate important benefits through our system such as:

- Enhanced security: given the sensitive nature of the data related to land management and land titles, blockchain now through this system, will dramatically change the way strategic information will be perceived; by creating an unalterable and end-to-end encrypted record. It will help prevent fraud and unauthorised activity. Privacy issues can also be addressed in the blockchain, by anonymising personal data and using permissions to prevent access. Information is stored on a network of computers rather than on a single server, making it difficult for hackers to access the data.

- More transparency: Through the blockchain technology built into our new system, all transactions and data will be recorded identically in multiple locations, thanks to the distributed ledger that blockchain uses. All network participants with access authorisation see the same information at the same time, creating complete transparency. All transactions are recorded in a non-editable manner and are time-stamped. This allows members to view the entire history of a transaction and virtually eliminates the possibility of fraud.

- Instant traceability: The blockchain creates an audit trail that documents the provenance of an asset at every stage of its journey. With blockchain, provenance data can be shared directly with customers

- Increased efficiency and speed: Traditional paper-based processes are time-consuming, prone to human error and often require third-party mediation, especially in our case with deeds. By streamlining these processes with blockchain, transactions will run faster and more efficiently. Documentation can be recorded in the blockchain along with the transaction details, eliminating the need for paper exchange. As there is no need to synchronise multiple ledgers, validation and processing can be much faster.

- Automation: Transactions will be automated using 'smart contracts', resulting in greater efficiency and speed of processing. Once pre-specified conditions are met, the next stage of the transaction or process is triggered automatically. Smart contracts reduce human intervention and avoid the need for third parties to verify that the provisions of the contract have been met.

In short, the use of blockchain in the land register is primarily valued for its potential to enable the "near-instant" transfer of property in a secure manner. With smart contracts allowing self-execution when certain conditions are met, transactions could be completed more quickly. For example, a rule could be put in place to facilitate the automatic transfer of title to the new owner when the new owner deposits funds in the appropriate account. It is also possible to eliminate the registration delay. The use of smart contracts would speed up the process by automatically updating the ledger, instead of buyers having to transfer the property through a form to be filled in or just a bill of sale as in our case.

## 1.4 Problem Statement

This research focuses on the current land management process in the DRC, information gathered through an open interview with the head of the land registry service and his collaborators by telephone. This management process clearly demonstrates the core of the problems that plague this process. This land management process begins with the registration of the inhabitants to obtain the title to the land. The registration service provides a form called an identification form (see annex: identification form) on which the inhabitant fills in the following information: name, surname, first name, place and date of birth, profession, nationality, identity card or passport number, marital status, marital status, name of the wife or husband, address of residence, and telephone number. The inhabitant must also present a document proving that the property belongs to him (according to this service, he must present either a deed of sale duly signed by the former owner who is the seller, the witnesses of this event as well as the signature of the buyer with the coordinates of all these participants, or another land title delivered by the land registry service) The service will proceed to the field to verify the address and the measurements of the parcel in order to reconcile the data of the inhabitant and the reality of the land before delivering the official document.
In order to apply for land at the land registry office, the resident must fill out a land application form (see appendix "Land Application"), providing the following information: name, surname, first name, place and date of birth, occupation, nationality, identity card or passport number, marital status, marital status, name of spouse, residence address, telephone number, plot of land held (he/she must specify where he/she lives if he/she is a tenant, owner or temporary occupant). On this form, the land registry service will be able to complete the rest of the information related to the requested parcel, including the complete address, cadastral number, surface area, technical opinion.
As described in these processes, they are entered manually in a register at the cadastral service.
The documents presented at the time of the request for land or at the time of identification come from practices such as, at the time of the sale of land between the inhabitants, the salesman who is the owner of the plot, informs the population that he has a plot of land to sell and the one who is interested, will be able to contact him to discuss the modalities of purchase of the plot. Once an agreement is reached between the two, they will call in a local authority and third parties to witness the signing of a sales contract.
The sale contract must have the terms of the sale agreement and the identities of the seller and the buyer, the address and dimensions of the land sold, the names of the various people acting as witnesses to the sale and the signatures of all. After sale, the seller is obliged to write a new document called the Deed of Sale to transfer the sold land to the new owner, and it is this document that the new owner will be able to show to the land registry service, if he wants to be identified or to ask for the land title for his parcel.
This does make the current land management process non-existent, as it is neither reliable nor transparent, nor even secure, as the same seller can make the same process of selling the same plot of land to several people or buyers, and this is the basis for land conflicts.

### 1.4.1 Hypothesis and Research questions

Based on the problem statement, this project will study an implementation of a blockchain-based land registration and control system through a cloud platform to provide the land registry service and the inhabitants with a secure, transparent and available system for land management issues.

1. Would the integration of blockchain technology into the land management system of the cadastral service of the province of North Kivu in the Democratic Republic of Congo be an effective solution to the current problems?

2. Will the proposed land management system increase security and transparency in the sale, purchase, or transfer of property?
3. How will the proposed system be designed to be effective, efficient, and satisfactory to the intended users in terms of accessing the information needed to sell/purchase land and/or property?

## 1.5 Study Scope

This study focuses on how blockchain can be used to facilitate transparency and availability in land management (land titles) using blockchain-based smart contracts deployed in a test network. Below are some elements that will not be the focus of our research

- the details of how blockchain works will not be explored in detail in our work.
- Performance in relation to the chosen algorithm will not be evaluated.
- This study will not cover the evaluation of performance characteristics related to the deployment of smart contracts with blockchain.
- No specific cryptography algorithm for encryption and decryption of data related to land management will be chosen.

## 1.6 Organization of the Study

This research will be based on a set of six chapters except for the summary, among which we have:

- Chap. I: which introduces our research with the statement of the subject, its why, the specific problems as well as the proposal of the feasibility.
- Chap. II: Theory, introduces blockchain and related which we will try to go through the different research works that are like the field we are talking about here and see what nuance they have in relation to our subject.
- Chap. III: Research methodology: here we will explain the methods we will use in the implementation of our project, because the best explanation and understanding of it, will lead us to a clear implementation plan.
- Chap. IV: Results and analysis: in this chapter we explain our proposed system models, proposed simulation parameters and finally the simulation scenarios.
- Chap. V: Discussion: this part will concern the explanations related to our obtained results and the presentation of the graphs of our results.
- Chap. VI: Conclusions and recommendation in connection with our project.

In this first chapter we have demonstrated the problems related to the management of land titles in North Kivu province, which allowed us to reformulate the questioning.
The realisation of the proposed system will only be possible by drawing on previous work in the same field of research as us, to provide us with an overview of what they have achieved in relation to what we are trying to do, and to enable us to complete our idea without repeating what has already been done.
This is only possible through our second chapter, which will help us to determine what has already been done in the various works in the same field of land management that we have examined.
To do this, we will rely on the third chapter, which will demonstrate the methods to be followed.

## 1.7 State of the Art

### 1.7.1 How can be used Blockchain in Land registration management

As already demonstrated in (point 1.2), the advantages of using blockchain technology in land management are compelling and beneficial. The following articles (Mohaghegh & Panikkar, 2020), (Aquib et al., 2020), (Goyal & Mittal, 2021), (Gururaj, 2020), further support the gain of land management through blockchain.

### 1.7.2 How can be used Smart Contracts?

In digital management and administration, new opportunities are arising in relation to data management of any kind, with cloud storage becoming a common and unavoidable procedure in all sectors. The land sector is not spared, so it is imperative to ensure that land owners (residents) have full control over their information by providing enabling means for sharing this data to trusted recipients in a secure, transparent mannerand available (Islam et al., 2020a), (Manocha, sep 3-4, 2021), (Majumdar et al., 2020).
Blockchain with its smart contract technology may be the solution to these challenges. The interest in smart contracts has been growing steadily since the integration of the use of Ethereum (Suganthe et al., 2021).
The following citations such as (Suganthe et al., 2021), (Goragandhi et al., 2021), (Gupta et al., 2019), demonstrate how smart contracts can enable land owners to have access to data, secure data exchanges and guarantee the confidentiality of these exchanges.
Several research papers and articles look at how smart contracts can be used in land management. They discuss various implementation methods based on different focal perspectives to create conceptual designs using blockchain-based smart contracts. Few of these designs have been tested in real-life scenarios, which has provided valuable data for further work and research.
Based on the functioning of a smart contract as mentioned in some articles, when selling, buying or transferring land, there are keys that are generated by the system for the sellers and buyers from the private key of the seller of the smart contract to make them legitimate. The first public key is the one provided by the creator of the contract. It is used to prove that the smart contract is activated by a private key because a smart contract can only be activated by a user or by another smart contract. The second key represents the contract itself and acts as a unique digital identifier for each smart contract. All this can only be applied under certain conditions. These conditions are listed in the computer program making up the smart contract. Each validated condition is stored in the blockchain irrevocably, which guarantees the security and veracity of the data. Once all conditions are validated, the contract can be executed automatically (Suganthe et al., 2021), (Goragandhi et al., 2021), (Gupta et al., 2019).
Note that the data is encrypted and then stored in the Blockchain, and only authorised trusted parties will have an access key to decrypt the data. Access permissions, data hashes and pointers to the data are stored in the blockchain. However, residents have full control over their data as they must approve any transfer or modification.

# Chapter 2

# Theory

Although this work does not really go into the depth of the detailed operation of blockchain technology in relation to these technologies, it is important for our outcome and discussion to understand the technology. this chapter presents the key theoretical requirements selected for the application of blockchain in land management. we will start from these three elements:

1. Blockchain Technology
2. Smart contracts in Land registration
3. Qualitative research

## 2.1 Blockchain Technology

A record keeping system is based upon blockchain, and it removes the vulnerabilities to the sensitive data. It is because of this reason that blockchain uses cryptographic primitives for the process of authentication. That is why blockchain can be used to reduce the trust on the third party by decreasing cost through the process of a programmed transaction recording system (Mizrahi, 2015).
Those applications that are being controlled and managed by the single or central user are called centralized applications. In centralized applications, all the parties reconcile their local databases with a centralized electronic ledger that is maintained and controlled by a trusted central party (in our case here with an excel or google doc file for land management). Moreover, record keeping has always been a centralized process that always requires trust in the record keepers. Blockchain technology, which has been widely used for the design of decentralized currencies, self-extracting digital contracts, and intelligent assets over the Internet, can serve as a replacement for centralized control over records (Natarajan et al., 2017). Centralized systems are numerous, and today's world is the world of social networking. Social networking platforms like Google and Facebook have created the revolutionary connection in humanitarian society. Also, with these platforms, it also made it great responsibility to manage user privacy and one's data that are very much vital for him. In these social networking systems, there lies a central server where all their data reside (Suryanarayana & Taylor, 2006).
The Figure 2.1 for depiction. A centralized system are systems that use client/server architecture where one or more client nodes are directly connected to a central server. This is the most used type of system in many organizations where a client sends a request to a company server and receives the response, i.e., the central controls and manages all the events and coordinates with the whole system (Chakraborty et al., 2020). In contrast, in a decentralized system A decentralized system is an interconnected information system where no single entity is the sole authority. In the context of computing and information technology, decentralized systems usually take the form of networked computers. For example, the Internet is a decentralized system, although it has become increasingly centralized over time,

every participant/entity is completely self-directed. In this autonomous system, each entity is referred to as a peer. In a more comprehensive way, we can say that instead of a centralized system, the use of a decentralized system is becoming mandatory, because everyone wants security, traceability, and resilience in their system. And these emerging technologies like blockchain can play their part to accomplish this much needed task (Mattila & Seppälä, 2018).

As the time has passed and new trends have been settled in the technology stack, blockchain has also got more and more attention. Now, it is being used in almost every organization of the government and supply chain and in many other numerous areas.

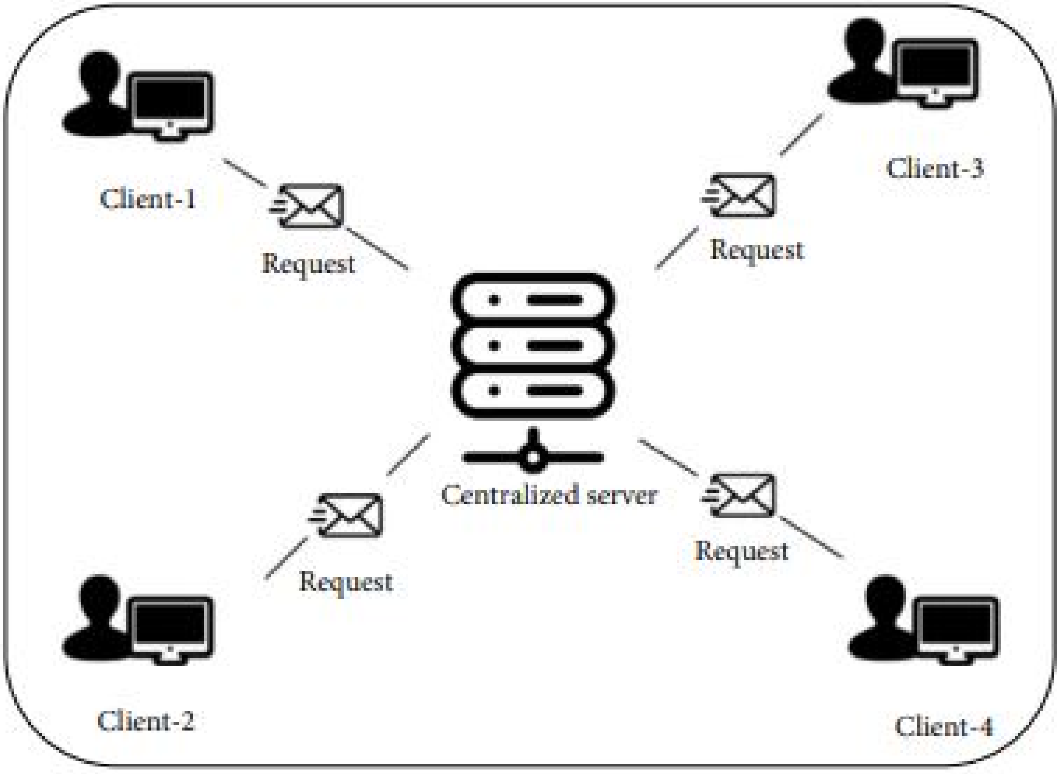



Figure 2.1: Centralized System by (Islam et al., 2020b)

Blockchain has smoothed the problematic, time-consuming processes that were at the risk of failure. In simple words, it has made human more powerful towards the implementation of transparency and accountability and in maintaining trust and security. In this decentralized system, there is no intermediary intervention, and the system can be evaluated for the required performance (Rosado et al., 2006).

Please see Figure 2.2 for the elaboration of decentralized systems. Every technology will have its own limitations and problems/issues. Though decentralized systems have given strong support to manage security, still these systems are facing problems. For instance, there is an increase in blockchain emerging decentralized technology usage, and the volume rise in the number of transactions occurs daily. Due to the variations in the size of each block, in the same way, the time to produce a novel block becomes a primary cause of the not reacting behavior of blockchain (Zheng et al., 2018). Another rising issue of decentralized systems is the leakage of transaction privacy; this happens because details of the public keys are visible to each participant that is available on the blockchain network (Meva, 2018).

Apart from the advantages of the technologies, there exist few or more cons too; on the one side, blockchain is improving the current state of almost every aspect of data storage and security. It also suffers from few prevailing and alarming problems. In the same way, decentralized systems, i.e., blockchain, are also facing the fork problem. The problem of

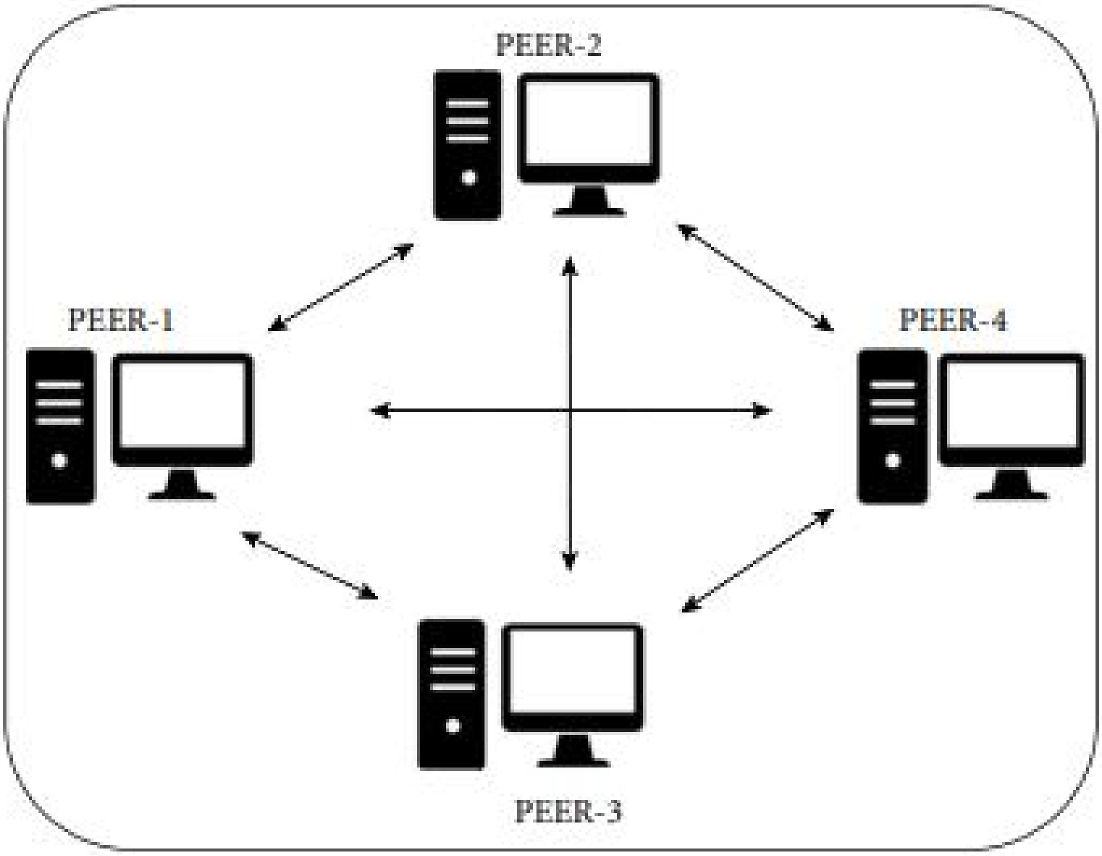



Figure 2.2: Decentralized System by (Islam et al., 2020b)

forks mainly occurs when blockchain is divided into two branches; it can happen due to the change in the consensus algorithm or when there happen some changes to the software.
These two problems are directly related to the blockchain's architecture. Normally when there is a change in the consensus algorithm, the soft fork takes place, as at this point the older nodes of the blockchain are unaware about the consensus rule changes. This soft fork can be harmful to the effectiveness and stability of the network. On the other hand, hard fork condition occurs, in decentralized systems when there is a permanent divergence in the blockchain, and this happens when the old nodes have not upgraded themselves to the newer version, and as a result, they cannot validate the transactions (Elmaghraby & Losavio, 2014).
In North Kivu, land record data are still being stored either on a centralized server (Excel file) or on paper-based huge registers that are being monitored by a single person who is known as custodian of property titles. Although the government has taken steps in digitization of land record, still many land data need to be saved onto a computer which is a centralized server in nature. This centralized server can become a single point of failure, i.e., due to attacks of hackers and due to environmental factors, and the person who is managing and overseeing the complete system can also forge the data (**swan**).
Now, when we talk about land or land titles, there comes a question in everyone's mind as these are the heaps of records that are very abundantly sensitive and vibrant at the same time. And how one can achieve this whole record? The answer to this question is to have land registries that are intended to manage and organize to store land record data in a normal and appropriate way.
The process of storing land record data onto a computer is called digitization. The process of digitizing land records was accepted with the intent to reduce flaws in the record keeping systems. In this, process all the records, i.e., sales, purchase, information about the land, and information about the current and former ownership stored in a centralized system. The system was expected to greatly lessen the number of land disputes, as fake documents would

be hard to come by and would not have little legal use (Benbunan-Fich & Castellanos, 2018).

### 2.1.1 Blockchain Architecture

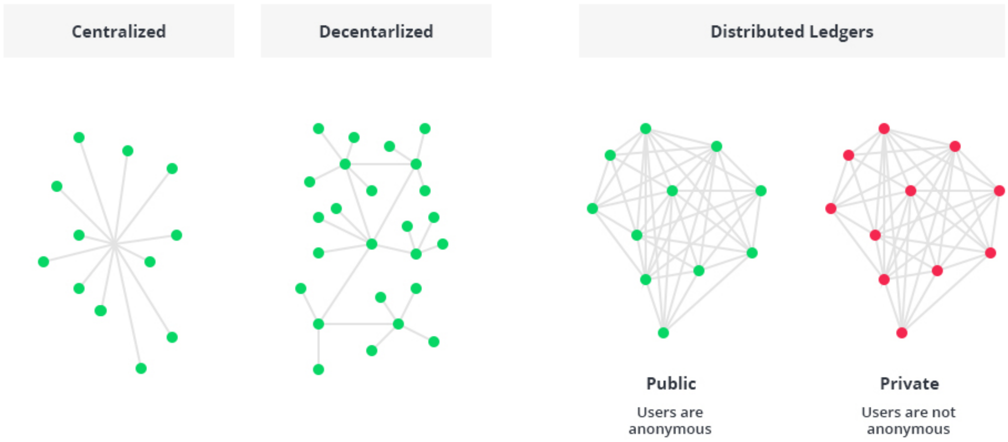



Figure 2.3: Blockchain Architecture by (Anastasiia Lastovetska – November 12, n.d.)

To continue, let's recall what blockchain technology is. Logically, a blockchain is a chain of blocks that contain specific information (database), but in a secure and authentic way, gathered in a network (peer-to-peer) (Sen & Wang, 2002). In other words, the blockchain is a combination of computers connected to each other instead of a central server, which means that the whole network is decentralised.

Starting with an easier example, the concept of blockchain can be compared to the work done with Google Docs (Zhou et al., 2012). You may remember the days of throwing out documents and waiting for other participants to make the necessary changes. Nowadays, with the help of Google Docs, it is possible to work on the same document simultaneously. Blockchain technology allows digital information to be distributed, rather than copied. This distributed ledger ensures transparency, trust and security of data.

The blockchain architecture is widely used in the financial sector. However, nowadays, the technology is used to create software development solutions for crypto-currencies and record keeping, digital notary and smart contracts...

The traditional architecture of the World Wide Web uses a client-server network. In this case, the server keeps all the required information in one place so that it can be easily updated, as the server is a centralised database controlled by a number of administrators with permissions.

In the case of the distributed network of the blockchain architecture, each participant in the network maintains, approves and updates new entries. The system is not only controlled by separate individuals, but by everyone in the blockchain network. Each member ensures that all records and procedures are in order, resulting in valid and secure data. Thus, parties who do not necessarily trust each other are able to reach a consensus (De Rossi et al., 2019).

To summarise, the blockchain is a decentralised and distributed (public or private) register of different types of transactions organised in a P2P network. This network is made up of many computers, but in such a way that the data cannot be changed without the consensus of the whole network (each separate computer).

The structure of blockchain technology is represented by a list of blocks containing transactions in a particular order. These lists can be stored as a flat file (txt. format) or as a simple database. The two essential data structures used in the blockchain are the following:

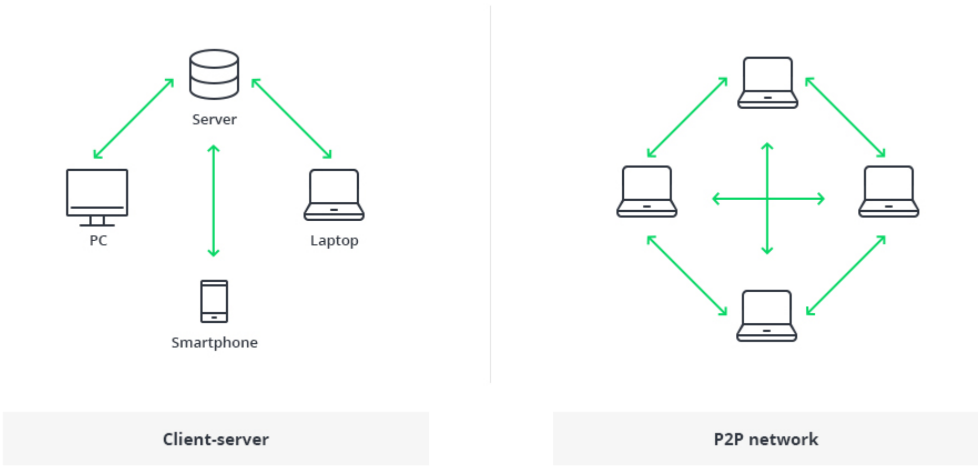



Figure 2.4: Database vs. Blockchain Architecture by (Anastasiia Lastovetska – November 12, n.d.)

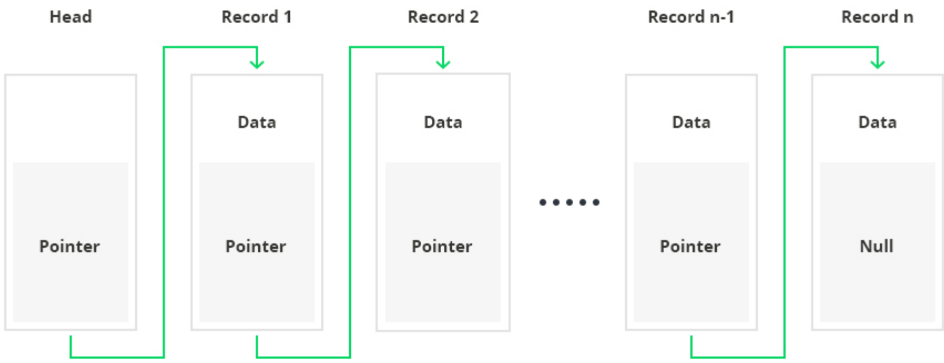



Figure 2.5: Structure of Blockchain Technology by (Anastasiia Lastovetska – November 12, n.d.)

- Pointers: variables that hold information about the location of another variable. More precisely, it is a pointer to the position of another variable.
- Linked lists: a sequence of blocks where each block contains specific data and is linked to the next block using a pointer.

Logically, the first block does not contain the pointer since it is the first in a chain. At the same time, there will potentially be a final block in the blockchain database that will have a pointer with no value. Basically, the following blockchain sequence diagram is a connected list of records:
There are different hashing algorithms and Blockchain uses the SHA-256 algorithm that generates a hash output length of 256-bit every time (Liang, 2020).
Figure 2.6 shows how blocks are chained together to form a blockchain. A block consists of the block header and the block body. The block body consists of transactions and, as mentioned earlier, the number of transactions depends on the size of the block and the size of each transaction. The block body consists of constants such as the timestamp, the hash of the previous block, the Merkle root and the variable of a nonce which is relevant for consensus algorithms such as proof of work. One of the most important parts included in

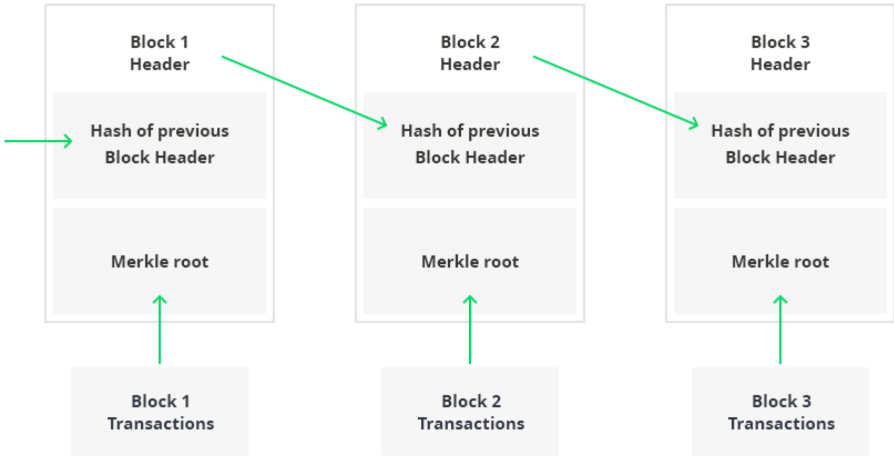



Figure 2.6: Structure of Blockchain Hashing by (Anastasiia Lastovetska – November 12, n.d.)

the block header is the hash of the previous block. For each block, a hash of the previous block header is included. The hash of the previous block links each valid block to the blocks that precede it. Therefore, by linking to the previous block, a chain of blocks is created and a Blockchain is established. The first block of a blockchain is called the genesis block and has no previous block hash (Zheng et al., 2017).
The Merkle tree is an important feature that ensures that transactions are not modified. Each transaction on the blockchain has a hash associated with it, and these hashes are structured as a tree that is linked together, forming a parent-child relationship. This results in the most important feature of the blockchain, namely its immutability. If changes are made to the block, the output of the hash will change, causing the chain to break. This is one of the reasons why blockchain is immutable. Immutability ensures that records cannot be retrieved or changed once they have been created. The only way to change anything after it has been stored in a blockchain is to create a new record to update the old one. Bitcoin is a public blockchain where anyone can participate in the mining process. Different miners can produce different valid blocks, but only one miner is allowed to add his valid block. This is why it is necessary to reach a consensus in a distributed network, which can be done in different ways (Goragandhi et al., 2021).

### 2.1.2 Types of Blockchain

Blockchain systems are classified into three broad categories (but there is a fourth which is a hybrid of private and public): public blockchain, private blockchain, hybrid blockchain and consortium blockchain (Sheth & Dattani, 2019).

- A public blockchain is a permissionless blockchain. Anyone can join the network without permission and take part in the consensus process and transactions, with the records being publicly visible. Therefore, these records cannot be altered, as many participants store the records. In addition, the system will face efficiency problems due to poor performance during transactions.

- A private Blockchain is an authorisation Blockchain and is entirely controlled by a single organisation. The Blockchain system is therefore in all respects considered a centralised network, most obviously in the consensus process in which the organisation regulates the network by accepting only those approved and/or affiliated with the organisation.

- Hybrid blockchain: a type of blockchain technology that combines elements of private

| | Public (permissionless) | Private (permissioned) | Hybrid | Consortium |
|---|---|---|---|---|
| ADVANTAGES | + Independence<br>+ Transparency<br>+ Trust | + Access control<br>+ Performance | + Access control<br>+ Performance<br>+ Scalability | + Access control<br>+ Scalability<br>+ Security |
| DISADVANTAGES | – Performance<br>– Scalability<br>– Security | – Trust<br>– Auditability | – Transparency<br>– Upgrading | – Transparency |
| USE CASES | Cryptocurrency<br>Document validation | Supply chain<br>Asset ownership | Medical records<br>Real estate | Banking<br>Research<br>Supply chain |

Figure 2.7: Blockchain category by (2021, n.d.)

and public blockchain. It allows organisations to set up a private, permission-based system alongside a public, permission-free system, allowing them to control who can access specific data stored in the blockchain, and which data will be open to the public. In general, transactions and records in a hybrid blockchain are not made public, but can be verified if necessary, for example by authorising access through a smart contract. Confidential information is kept inside the network but remains verifiable. Although a private entity can own the hybrid blockchain, it cannot modify the transactions. When a user joins a hybrid blockchain, they have full access to the network. The user's identity is protected from other users, unless he or she performs a transaction. In this case, his identity is revealed to the other party.

- The Consortium Blockchain is similar to an Authorisation Blockchain, but governed by several network organisations. It is therefore considered partially decentralised, as a group of pre-selected nodes is responsible for validating blocks in the network (Syed et al., 2019).

Private and consortium blockchains are more efficient than public blockchains in terms of transaction throughput, due to the reduced number of validators (Zheng et al., 2017). The first permissionless blockchain was Bitcoin and its main application is the transfer of digital currency between users. Ethereum is another permissionless blockchain (Syed et al., 2019).

### 2.1.3 Consensus Algorithms in Blockchain

The consensus process allows read from and update to the shared state that ensures ordering of transactions and further guarantees integrity of contents across geographically dispersed areas in a decentralized fashion. Different blockchains have employed various consensus models which include Prove-of-Work, Proof-of-Bayzantine-Fault-Tolerance (PBFT), Proof-of-Stake (PoS), and Proof of Elapsed Time (PoET). Generally, consensus protocols are selected based on three essential properties; namely, 1. Safety, 2. Liveness, and 3. Fault Tolerance. We provide a brief information about some consensus protocol in the following subsections (Ali Syed et al., 2019).

1. *Proof-of-Work* To add blocks to a blockchain, some proof of work must be communicated. Bitcoin uses PoW concept as consensus mechanism, which scales over 1000 of nodes. PoW requires the initiator to solve a puzzle, a mathematical or cryptographic operation by brute forcing and to produce a value (also called wining value), which is less than a defined one as set forth by the network. At times, more than one node produces winning value at the same time to add block and thereafter ask for reward. This situation creates a fork and is resolved by the network by analysing the maximum value of prove-of-work i.e., maximum work done by a node. The update request by

| | PoET | Proof-of-Work | BFT (Federated) | PoS | BFT (Variants) |
|---|---|---|---|---|---|
| **Permissioned (or permissionless)** | both | Permissionless | Permissionless | Both | Permissioned |
| **Transaction Finality** | Probabilistic | Probabilistic | immediate | Probabilistic | immediate |
| **Performance** | Medium | Low | High | High | High |
| **Trust** | Untrusted | Untrusted | semi trusted | Untrusted | semi trusted |
| **Cost of Participation** | No | Yes | No | Yes | No |
| **Scalability** | High | High | High | High | Low |
| **Security** | Unknown | <= 25% | <= 33% | Depends on algorithm | <= 33% |
| **Power Consumption** | Medium | High | Low | Medium | Medium |

Figure 2.8: Comparison of Blockchain Consensus Mechanisms (Ali Syed et al., 2019)

the node with minimum proof-of-work is discarded. This way the consistency of state among all nodes is ensured. PoW fits best for those networks that requires scalability. Mostly permissionless blockchains utilize PoW as they have authenticity of the participating node, as a result the network size becomes very large. It suffers from few drawbacks; it requires every node to invest huge amount in purchasing equipment used in the mining process. It is more vulnerable to attack because of its open nature. It supports very low transaction rate of only 7 per second, which is far less as compared to Visa or Master card, which offers 10000 transactions per second. In case of fork, the transaction confirmation takes too much time. Beside it requires significant energy expenditure, and high latency; however, to ensure safety of consensus process, the operation is quite acceptable. Other variants of consensus mechanism as adopted by Bitcoin includes DogeCoin, LiteCoin (Bradbury, 2013), Monero and NameCoin (Baliga, 2017), (Kalodner et al., 2015). To implement consensus, RAFT, Paxos, and BFT (Byzantine Fault Tolerance) algorithms are some of the solutions used in distributed systems.

2. *Proof-of-Stake (PoS)* Proof of Stake replaces the mining mechanism of the PoW model which consumes power in abundance. Instead of e.g. purchasing equipment's to generate wining values, PoS suggests to purchase cryptocurrency and use the same to buy chances of block creation in blockchain (Vasin, 2014)–(Poelstra et al., 2014),(Kiayias et al., 2017).

3. *Proof-of-Elapsed-Time (PoET)* As per PoET, the model randomly selects next leader to finalize the block and to select the leader the model broadcasts election among all the participants to ensure fairness. To guarantee that the election is carried out in a secure environment, Trusted Execution Environment (TEE) is utilized. A validating node claiming a leader to mine a block must produce proof from Trusted Execution Environment that other nodes can easily verify. Prove must be submitted that it had shortest-wait-time before it is allowed to start mining the next block. Since it relies on specialized hardware, it is the main drawback of utilizing this consensus mechanism (Chen et al., 2017), (Wang et al., 2019).

4. *Byzantine Fault Tolerance* A Byzantine fault is any fault presenting different symptoms to different observers (Driscoll et al., 2004). A Byzantine failure is the loss of a system

service due to a Byzantine fault in systems that require consensus (Driscoll et al., 2003). In distributed systems, Byzantine Fault Tolerance is the dependability of fault tolerant computer system, where a node has failed and there is improper information whether the node is failed. Other nodes need to reach a consensus whether to declare node as failed or to remove it from the network based on concerted action. Certain aircraft systems, like Boeing 777 Aircraft Information Management System, the Boeing 777 flight control system, and the Boeing 787 flight control system consider Byzantine fault tolerance in their design, as BFT works well in real time systems and where low latency is required (Zurawski, 2014), (**yes**). The Linux foundation developed Hyperledger fabric, a famous permissioned blockchain, which is based on pluggable consensus model. It is designed for a known and registered group of participants, with registered identities on a central registry service. The Hyperledger fabric support two consensus models naming Practical Byzantine Fault Tolerance (PBFT) and its variation SIEVE to deal with non-deterministic chain code execution. Chain code, a smart contract based blockchain, is supported by BFT.

5. *Practical Byzantine Fault Tolerance (PBFT):* Miguel Castro and Barbara Liskov proposed PBFT algorithm for solving consensus and to compensate the failure of Byzantine. PBFT uses the conception of replicated state machine and replicas for state changes. PBFT provides many other features including encryption of messaging among replicas and clients. To tolerate failures of 'n' nodes, the algorithm uses 3n +1 replicas although it places some overhead in terms of messaging and performance over replicated nodes. Literature provides scalability details of 20 replicas for PBFT.

6. *Sieve Consensus Model* The chaincode has a non-deterministic approach were upon execution of different replicas, the results may be different over a distributed network. To deal with non-determinism, SIEVE consensus model is designed, which speculatively executes all transactions and then results produced by various replicas are analysed. If the divergence between the output is small over small number of replicas, then the diverging values are served. If the observed divergence is across many processes, then the operation is served itself.

   A high-level comparison of various blockchain consensus mechanisms is provided in Table 1 based on specific characteristics of blockchain. These characteristics are confined to type of blockchain, performance in terms of transaction rate, the trust component, cost of participation i.e., cost to join the network or use specific services, scalability of the network i.e., addition of new nodes, security, and power consumption. The factors are not exhausted, rather these are representative enough to compare usage of various consensus mechanisms. In the next subsection, there are some recent variants of PoW consensus algorithms proposed. The author provided its analysis separately in following section.

7. *Flavors of PoW* A variant of PoW consensus algorithms are proposed recently. Those are discussed below briefly. Proof-of-Authority (PoA) is an energy-efficient and fast consensus mechanism mostly used in permissioned blockchains as being a bit centralized. It is used by Vechain, Ethereum, Kovan, Testnet. In PoA based networks, transactions and blocks are validated using validators that run the software for putting the transactions into blocks once the identity is verified on-chain. For upholding the transaction process, the validators are provided incentives as well.

### 2.1.4 Technical properties

- *Indivisible:* An NFT cannot be split into pieces, just as bitcoins can be split down to their smallest unit, the satoshi (=10ˆ8 btc). An NFT is a uniquely defined entity (on Ethereum: smart-contract address, token ID). Even if its property can be shared by consensus, the NFT will remain intact from the smart-contract's point of view. However, it is conceivable that this "shared property" can in turn be exchanged, as it in turn takes on the characteristics of an NFT.

- *Non-interoperable:* Each Nft is linked to a specific smart-contract, which contains the properties linked to the token, as well as the functions that can be executed on it. Indeed, an Aavegotchi character is not natively allowed in the CryptoKitties protocol for example, despite the fact that these logics are on Ethereum. Smart-contracts are developing rapidly, and more collaborations between teams and projects are emerging, allowing for richer interactions between different environments in the future.

- *Indestructible:* As the structure of the NFT and its information is stored in the smart-contract, this data is public and cannot be irretrievably deleted. Even if it is possible to "burn" an NFT by sending it to a random address such as 0x000..., this will simply disable the possibility that anyone can transfer or modify it. Indeed, the token and its data are always accessible on the smart-contract managing its identity.

- *Verifiable:* It is possible for anyone to trace any movement of an NFT from its origin, making it easy to verify the nature of the NFT you would like to purchase, alerting you to the possibility of acquiring a fraudulent one. Any attempt at replication or forgery will raise suspicions with the buyer. For example: if the famous NFT you want to buy was generated only 4 days ago.

The owner of an NFT is therefore the only one who can move it, he is, for example, the only one who owns the rights to this work of art although he is not the creator. Even the company that issued it may eventually lose all rights to modify it (ownest, n.d.), (Chohan, 2021)

### 2.1.5 Cryptography

Cryptography is the study of securing communications from outside observers. Encryption algorithms take the original message, or plaintext, and convert it into ciphertext, which is not understandable. The key allows the user to decrypt the message, thus ensuring that they can read it. The strength of the randomness of an encryption is also studied, which makes it more difficult for anyone to guess the key or the input of the algorithm. Cryptography allows us to establish more secure and robust connections to enhance our privacy. Advances in cryptography make it harder to break encryptions, so that encrypted files, folders or network connections are only accessible to authorised users.
Cryptography focuses on four different objectives:

1. *Confidentiality:* Confidentiality ensures that only the intended recipient can decrypt the message and read its contents.

2. *Non-repudiation:* Non-repudiation means that the sender of the message cannot go back in the future and deny the reasons for sending or creating the message.

3. *Integrity:* Integrity focuses on the ability to be certain that the information contained in the message cannot be altered during storage or transit.

4. *Authenticity:* Authenticity ensures that the sender and receiver can verify each other's identity and the destination of the message.

These objectives ensure a secure and authentic transfer of information.

#### Types of cryptography

Cryptography can be divided into three different types (Consulting, n.d.), (Kaspersky, n.d.)

#### secret key cryptography

Secret key cryptography, or symmetric cryptography, uses a single key to encrypt data. Both encryption and decryption in symmetric cryptography use the same key, making it the simplest form of cryptography. The cryptographic algorithm uses the key in an encryption to encrypt the data, and when the data needs to be accessed again, a person entrusted with the secret key can decrypt the data. Secret key cryptography can be used for data in transit and in standby, but it is generally only used for data in standby, as sending the secret to the recipient of the message can be compromised. As examples we have : AES, DES and Caesar Cipher.

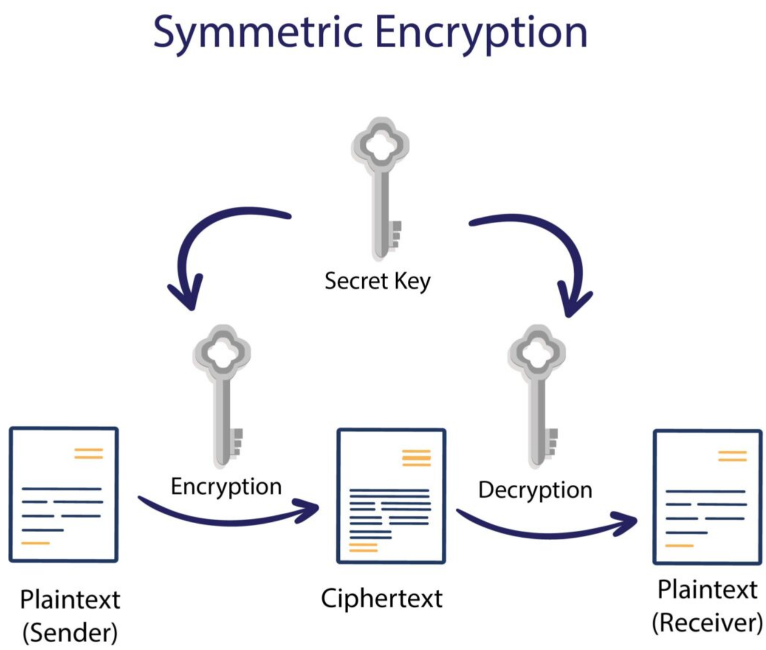



Figure 2.9: symmetric cryptography by (Kuznetsov et al., 2019)

#### Public key cryptography

Public key cryptography, or asymmetric cryptography, uses two keys to encrypt data. One is used for encryption, while the other can decrypt the message. Unlike symmetric cryptography, if one key is used for encryption, that same key cannot decrypt the message, the other key must be used.
One key remains private and is called the "private key", while the other is shared publicly and can be used by anyone, hence the name "public key". The mathematical relationship between the keys is such that the private key cannot be derived from the public key, but the public key can be derived from the private. The private key must not be distributed and must be kept only by its owner. The public key may be given to any other entity. For this category we have: ECC, Diffie-Hellman and DSS.

#### Hash functions

Hash functions are irreversible, one-way functions that protect the data, at the cost of not being able to recover the original message. Hashing is a means of transforming a given string into a fixed length string. A good hashing algorithm produces unique results for each given input. The only way to crack a hash is to try all possible entries, until you get exactly the same hash. A hash can be used for hashing data (like passwords) and in certificates. The most common hash algorithms (Kuznetsov et al., 2019) are MD5, SHA-1, SHA-2 Family

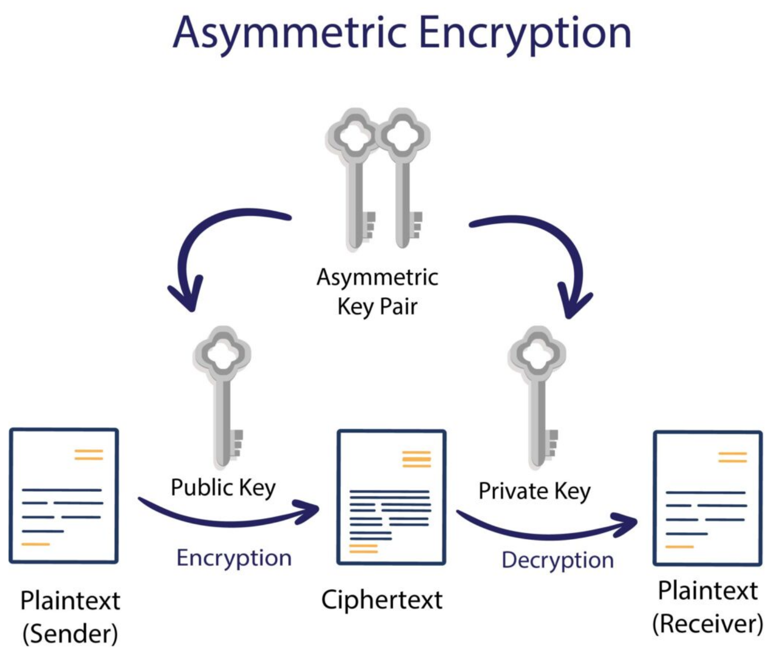



Figure 2.10: asymmetric cryptography by (Kuznetsov et al., 2019)

(which includes SHA-224, SHA-256, SHA-384 and SHA-512), SHA-3, Whirlpool, Blake 2 and Blake 3

## 2.2 Smart Contracts

*"A smart contract is a computer protocol intended to digitally facilitate, verify, or enforce the negotiation or performance of a contract. Smart contracts allow the performance of credible transactions without third parties. These transactions are trackable and irreversible"*(Aldweesh & v Moorsel, n.d.). It can be considered as a computer program that is running at the top of blockchain. Smart Contract contains a set of rules which can automatically start executing the program when specific set of rules agreed the event. Transparency can be maintained by the smart contract. The Smart Contract deals with businesses, finance, contract law and Information Technology (Pacific, n.d.-a), (Pacific, n.d.-b).
The Smart Contract Verifies the Agreement makes an agreement and transacts an agreement. Smart contract can help us to exchange money and property transparently while avoiding the services disputed by the arbitrators. A smart contract cannot be changed at any time, or no one can compromise the contract with its irreversible property. Contracts are distributed making it impossible for an attacker to force control because all other participants would be notified of the malicious attempt and would by consensus declare it invalid. As a result, the contract would be blocked by everyone in the network, like a transaction on the blockchain (Aruna, n.d.).
The rules of the transaction processes are commanded by the smart contract applications, it eliminates the issue of trust from these (Aruna, n.d.). It is not required by the users to know the transaction rules as they are dictated by the smart contract. Hence, malicious actions and misinterpretations are ruled out by the system since they are carried out automatically according to the defined protocol (Aruna, n.d.). By using smart contracts individuals and small companies can communicate without knowing each other and feel secure for their money because it is the contract that regulates the result. The smart contract in Ethereum network is written in solidity.

### 2.2.1 Ethereum and NFT

- *Ethereum* was proposed in late 2013 by Vitalik Buterin, a programmer and cryptocurrency researcher, as an open-source, public blockchain-based distributed computing platform and operating system featuring smart contract (scripting) functionality (Bragagnolo et al., 2017). Ethereum supports an advanced version of Nakamoto-consensus mechanism which works basically on "Memory Hardness" instead of fast processing power machines. With Bitcoin PoW large organization and substantial mining pools can influence the network. However, with ehtereum's reliance on fast memory data movements this problem is reduced. The Ethereum Virtual Machine (EVM) is provided by Ethereum which is a decentralized virtual machine for executing smart contract code on ethereum nodes. Ethereum network is permissionless i.e., any node can join ethereum network if user downloads ethereum client to create account. Moreover, it uses its own consensus model known as EthHash PoW. It is capable of executing scripts using an international network of public nodes. Gas is a transaction pricing-based mechanism to mitigate spam and allocate resources on the network. Minors on the network defines the price of the gas and if a transaction is less the defined gas it will be declined. The system went live on 30 July 2015, with 11.9 million coins "premined" for the crowdsale (Pérez Jiménez, 2018).

  As such, the blockchain contains an un-editable record of all the transactions made. However, blockchain functionality is not limited to cryptocurrency, rather it can also be adopted to any distributed business environment. For example, due to its transparency and auditability features Sierra Leone a west African country conducted world first E-voting system using blockchain technology. Bitcoin placed the building block for the new era of computing. However, Bitcoin does not fit in all scenarios as each, and every sector has its own requirements (Androulaki et al., 2018). To adopt blockchain technology in different sectors, general purpose blockchain models are required that should be mature enough to handle all the business logic and practices accurately. Due to this reason world renown IT, financial, and other organizations are taking interest in permissioned blockchain model. Each of them are developing their own solutions for different sectors. Some of the organizations include IBM, Intel corporation, and Wall Street.

- *NFTs* are tokens that we can use to represent ownership of unique objects. They allow us to turn things like art, collections, or even real estate into tokens. They can only have one official owner at a time and they are secured by the Ethereum blockchain, no one can change the ownership record or create a copy of an NFT.

  NFT stands for non-fungible token. Non-fungible is an economic term that describes things like your furniture, a music record or your computer. These things are not exchangeable for other items because they have unique properties.

  Fungible objects, on the other hand, can be traded because their value defines them rather than their unique properties (Chohan, 2021), (Gayte, n.d.).

  NFTs are different from ERC-20 tokens, such as DAI or LINK, each individual token is completely unique and not divisible. NFTs provide the ability to assign or claim ownership of any unique, traceable digital data using the Ethereum blockchain as a public ledger. An NFT is created from digital objects to digitally or non-digitally represent an asset.

### 2.2.2 Solidity:

Solidity is a high-level language, which is been influenced by languages like C++, Python and JavaScript. It is made from mixer of python, JavaScript, and C. The syntax is quite similar to the JavaScript programing language. Solidity is being statistically typed and supports many of the above language features. The contracts or agreements are said to be smart as the transaction will place as soon as the agreements or rules are agreed, due to which it is also known as self-executing contracts. The smart contracts remove the middleman as where physical contracts need it for authentication. It is a high level, contract-based programming language. It works on Ethereum virtual machine.

### 2.2.3 DApp

The word itself is not defined and it can mean different sets of things for different people. David A. Johnston defines that an APP will be considered DAPP if it completes the following criteria. The application needs to be essentially open source, it should be operated autonomously, and none of its units should control its most tokens. The application can customize its protocol in response to proposed improvements and market response, but all changes should be decided by its users unanimously. To avoid any central point of failure, records of application and operation of the application must be stored cryptographically in public, decentralized blockchain. The application should use cryptographic token which is essential for access to the application and the price should be contributed by the value in the token of the application.

### 2.2.4 Smart Contract Benefits

Most traditional digital agreements involve two parties who do not know each other, which introduces the risk that one of the participants will not fulfil its commitments. To address counterparty risk, digital agreements are often hosted and executed by larger, centralised institutions, such as a bank, which can enforce the terms of the contract. These digital contracts can be concluded directly between a user and a large company or involve a large company acting as a trusted intermediary between two users. While this dynamic allows for the existence of many contracts that would otherwise not take such a risk, it also creates a situation in which large, centralised institutions have an asymmetric influence on contracts. Smart contracts enhance digital agreements by offering several advantages.

- Security: Executing the contract on a decentralised blockchain infrastructure ensures that there is no central point of failure to attack, no centralised intermediary to corrupt and no mechanism that either party or a central administrator could use to alter the outcome.
- Reliability : The fact that the logic of the contract is redundantly processed and verified by a decentralised network of nodes provides strong guarantees of tamper-proofness, availability and accuracy that the contract will be executed on time and according to its terms.
- Fairness: The use of a decentralised network to host and enforce the terms of the agreement reduces the possibility of a for-profit intermediary using its privileged position to seek rent and siphon off value.
- Efficiency : Automating the back-end processes of the agreement-escrow, maintenance, execution and/or settlement-means that neither party has to wait for data to be entered manually, for the counterparty to fulfil its obligations or for an intermediary to process the transaction.

Smart contracts are simply programs stored on a blockchain that execute when predetermined conditions are met. They are typically used to automate the execution of an agreement so that all participants can be immediately certain of the outcome, without the intervention of an intermediary or loss of time. They can also automate a workflow, triggering the next action when conditions are met . A smart contract can be developed to send funds between two parties, obtain an agreement between two parties, or record and transfer data.
When a smart contract is deployed and executed in the Blockchain, it is added to a block of the Blockchain, and cannot be modified or deleted due to the security and immutability that the Blockchain offers. Most smart contracts are written in a suitable programming language, such as Solidity, which is the most popular programming language for smart contracts as it is supported by Ethereum developers (Pacific, n.d.-a), (ConsenSys, n.d.).
Before a smart contract can be deployed and executed on a Blockchain, a payment fee for transactions is required in order for the smart contract to be added to the Blockchain. The smart contract will then, in the case of the Ethereum Blockchain, be executed on the Ethereum platform (Delmolino et al., 2016), (Pacific, n.d.-a). When smart contracts become complex, the gas costs for deploying and executing smart contracts are higher. Therefore, gas charges also prevent smart contracts from over-consuming resources on the Ethereum platform (Delmolino et al., 2016), (CryptoCompare, n.d.).

## 2.3 Qualitative Research

*"The goal of qualitative research is the development of concepts which help us to understand social phenomena in natural (rather than experimental) settings, giving due emphasis to the meanings, experiences, and views of all the participants"* (Mays & Pope, 2020). Although there is no standard definition of qualitative research, most authors agree on its main characteristics. Creswell puts it this way: "Writers agree that qualitative research is undertaken in a natural setting where the researcher is an instrument of data collection that gathers words or images, analyses them inductively, focuses on the meaning of participants, and describes a process that is expressive and compelling in language" (Williams et al., 2007). Doing qualitative research is a way of looking at social reality. Rather than looking for the right answers, qualitative research is also concerned with asking the right questions. Qualitative data collection takes many forms, but interviews and observation are among the most used, regardless of the researcher's theoretical tradition.

- Firstly, qualitative research encompasses all forms of field research of a non-numerical nature, such as words and stories. There are different sources of qualitative data, such as observations, document analysis, interviews, images, or videos, etc. Each of these techniques of data collection is used to collect information on the subject. Each of these data collection techniques has its strengths and weaknesses, which should be considered when choosing a particular qualitative research technique.

- Secondly, the purpose of qualitative research is to provide a 'rough description' and a grounded, in-depth understanding of the subject of the investigation. The advantages of well-conducted qualitative data collection lie precisely in the richness of the data collected and the deeper understanding of the problem under investigation. They aim not only to describe, but also to help obtain more meaningful explanations of a phenomenon. Qualitative research is also useful for generating hypotheses (Sofaer, 1999). The types of research questions usually informed by qualitative research are "What is going on? What are the dimensions of the concept? What variations might exist? Why is this happening" (Huston & Rowan, 1998). Qualitative research techniques are primarily used to trace "the meanings that people give to social phenomena" and "interaction processes", including the interpretation of these interactions (Mays & Pope, 2020). "They allow people to express themselves in their own voice, rather than conforming to categories and conditions imposed on them by others" (Sofaer, 1999).

- Thirdly, one of the strengths of qualitative research is that it studies people in their natural environment rather than in artificial or experimental situations. Since health-related experiences and beliefs are closely related to everyday situations, it is less relevant to study them in an artificial or experimental context. Therefore, data are collected by interacting with individuals in their own language and observing them on their own turf (Kirk et al., 1986) or at a location of their choice. Therefore, some qualitative research methods are sometimes referred to as 'naturalistic' (Mays & Pope, 2020). It should be noted, however, that this characteristic is not always relevant to the use of QRM (Qualitative Research Method). For example, interviews or focus groups are not usually conducted in the natural setting of the participants, but rather in a meeting room.

- A fourth characteristic of qualitative research is the frequent use of several different qualitative methods to answer a single research question (Mays & Pope, 2020). This is partly due to what is known as triangulation, the process of comparing results from several data sources (Mays & Pope, 2020); (Bloor & Wood, 2006).

- Finally, qualitative research is always iterative: it must be reviewed on the basis of assumptions, hypotheses or general theories that change and develop throughout the successive stages of the research process.

### 2.3.1 The main techniques for collecting qualitative data

The main qualitative data collection techniques useful for conducting research are individual interviews, focus groups and observation.

- The semi-structured individual interview aims to collect data by interviewing participants face-to-face (or at a distance) using conversational techniques. The interview is then structured with the help of an interview guide containing a list of open-ended questions or a list of topics to be addressed during the discussion. The use of such a process in the research context is justified when the objective is to identify views, beliefs, attitudes, experience, etc. Similarly, the individual character is appropriate when no interaction between respondents is necessary or desired, such as when the subject of study is sensitive. This technique can also be chosen for practical reasons, for example when participants are not easily "movable» or lack time.

- The focus group is a form of semi-structured interview. It consists of a series of discussions within different groups of participants and facilitated by a researcher. The aim of focus group data collection is to provide data (via intra-group interaction) on the beliefs and norms of the group regarding a particular topic or set of issues (Bloor & Wood, 2006). This technique is useful when interactivity and brainstorming between participants needs to be enhanced to gain knowledge and generate ideas for further study (**bow**). A focus group is not the same as a "group interview": in focus groups, participants are recruited specifically for the research, using a certain method. It is a group interview in the sense that it collects data collectively (Quick & Hall, 2015). However, they differ from a group interview in that there is an emphasis on interaction between participants, through which participants can modify their views. In a group interview, the interaction between participants is limited, and occurs mainly between the interviewer and the interviewees. Ideally, focus groups should be internally homogeneous on criteria relevant to the research question, but heterogeneous between groups. Homogeneity within the group aims to capitalize on the participants' common experiences (Kitzinger, 2006).

- Observation, on the other hand, is useful for understanding more than what people say about (complex) situations. More than just looking around, it is about actively recording information along several dimensions, such as places, people (actors) and activities (Spradley, 1980). Observing means paying attention to (1) the detail of the observation, (2) visual as well as auditory information, (3) the temporal dimension, (4) the interaction between people, and (5) making connections with mental categories. The collection tools are checklists and field notes.

### 2.3.2 Interviews

#### Definition

According to the Larousse dictionary, an interview is a conversation between two or more people on different subjects. The people can be friends, family members or others. In the scientific sense, the interview is a method of research and investigation. Through this method, the interviewer seeks to obtain information about the attitudes, behaviours and representations of one or more individuals in society. Quivy and L. Van Campenhoudt point out that this method allows 'the analysis of the meaning that the actors give to their practices and to the events they are confronted with their value systems, their normative reference points, their interpretations of conflictual or non-conflictual situations, their readings of their own experiences' (CAMPRENHOUDT & QUIVY, 2011). The interview questions are prepared before the interview takes place. Indeed, before going into the field, the researcher develops a series of questions that will serve as a guide throughout the interview. Preparing the interview also involves selecting the people to be interviewed. The researcher will only interview people who are likely to have information about the research. In this regard, A. Anger indicates that *"the researcher interviews such and such a person because this person has such and such a characteristic, because he or she belongs to such and such a social stratum, because he or she has had such and such an experience"* (Angers, 1997).

**Types of interviews:**

There are three types of interviews. In general, it is the research topic that determines the type of interview the researcher can use.

1. *Non-directive interview:* In this type of interview, the respondent announces the theme of the interview without asking direct questions. The interviewer gives the respondent the freedom to organize his/her speech as he/she wishes. The interviewer's role in this case is not to encourage the informant to speak. On the contrary, he/she should adopt a neutral position. And he/she should appear as a person who is able to listen and accept what the informants say. The interviewer can intervene, but only to show agreement through words like (yes, I see, I agree, then). The advantage of this type of interview is that it is accessible to many people because it does not require any particular skills. However, it has the disadvantage that it does not delimit the precise subject on which the informant will speak. As a result, the informant addresses the subject of the survey in a general way (Baudry et al., 2010).

2. *The directive interview:* this type of interview is similar to the questionnaire method. Indeed, before going into the field, the researcher establishes a series of precise questions that he or she will ask the interviewees. To compare the data scientifically, the researcher will ask the same questions to all the interviewees. This type of interview is certainly reassuring for the researcher. The researcher arrives with a series of pre-established questions. However, it leaves the respondent little room for maneuver. Because of the limits set by the interviewer, the respondent does not have much freedom to express himself (Baudry et al., 2010).

3. *Semi-structured interview:* This third type of interview lies between the directive and non-directive interviews. It is characterized by the fact that it gives the interviewer a large space to express his or her point of view. The interviewer asks questions and leaves the respondent free to answer. The role of the interviewer in this type of interview is to encourage the informant to talk and give more information about the research topic. The questions asked in this type of interview are relatively open-ended. The interviewer must refocus them so as not to lose sight of the objective he or she has set (Baudry et al., 2010).

**The questionnaire**

1. Definition of the questionnaire: The questionnaire is a method of collecting information to explain and understand facts. Unlike interviews and observation, which are individual or collective methods, the questionnaire is a collective method only. Indeed, it is the quantity of elements collected that gives the questionnaire its validity and allows the data to be judged authentic. According to the proponents of this approach, developing a questionnaire avoids the trap of subjectivity. The questionnaire method is based on a purely rational mathematical approach (Vilatte, 2007).

2. Types of questionnaires:

(a) The open questionnaire: in this type of questionnaire, the order of the questions and their formulation are fixed. However, the participant can express himself if he wishes. The respondent has the possibility to ask again ((Combessie, 2010)).

(b) The closed questionnaire: In the closed questionnaire, the questions, and the list of proposals to be submitted to the participant are fixed in advance. This is to enable the speaker to make the best possible choice ((Combessie, 2010)).

### 2.3.3 Analysis of qualitative data

As in any research process, analysis of the collected data is a necessary step in drawing conclusions. Analysis of qualitative data is neither a simple nor a quick task. Done correctly, it is systematic and rigorous, and therefore requires a lot of work and time: *"[...] good qualitative analysis is able to document its claim to reflect some of the truth of a phenomenon by reference to systematically gathered data"* ((Fielding, 1993)); in contrast "poor qualitative analysis is anecdotal, unreflective, descriptive without being focused on a coherent line of inquiry" ((Fielding, 1993); (Pope et al., 2000)). Qualitative analysis deconstructs the data, to construct an analysis or theory (Mortelmans, 2009). The means and techniques for analyzing qualitative data are not easy to describe. The difficulty of qualitative analysis lies in the lack of standardization and the absence of a clear universal set of procedures that fit each type of data and could be applied almost automatically. In addition, several approaches to analysis can be followed: for example, thematic analysis, general inductive approach, grounded theory, or framework analysis. Elements from different approaches can also be combined in a single analysis (Pope and Mays, 2006). The approach chosen depends largely on the design and objectives of the research. Some research designs and/or questions require an inductive approach, whereby themes emerge from the data, others a deductive approach, involving the application of a pre-existing theory or framework that is applied to the data.

# Chapter 3

# Methodology

## 3.1 Introduction

The objective of this chapter is to apply the theories demonstrated in the previous chapter on blockchain, the smart contract and qualitative research, how they will be applied through which methods to allow us to propose the effective solution to the problems raised by our first chapter at the problematic level.

## 3.2 Blockchain and Land management

### 3.2.1 Importance of blockchain

We chose to apply blockchain technology in land management in our research because, blockchain will help the proposed new system to work smarter and innovate faster. The secure sharing of data between citizens and agencies can increase trust, while providing an unalterable audit trail for regulatory compliance, contract management, identity management and citizen services. It uses a shared, undatable ledger with access restricted to members with the required permissions, which is not the case with the current land management system in North Kivu province in the Democratic Republic of Congo.

With the use of blockchain in this management, now all users of the proposed system will control what information each organization or user of the blockchain network can see, and what actions they can take.

Blockchain is built on trust; this trust is based on the enhanced security of the blockchain, its increased transparency and its instant traceability. Beyond trust issues, blockchain offers even more business benefits, including the cost savings resulting from its speed, efficiency, and optimal automation. By dramatically reducing paperwork and errors, blockchain significantly reduces overhead and transactional costs, and reduces or eliminates the need for third-party or intermediary verification of transactions.

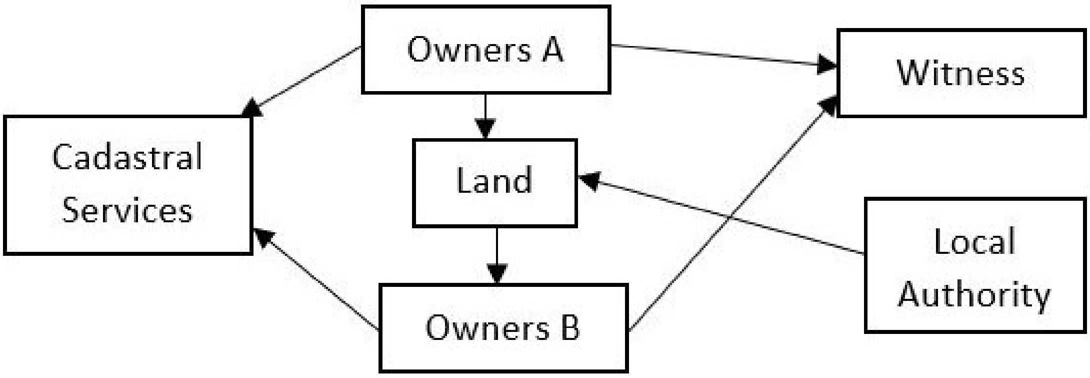



Figure 3.1: Current Land System

The current system we seek to replace despite its existence is not one, because not only is it managed through paper or a single file (Excel or google doc) as demonstrated in our introduction to this research, but its management depends on the will of an individual who manipulates and modifies it at will.
Figure 3.1 represents the functioning of the current land management system through these processes.

- For an owner to sell or buy a plot of land, he informs the public of the sale, the interested party contacts him for the sale discussions. If they agree among themselves, they call witnesses from both parties and the local authority on the day of the sale to witness the sale or purchase. This process culminates in a deed of sale document that the landowner will write and hand over to the buyer after everyone, including the witnesses, have signed. This document will be accompanied by another called the deed of sale to transfer the property to the new owner. If the new owner wants, he will go to the state department to declare his new property to start the land titling process which comes after years.

  This process takes time, nothing is secure or reliable at this level, no transparency, we can just believe in an arrangement and that triggers long lasting conflicts within the society because the empowered service is not even able to provide the land registration history, it is impossible to know who owns the land.

  Unlike blockchain, everyone is responsible for this information and shares it on the network where no one can change it. With blockchain, the information is managed locally on its own device.

- Regarding the purchase or sale of land between owners, we cannot refer to the Figure 3.1, but for the Figure 3.2, blockchain is the appropriate solution for the management of these operations in the sense that it makes available several techniques that can take care not only of the sale or purchase, but also of putting all the information of each person in a single non-modifiable ledger available to everyone for transparency and veracity, with a high degree of security due to the lack of access for anyone who is not part of the network.

- On the side of the transfer of property after the sale or purchase, blockchain again provides us with a technique that helps us to take care of this change.

### 3.2.2 Benefits of blockchain

The applicability of blockchain in this proposed new system is mandatory because the land registries that form the foundation of our system imperatively requires the presence of

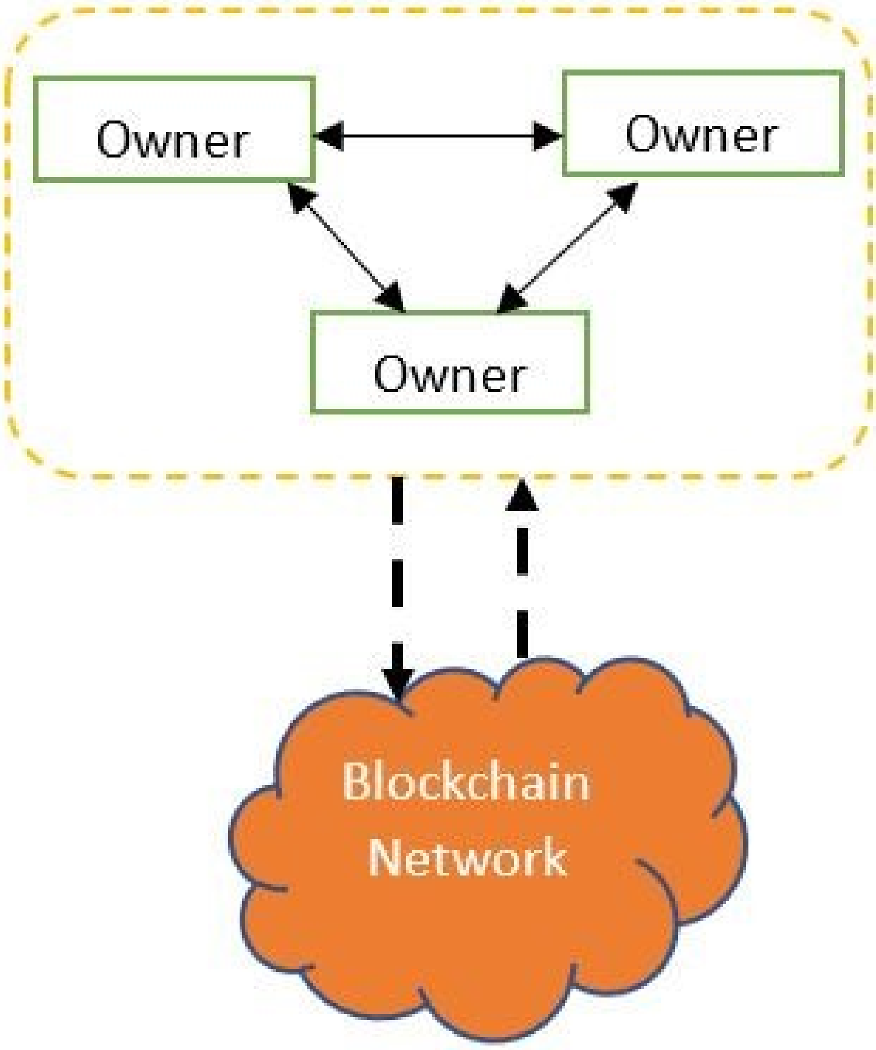



Figure 3.2: Proposed Land System

blockchain technology, as it has the capacity to revolutionize land transfers and can manage regulatory obligations, asset transfers and even financial transactions.
Blockchain is seen as the future of land registries because of the significant benefits it offers and includes, from the operations it enables such as validation transactions, collection of transactions for a block, dissemination of ballot transactions within the block and consensus on the creation of the next block, and finally, the chaining of blocks to form an immutable record.
Through these operations covered by the blockchain, our new system will benefit from the following elements, among others

- increases transparency
- provides reliable and accurate property data
- secures ownership of all registered properties
- reduces costs
- speeds up processes
- can now be completed in hours instead of weeks/months or years
- provides strong audibility for time-stamped transactions

- provides a distributed system to aid disaster recovery
- reduces paperwork,
- allows people to exchange properties remotely
- benefits many participants

At a time when the blockchain is emerging, it can appear as an opportunity to restore horizontality between network users, by making both digital and real service providers and users simultaneously, in a peer-to-peer approach: our land registry service has everything to gain by seizing this possibility to ensure the maintenance of registers of operations or property at the service of control, in its field as distinct as the monitoring of land rights and easements or the control of the chain of title. This development will not only allow for a better flow of exchanges, but also for easier control of operations, leading to efficient functioning. However, this development will require a substantial change in the controller/controlled party relationship, by placing the controlled parties in a position to ensure part of the control of the correction of entries in the chain.

### 3.3 Smart contracts in Land Management

Smart contracts are self-executing contracts with the appropriate terms of agreement between two parties. This agreement between the buyer and seller is written directly in lines of code. The code and the agreements it contain exist on a distributed and decentralized blockchain network. There are only a few buyers who take assets directly. Usually people take loans, which is too slow a process because of administrative or banking problems. This is where smart contracts come in, simplifying the process by automating the verification of transactions. With blockchain in a land registry system or platform, the seller and buyer can create a decentralized unique identifier. Compared to the traditional method, this makes the transfer of ownership faster and more transparent. When the registry confirms ownership, the blockchain smart contracts become active and the transaction between buyer and seller is recorded in the blockchain registry. Thus, records can always be traced.

- Step 1: User registration (Seller/Buyer). The Blockchain land register platform has an application through which all users (buyer and seller) register. The details required to create the profile are the identity of the natural or legal person and the evidence or documents of that land. A unique hash must be submitted by the users as identity information, and it is stored on the blockchain.

- Step 2: Details of the property to be sold or purchased (Images and documents related to the properties) must be visible on the platform by correctly indicating the location of the land with specific measurements. Each detail is recorded in the database register which is the ledger of the blockchain. The buyer can now see and verify the details recorded by the seller.

- Step 3: Interested buyers can send a request to the seller to access his specifications. Requests for access to goods are received by the seller. By viewing the buyer's profile, the seller can refuse or accept the request.

- Step 4: In the blockchain's land registry platform, the buyer and seller submit their documents, which are verified by the land inspector, and then the land inspector adds the authenticated record to the blockchain ledger. In the presence of the land inspector on the land registry platform, the seller and buyer sign the documents, the land inspector checks each required field, then records them in the database and the transaction is registered in the blockchain. The smart contract sees the application and transfers ownership to the buyer.

- Step 5: The hash value of the document uploaded by the owner is identical to the hash value at the time of the property purchase (signature), so the documents are 100% authenticated, the documents are original, and no changes have been made to the document.

In short, this is how the smart contract will work in our new system.

## 3.4 Qualitative Research

Starting from the literature on this method of research and investigation, we will demonstrate how to use some of these methods through this chapter to enable us to find the solution to the problems raised in this work.

We observed for a long time the way the cadastral service manages land title files in North Kivu province, to understand more about the problems related to land title management from what people say in relation to what we observe. This method allowed us to pay much more attention to the details during our observation, namely the dimension related to the conflicts that arise because of the poor management of land titles by the land registry service, namely the interactions caused even by these problems between the inhabitants.

From this observation, we relied on the ideas of ((Mays & Pope, 2020)), to move to the interview method to facilitate us to obtain information on the interpretations and reading of the situation on land management. As these problems are almost generalized, we interviewed only a few people who are much more concerned by these land conflicts arising from this mismanagement of land title information by the authorized service. As the interview has several types, in this research we used the semi-structured interview to give the interviewer enough space to express his point of view to the questions asked and leave him free to answer at his own discretion.

At this level, we used a questionnaire to collect information that could help us to understand the facts related to the mismanagement of land within the land registry service and to position ourselves regarding the solution to be considered. However, we relied on the open-ended questionnaire as suggested by ((Combessie, 2010)), to let the participants express themselves freely for as long as they wish.

In conclusion, we will discuss the results of this survey in the following chapter and lead us to propose the design of a new system to solve these problems.

# Chapter 4

# Results and Discussions

In this chapter, we will discuss the two elements including the results in terms of our interview guide and the presentation of the design proposal of the new system; the second part will concern the discussion of the result focusing much more on our research questions.

## 4.1 The results

### 4.1.1 Interview Analyse

Based on the various research studies in our literature related to quantitative research methodology, we relied on interviews, in addition to observation, to enable us to collect the data that was used to determine the starting point of the solution to our research problem. According to the interview guide for our research (see Annex E).

As mentioned above, we used the semi-structured interview method to talk to the target population to reconcile or confirm the information gathered from our observations of the problems of land management within the cadaster and the answers that our respondents gave us during the interview, which led us to the conclusion in the table below. It should be noted that we have just taken a sample number for this case because the problem of land spoliation is general and in addition, most people following the anger do not like to talk about it anymore.

The questions concern the causes of land conflicts, the inability of the empowered service to find solutions and the proposal of a new computerized system. We interviewed only 8 people who agreed to voluntarily respond to an interview guide consisting of four questions to find out whether they agreed with the proposal for a computerized system that would do land management through the land registry service. The factors are: (1) Strongly disagree (2) Slightly agree (3) Neither agree nor disagree (4) Agree (5) Strongly agree
In the appendices of our research, we will include the elements demonstrating the proof of the results that we display here in a single sentence. Most of the respondents expressed the wish to see the land service benefit from a working tool that would facilitate this management, which is at the root of many problems in the area.

### 4.1.2 System Analysis and Design

The results of our interview motivated us to prove exactly the need for the proposed new system for the management and control of land records as this is a handicap in the proper functioning of the land registry service.
In this point of analysis and design of the proposed new system, we have taken a particular look at the theories of our research by focusing on blockchains as the foundation of our

system. Based on this principle, this chapter has a main section that will analyze the existing system and demonstrate the design of the new system.

### System Analysis

Our analysis is based on the three elements of how properties (parcels and their owners) are registered, how this information is kept in the current system, and what the level of transparency in the system is. What is the level of transparency in the process of sales or purchases of land (plots) between two owners and what is the focus of the transfer of a property after the sale or purchase. These elements are well detailed in terms of the problems in our problematic and have enabled us through the analysis in Figure 4.1 to present Figures 3.1 and 3.2 (Current Land System Management and Proposed Land System).

We were able to improve figure 3.2 through the information received from our interview guide, which allowed us to revise and complete the new system by putting the block chain at the center of all the system's manipulations in order to have a perfect management of this.

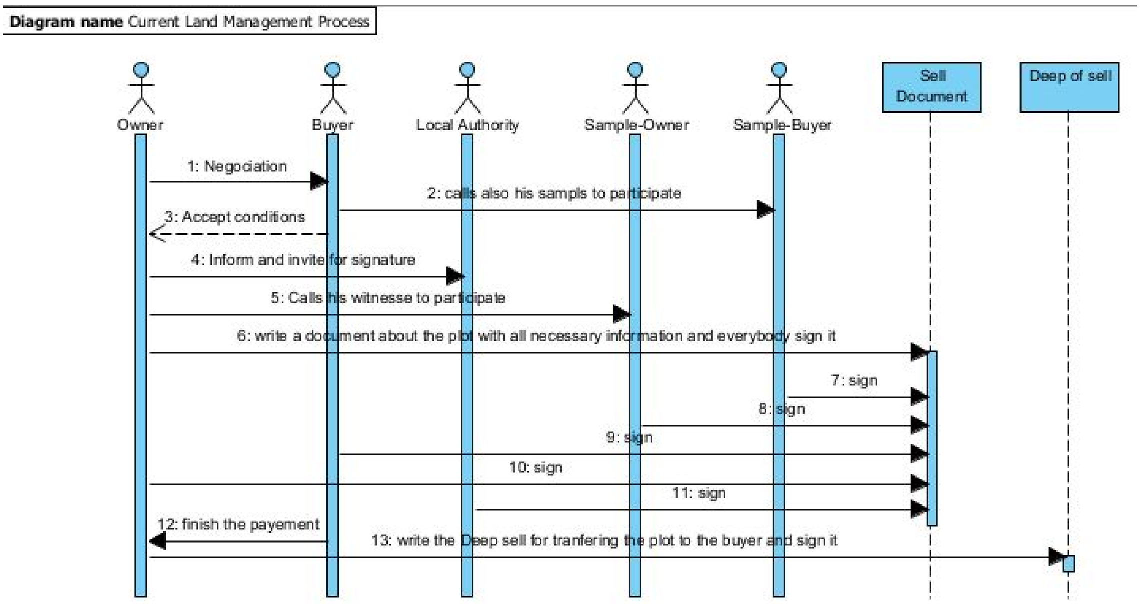



Figure 4.1: Current Land Management Processus

### Conceptual Design

As mentioned at the beginning, this system will be designed on the basis of the real problems affecting land management in North Kivu province in order to provide a solution. Based on the information gathered in this department through interviews and documentation (see documents in the annexes), we have come up with the model presented in the next section.

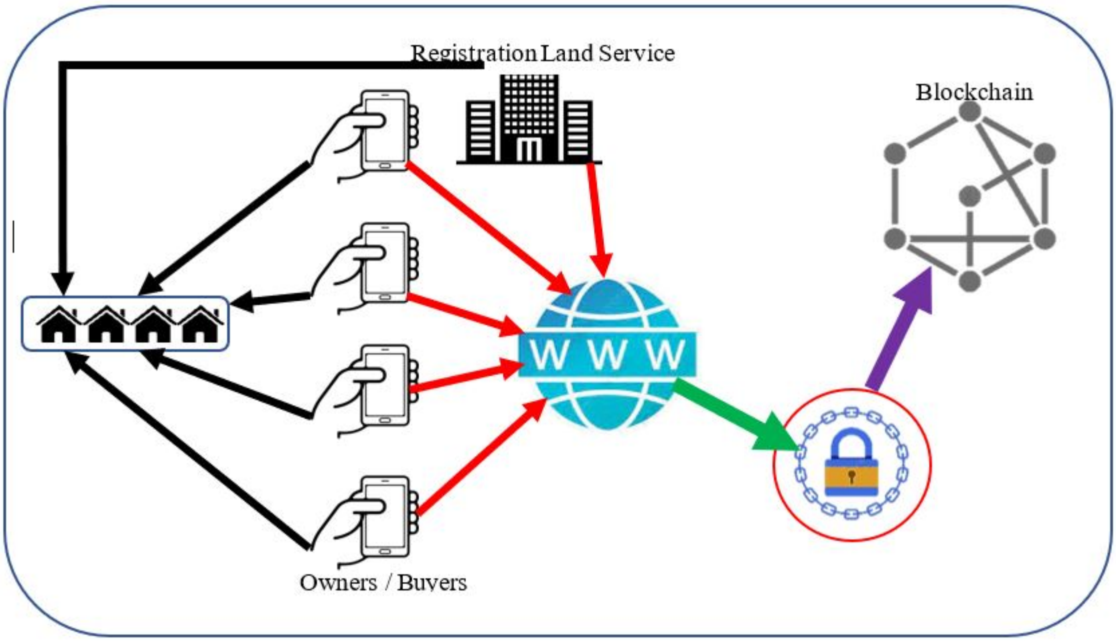



Figure 4.2: Architecture of the New System

**Implementation of Blockchain in our Design**

The blockchain is the center of all operations in the proposed system and the sole basis for management. For all tasks performed through the nodes, they will be added on the different types of ledgers of the block chain. All access to the system is conditioned by the unique identifier received at account creation.
In the new systems, owners can add land ownership information in collaboration with the cadastral service through evidence documents which will now also be integrated into the system. This proposed system limits its centralized administration to one station, all users manage their information in a decentralized way.

Regarding the sale or purchase, the system facilitates these two users the contact and the access to the information necessary for its availability to allow the sale or purchase. For the payment in this system, the deal will happen between the seller and the buyer, but the confirmation of a proposed amount will be in the system and the confirmation of this amount by both parties must be done to facilitate the system to validate the tasks of this block. Once the process is complete, ownership will be transferred, and a new block will be created in the blockchain. The information that will be generated in the new block is the following: hash of the previous block, land information, payment information, current owner information, hash of the current block. There is another type of user, these are: Buyers and sellers. They can register on the system by providing their authentic information to buy and sell. The system will verify the authentication of the information. Buyers and sellers will perform all tasks related to the transfer of land ownership through the system. The cadastral service will only accompany them to participate in the validation with the other parties and be aware of the different transfers. With this system, buyers and sellers can now provide their original contact information if they are interested in buying or selling land.

For the clarification of the working procedure, these steps are as follows: In the very first step, a user authenticates to the system as a buyer, seller, or clerk of the cadastral service. For those who do not have an account, it is mandatory to create one at this level, otherwise they will not be able to do anything in the system except read and browse the information available in the system for all external public.

After authentication, the person who authenticates as a seller will upload his basic information and that of the land into the system. And if one authenticates as a buyer, he will search for land to buy. If you authenticate as a cadastral service, you will only be able to participate in the validation of the sale, purchase, or transfer by the system if necessary.

If a buyer likes a plot of land and its basic information, he can send a request for access to the detailed information to the seller via the system. After that, a seller will receive this request and either confirm it or refuse it. After the initial stage, the buyer and seller can reach an agreement by negotiation by contacting each other. If they confirm the agreement, they add the terms and conditions using the system. The system records this information for verification, if necessary, especially when transferring and confirming the sale or purchase. If it finds any inconsistencies, it informs the party concerned and closes the transaction.
If all the information is correct, it also checks the validation of the parties, if it is confirmed by all the respective parties, it changes the ownership through the smart contracts and informs the buyer, the seller, the cadastral service, and the system (for the update). Thus, the system will close the whole process by adding a new block to the existing blockchain.

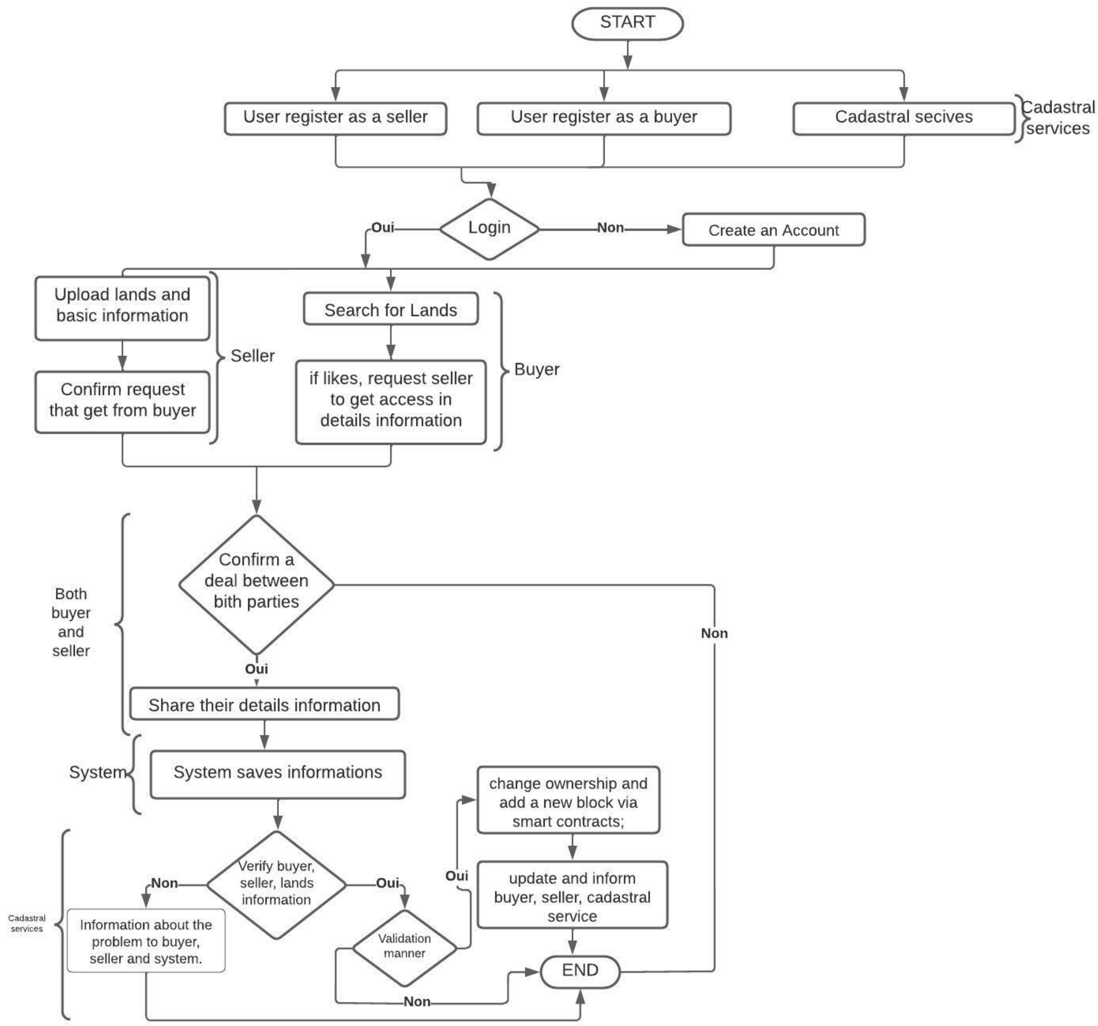



Figure 4.3: System Work based on (Sakibul et al., 2020)

## 4.2 Discussion

1. **Would the integration of blockchain technology into the land management system of the cadastral service of the province of North Kivu in the Democratic Republic of Congo be an effective solution to current problems?**

   The research questions of our thesis are answered through our objectives. The research work for this thesis has allowed us to propose a solution on how blockchain-based smart contracts can be used to achieve shared consent on data management. Our design shows that it is possible to achieve land management using blockchain, where an owner can have full management and unlimited access to their information. In this design, it was important to know why blockchain was used. It is true that the blockchain is complex and difficult to understand if we are not next to experts who facilitate its understanding because it is difficult to develop a system without involving trust and we must know that blockchain is irreversible, and that by introducing data we can incorporate errors and false information (human errors).

   However, the management of information, the ability to store transactions and the possibility of tracing transactions to guarantee transparency, all are immutable and make it an attractive platform within blockchain for all areas in which it is applied. As the blockchain policy is based on encryption, being a key element in its design and as proposed in all systems with blockchain, we have chosen to use symmetrical and asymmetrical encryption in our system as well, even if they are not visible in the implementation. The land data being stored on the data host (the user's terminal) is encrypted by symmetric encryption, while the symmetric encryption key is itself encrypted by asymmetric encryption.

   Indeed, we have chosen to use asymmetric encryption to add another layer of security, as it uses two different keys, i.e., a public key that is accessible to all is used to encrypt (the symmetric encryption key) and an associated private key that is never shared is vital to decrypt (the asymmetric encryption key). Asymmetric encryption ensures that only the intended recipient, i.e., the owner of the asymmetric private key, can decrypt the requested data. By using a combination of symmetric and asymmetric encryption, we improve both the efficiency and security of our management.

   Coming back to the point, the integration of this technology in the management of the land system at the level of the cadastral service is not only a technical solution but also and above all a transparent one for both parties involved in the management. The cadastral service manages the data provided by the owners of the land to provide them with real estate titles. Now through blockchain this management is decentralized within the system and all stakeholders in the system can participate in this management, which increases the credibility of the system and the confidence of the users.

   As stated in the theories and in our introduction, blockchain limits all individual consents that exist in the will of the current system administrator in the sense that he can no longer falsify records, backdate them, or modify them. Blockchain cannot do this. A record made through blockchain is uniquely created and shared by all the nodes in the blockchain system, so it is difficult to bring all these nodes together to facilitate modification if necessary. It requires the consent of all, which would not be easy if it were a matter of tampering with the information.

   The current problems of land management are centered on registration, sale, and purchase and to transfer properties, which the blockchain does through its multiple technologies. So, for this case, we proposed the application of this technology because it is the best place for security, accessibility on information, traceability, transparency, and availability of information as being on a local equipment at its disposal.

2. **Will the proposed land management system increase security and transparency in the sale, purchase or transfer of property?**

   We have just demonstrated in the previous question how blockchain technology is responsible for managing security with data encryption at all levels, but also for limiting access to the system.

   With blockchain security, everything is based on authentication in the system. You cannot access the blockchain system if you do not have the unique authenticator regenerated by the blockchain itself when you create your account. This authenticator is a unique key considered as the user's ID which is composed of 12 words arranged according to the hash algorithm of the block chain and that no one can disturb the succession of words as the algorithm prevails. This identifier must be kept secret by the user in a safe place because once forgotten or lost, it will be complicated to access the system without this identifier, but this will change depending on the terminal on which one is connecting for the first time. It is therefore in everyone's interest to keep it jealously guarded and out of reach.

   Another security aspect is linked to the validations in the transfers at the system level. Speaking of these validations, a transfer can only take place if it is validated by all the stakeholders likely to participate in this process and who have all given their consent by validating the process so that it can take place. That is, the parties accept the agreements of the contract and validate it in this case, they give their agreement to the system to validate or execute the process to its end. In the case of the sale, once the seller and the buyer agree on their contract of sale outside the system, both come to complete the information related to this contract in their profile in the system to allow the system to know the validation criteria. If these criteria are needed, the system will only check whether all parties involved have fulfilled this commitment. This is where we are going to talk about this validation so that the process is now carried out without any constraints.

   This procedure leads us directly to talk about the intelligent contract that the blockchain makes available to us in a system. Through the blockchain system, the smart contract can only be signed and validated when all parties involved have expressed their consent to a process (validate or accept). If one party has not validated, the process fails, which is another reason for the security of blockchain in transactions, sales or purchases across all areas that have systems based on this technology. This contract facilitates the participation of all parties in the process and guarantees a facilitated history of the transactions in the blockchain.

   In terms of transparency, each step of the process is well defined. Everyone can follow the changes that have taken place in the process. There is no risk of tampering or corruption because there is no unauthorized access to the system. As mentioned earlier, when a transaction takes place, the whole process is transparent. We also looked at the traditional method of storing land registers in our case study. In the current method of storing the land register, the seller and the buyer must discuss through intermediaries of several parties if not land agents, these are organizations or even the cadastral service for the purchase or sale of land, let alone if it is a question of having the land documents, there it is months or even years to be in possession.

   There is no central authority in the proposed system, each block participating in the process verifies the transaction. There is no risk of data loss or corruption in a blockchain-based system, as the blockchain uses a time-stamping method that allows users to track any data changes. We can conclude that our proposed system is far superior to the current standard practices of storing land information in our study environment.

3. **How will the proposed system be designed to be effective, efficient and satisfactory to the intended users in terms of accessing the information needed to sell/buy land and/or property?**

   The system is designed to be simple to operate for users. As we have just demonstrated through the previous questions, security is the basis for this effectiveness in relation to our proposed system, but we have also considered the notions of user experience in relation to the use of the system.

   For this question, we focused much more on the user experience which is at the convergence of three main areas of activity, the human factor, which is the behavior of the users in relation to the interfaces and/or any object that interacts or not with our proposed system.

   The graphic/web design, which orients the user to go for an emotion a current trend of iconographic codes as well as the technology we have used for the realization of the system. In this context, we tried to meet the requirements of user experience, based on the elements such as: useful, usable, attractive, findable, accessible, credible, and valuable.

   - Our proposed system is useful because it exactly meets the needs of users according to our research problems. However, keep in mind that here we are not referring to the whole population to necessarily say that the system must offer tangible results, this will depend on each individual and what they want to have or see through the system.
   - The proposed system offers a good user experience i.e., it is easy to use because it is designed in a way that is familiar to the user and therefore simple to understand. The aim is that the learning curve is short and without major difficulties for self-learning to use the system.
   - The system facilitates the visual identification of its elements just through the interfaces. Nothing is to be searched for too much in links or clicks.
   - The system will be within the reach of everyone. So, a web platform with just your terminal you will have access.
   - Through the operation of the system and by the technology proposed for its implementation and the security it offers, we conclude that this system is credible.
   - From the functionalities that are the answers to the needs expressed to set it up, this system to mount an added value for its users.

   We have put some captures of the figma prototype related to the realization of the system in our appendices which can also provide another additional explanation.

4. **Conceptual Design Limitations**

   Despite the proposal of our new system, our research has some limitations in the context of the adoption of the blockchain-based system in our community. Being based on new communication and information technologies, it will be mandatory for all users to be at least able to use a computer system, as we will not be surprised by the medium of our study as we have information about this.

   It will also not be easy to convince some of the better placed agents of the land service to integrate a new system that stands in the way of personal interests benefited with the old system for the replacement of the proposed new one that will be decentralized and managed by all

   The blockchain with these technologies is not yet applicable in the Democratic Republic of Congo in the context of money transfer, which is why we have limited our conception only to the applicability of the blockchain in land management without considering the use of any cryptocurrency.

# Chapter 5

# Conclusions

The objective of our thesis was to investigate the feasibility of using and implementing a blockchain-based land management system in land registry management, based on the impact that blockchain represents in improving systems in several sectors.
Our prototype realization, or appendices, addresses our major design concern, the impact of using blockchain to keep land records secure, transparent, and immutable. Blockchain has many qualities, such as traceability and immutability, which can benefit the land sector. We looked at different types of blockchain and consensus algorithms and assessed which type was best suited to our design.

As a result, our design is most suitable for an Authorized Consortium Blockchain with Proof of Authority as the consensus algorithm. The proposed solution aims to improve the management, control, transparency over one's own land data and this thesis shows that there is potential value in implementing the proposed design.

The solution was proposed as a result of the literature review conducted in the thesis. Using blockchain-based smart contracts, we have created a design (Figma prototype) where the users of the system (seller, buyer, and land registry) are in full control of and therefore responsible for their own land information but under the management and security of the blockchain via the system, they are collaborating with unmodifiable sharing of information on their same blockchain network with full confidence.

The design illustrates scenarios to demonstrate how a user can sell or buy land through smart contracts by demonstrating a theory on the validation of this contract.

Our current version of the proposed model has limitations and leaves room for future work.

Appendix A

# Land request

**REPUBLIQUE DEMOCRATIQUE DU CONGO**

PROVINCE DU NORD-KIVU
CONSERVATION DES TITRES
IMMOBILIERS DE..................

*Visa du Bureau du Domaine Foncier*

# DEMANDE DE TERRE

NOM:........................................................................................................................
POSTNOM:..................................................................................................................
LIEU ET DATE DE NAISSANCE:.....................................................................................
NATIONALITE:............................................................................................................
N° CARTE(Pour Citoyen,d'Electeur, Mécano ou Passeport):.............................................
LIEU ET DATE DE DELIVRANCE:...................................................................................
ETAT CIVIL:................................................................................................................
NOM ET POSTNOM DE L'EPOUSE(EPOUX):...................................................................
REGIME MATRIMONIALE:..............................................................................................
ADRESSE DE RESIDENCE:............................................................................................
ADRESSE B.P.:............................................................................................................
PROFFESSION (EMPLOI,ACTIVITES,GRADE EXACT):.......................................................
NOM ET ADRESSE DE L'EMPLOYEUR:...........................................................................
PARCELLES DETENUES A:............................................................................................

- EN PROPRIETE DE DROIT ECRIT:...........................................................................
- DONNEES EN LOCATION PAR ET A:.........................................................................
- OCCUPEES SUIVANT LIVRET DE LOGEUR:.................................................................
- LA OU LES PARCELLES EST(SONT)MISES EN VALEUR:...............................................
- PARTIELLEMENT:..................................................................................................
- ENTIEREMENT:......................................................................................................

PARCELLES RETIREES, VENDUES OU TRANSFEREES:.......................................................
RENSEIGNEMENTS CONCERNANT LA PARCELLE SOLLICITEE:.........................................
COMMUNE DE:...........................................................................................................
LOTISSEMENT:...........................................................................................................
USAGE:......................................................................................................................
NUMERO CADASTRAL:.................................................................................................
SUPERFICIE:...............................................................................................................
PROGRAMME DE MISE EN VALEUR:...............................................................................
JUSTIFICATION DES POSSIBILITES FINANCIERES:..........................................................
JE SOUSSIGNEE:......................................................DECLARE SUR L'HONNEUR
QUE LES RENSEIGNEMENTS FOURNIS SONT EXACTS.

N.B.: L'INEXACTITUDE DES RENSEIGNEMENTS CI-DESSUS FOURNIS ENTRAINERONT
LE REJET PUR ET SIMPLE DE LA DEMANDE.

AVIS TECHNIQUE
REÇUE LE.........../.........../...........
ET INSCRIT AU REGISTRE DE

DEMANDE DE TERRE N° 0009323

................,le.........../.............../.................

SIGNATURE

Code 0730
PROV. DU N / KIVU

Appendix B

# Identification Certificate

**REPUBLIQUE DEMOCRATIQUE DU CONGO**

*MINISTERE DES AFFAIRES FONCIERES*
*PROVINCE DUNORD-KIVU*
*CONSERVATION DES TITRES*
*IMMOBILIERS DE GOMA*
*B.P 81 GOMA*
***Bureau d'Enregistrement et Notarial***

# ATTESTATION D'IDENTITE



*NOM :.......................................................................................................*

*POST NOM :.......................................................................................................*

*PRENOM :.......................................................................................................*

*LIEU ET DATE DE NAISSANCE :.......................................................................*

*PROFESSION :.......................................................................................................*

*NATIONALITE :.......................................................................................................*

*N°CARTE (d'identité, d'électeur, passeport, Mécano) : ......................................*

*LIEU ET DATE DE DELIVRANCE :.......................................................................*

*ETAT CIVIL :.......................................................................................................*

*REGIME MATRIMONIAL :.......................................................................................*

*NOM DE L'EPOUSE OU DE L'EPOUX :.......................................................................*

*ADRESSE :.......................................................................................................*

*B.P. / Tél :.......................................................................................................*

*Goma, le ......... /.............. /201*

***Visa du Commis***

*Signature du Concessionnaire*
*Nom et Post nom*

**REPUBLIQUE DEMOCRATIQUE DU CONGO**

MINISTERE DES AFFAIRES FONCIERES
PROVINCE DUNORD-KIVU
CONSERVATION DES TITRES
IMMOBILIERS DE GOMA
B.P 81 GOMA
**Bureau d'Enregistrement et Notarial**

# ATTESTATION D'IDENTITE

## Personne morale

NOM ET POST NOM DU REPRESENTANT:…………………………………………………………

QUALITE DU REPRESENTANT:……………………………………………………………………

DENOMINATION (Institution- Société –ASBL- ONG):…………………………………

……………………………………………………………………………………………………………

……………………………………………………………………………………………………………

ADRESSE :………………………………………………………………………………………………

NUMERO DE L'ARRETE :…………………………………………………………………………

NUMERO DE LA DECISION : …………………………………………………………………

SIEGE SOCIAL (adresse):………………………………………………………………………

DATE DE CREATION:…………………………………………………………………………………

ADRESSE :…………………………………………………………………………………………

B.P. / Tél :………………………………………………………………………………………

Goma, le ……… /………….. /20……

**Visa du Commis**

Signature du Concessionnaire
Nom et Post nom

# Appendix C

# Commune of Goma

| NÂř | Quartiers | Cellules | Avenues |
|---|---|---|---|
| 01 | Lac Vert | Mugunga | Lushagala, Rutanda, katwa |
| | | Paypay | Xaverie, Burora, Kabutembo |
| | | Nyabyunyu | Kabande, Majengo, Nyarutsiru |
| | | Shabakungu | Kibangouiste, Mungirima, Universitaire |
| | | Bulengo | Burungu, Mabanga |
| 02 | Kyeshero | Buhumbira | Du Lac, Kibati, nziyunvira, Lemera, Maendeleo |
| | | Gasiza | Eringeti, Kituku, Bukama, Rivuze, de lâĂŹenseignement |
| | | Katchetche | Bobila dawa, Kinshasa, Kisangani, Tshopo, Mbujimayi, Lubumbashi, Lusambo, Topographe, Katchetche, Rumimbi I, Mayi moto, Rumimbi |
| | | Burenge | Bigiri, Abattoir, Rwamichacha et Mbau |
| | | Karibu | Maman Christine, de sport I, Ruzizi, Byahi, Mulu |
| | | Nyarubande | De lâĂŹĂľglise, du marchĂľ, de sport II et Luzuba |
| | | Chamahame | Mirugi, Magene, Lusaka, Miakano, de la conferencede la pacification, Keshero I, Keshero II , |
| 03 | Himbi | Universitaire | |
| | | Bukavu | De Goma, Baraka, Presidentielle |
| | | Lumumba | De la paix, loashi, du Musee |
| 04 | Katindo | RVA | Masisi et du lac |
| | | Du Golf | Bunagana, la frontiere et Ishasa |
| | | Du 20 juillet | Maniema, Beni et du carmel |
| 05 | Les Volcans | Sud-Est | Circulaire |
| | | Paypay | Xaverie, Burora, Kabutembo |
| | | Mulembezi | Jacarandas, Tulipiers, du Gouverneur |
| | | Commerciale | Du rond-point, mont-goma, Acassias, Grevilleas, Bourgaivilliers, des orchidees, touriste, Butembo, Walikale, des Ulbis, du port, du golf, Bld sake, des pelicans, Bld Kanyamuhanga, ParallĂĺle, de la comiche, Beni, le Messager |
| 06 | Mikeno | Kibabi | Lubutu, Kitona et Kamina |
| | | Bishogo | Kasongo, Bukavu et Kalehe |
| | | Feruzi | Deu 20 mai, kiboko et Mugunga |
| 07 | Mapendo | Mapendo | Bweremana, Kirambo, Mwangaza, Idjwi, Minova, Kisangani |

Table C.1: The districts, cells and avenues making up the commune of Goma

# Appendix D

# Commune of Karisimbi

| NÂř | Quartiers | Cellules | Avenues |
|---|---|---|---|
| 01 | Bujovu | Byahi | Bunyerezo, Burengera, Jolis bois, Hanika |
| | | Nyarubande | Buheka, Gasiza, Gakuba, Nyarubande |
| | | Tyazo | Cyirambo, Basunga, Nyakagazi |
| 02 | Kahembe | Birere Nord | Kanyamanjanja, Bahizi |
| | | Kasika | Mikundi 1, Mikundi 2 |
| | | Les volcans | 4 janvier, la Rwindi, Lubero |
| | | Birere Sud | Kitovu, Butembo, Mont Hoyo |
| 03 | Mabanga Nord | Salongo | Salongo I, Salongo II, Salongo III |
| | | Osso | Lubango, Itebero, Katoyi I, Osso II, Kindu |
| 04 | Mabanga Sud | TKM | Kinshasa, Industrielle, Mokoto, Mushunganya, Ikobo, Karisimbi |
| | | Kakuru | Mutakato, Mulimga, Lowa, Ruyange |
| | | Roba | Mutongo, Ndalanga,Amani, Ntoto, Rutoboko, Circulaire |
| 05 | Kasika | Konde | Mundiay, Dikuta, Nyamaseka, Mulamba, membi, Boteti, Mutshatsha, Bobozo, Kibati, Du fleuve, Mulige, Kabego, Kasika |
| | | Katsambya | Mbati, Itala, Mont Bleu, Bwisha,des geometres, Rwindi, Kirumba, Lwalaba, Luenge, Nyakakoma |
| | | BEAD | Kilimanyoka, Katoyi, Bulende, Lukwetti, Luotu, Mweso, Bamate, Ngelo, Bikindwe, Nyandondo, Kyambegho, Bakisi, des deometres, Tongil |
| 06 | Katoyi | Nyabushongo | Pinga, Vitshumbi I, Kilimadjaro II, des techniciens |
| | | De lâĂŹunite | Kasindi I, Kasindi II, des geometres, kilimanjaro I |
| | | Kibwe | Bukohwa, Kisibangi, Kasindi III, Maendeleo, Bitati, des Plateaux |
| 07 | Majengo | Don Bosco | Kibinda, Bakungu, Mulumba, Mulindwa |
| | | Umoja | Umoja |
| | | Kisima | Bugiti, de la paix, Optigo |
| | | Kinyanguge | Mahindule, Sangiro, Mapinduzi, Tengenezo |
| | | Kisigari | Bwisha, Maendeleo, Kabasha, Kabingwa |
| 08 | Murara | Office Nord | Nyiragongo I, Haut-Congo, CoopÃľrative, Nyamulagira, Lowa, Busimba, de la plaine II |
| | | Office Sud | De la plaine I, du marchÃľ I, Du CollÃĺge, Uele, Bananier, Palmier, Ruwenzori, Lac vert, Lac Kivu, Du Commerce, DâĂŹallias |
| | | CEPAC | Loashi, Kabare, Pangi, Uvira, Kasavubu, Lumumba, Nyiragongo |
| | | Anglicane | Murara, Mukosasenge, Bunia, Tshela, Ndoromo, Fikiri |
| 09 | Virunga | Virunga Nord | Bigaruka, Muteberwa, Kagephar, Coin du marche |
| | | Virunga Sud | Des aviateurs, Monigi, Kibati, Idjwi, des alysees, Semuliki, des sports, du parc, Nyiragongo |
| | | Kimbangu | Sabinyo, Muzindushi, de la lave, Osso I, Kindu I, Buhimba |
| 10 | Mugunga | Lutale | Centre arche, Lushagala, Rutanda |
| | | Kibirizi | 17 janvier, Hewa Bora |
| | | Tulia | Croix rouge, Bunyatenge, Kashaka |
| | | Ndali | NâĂŹdjili, Bandahungwa, des archevÃłchÃľs |
| 11 | Ndosho | Munanira | Rulenga, Mitumba, Garamba, Kito, de la DÃľmocratie, Mutwanga |
| | | Des Ãľcoles | Kako, Mitumba, CarriÃĺre |
| | | Ndebo | Itimbiri, Ubangi, Luapula, Renga, Kiwandja, Kalima, Ngungu |
| | | CAJED | Minova, Orphelinat, Kisani, Maendeleo, Lulua |
| | | Okapi | Bugamba,Rwasama, Kasavubu, Kabasha, Muhabura |



Table D.1: The districts, cells and avenues making up the commune of Karisimbi

Appendix E

# Figures of Problems related Land registration


Figure E.1: Land Problem in DRC

# Appendix F

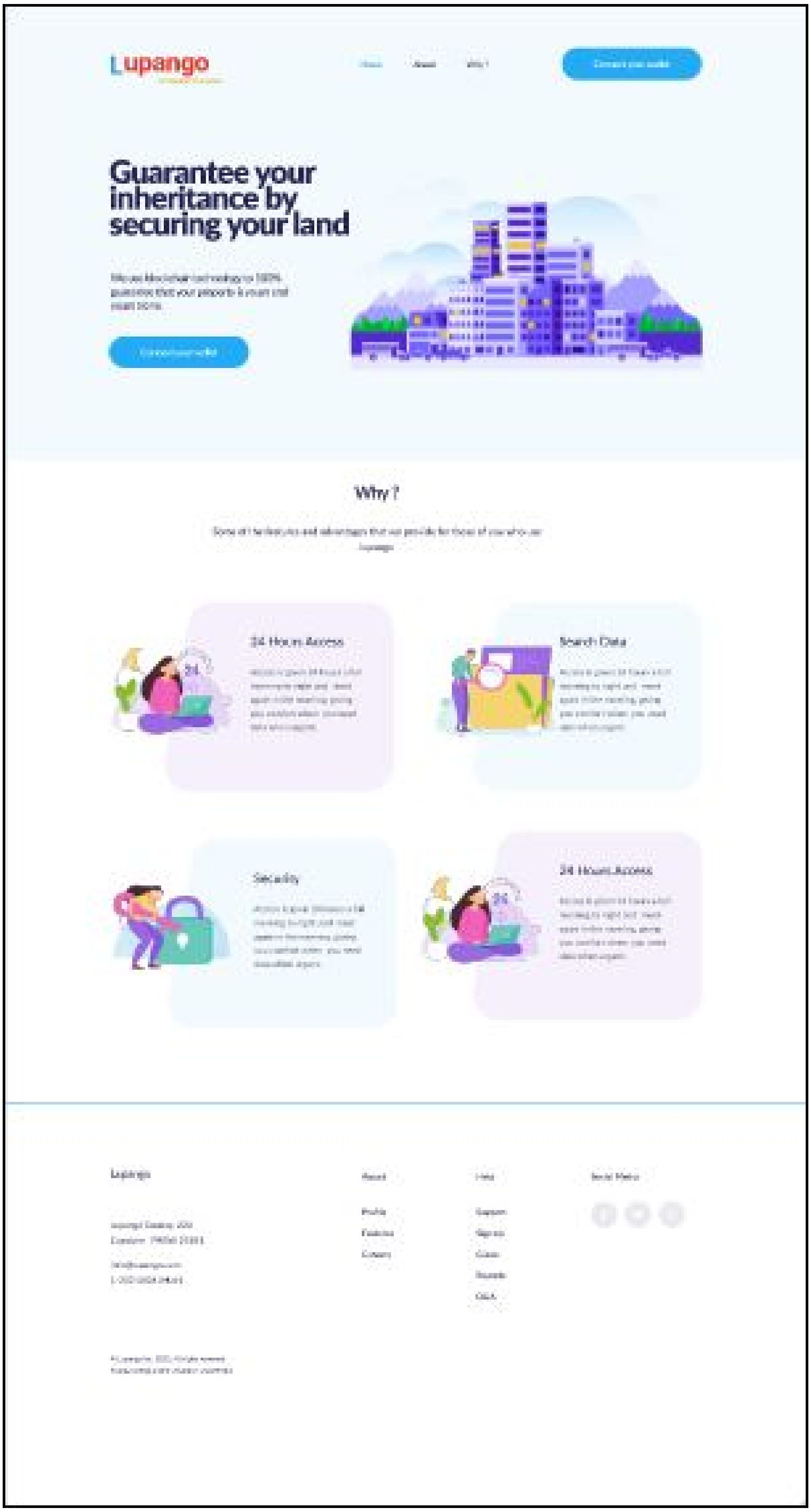
# Interview Guide

We are students in the Department of ()Software Engineering at Agder University in Grimstad, Norway, we are conducting research as part of our postgraduate study on the topic "Impact of implementing a blockchain-based land (parcel) control and registration management system. Case of North Kivu province in DRC", we would like to have your contribute inputs to bring our research to the end and find the solution regarding this. We will just beg you to take a little time to help us answer this questionnaire.
Your age: ..........................................................................
Address: ...........................................................................

1. what are the formalities of buying land in your area? ..............................................
2. Why are there conflicts over plots in your area? ..............................................
3. What do you think all these problems are related to? ..................................
4. Why does the public prosecutor's office, in case of land disputes, fail to find the real solution, especially when both complainants come with documents proving the ownership of the plot, is it a mistake on the part of the cadastral service to deliver land documents to two different people for the same plot?............................................
5. Do you think that with a new information system in place, the cadastral service can overcome the problems of managing land information that they are missing?......
6. who are the actors to be involved in a blockchain-based land (parcel) control and registration management system to reduce land conflicts in your area? and what would be their contributions?.........................
7. In your opinion, would landowners' participation in land management allow for transparency and security of their land data?.....................................
8. what means do you suggest that can facilitate landowners' participation in the transparent management of their land information (land titles/plots)?.............................
9. what are (could be) the challenges to implementing this new blockchain-based land (parcel) control and registration management system to reduce land conflicts in your area?.....................................

## Appendix G

# Figma Prototype Design


Lupango
Guarantee your inheritance by securing your land
Why ?
24 Hours Access
Search Data
Security
24 Hours Access

# Appendix H

# Figma Prototype Design(Con't)

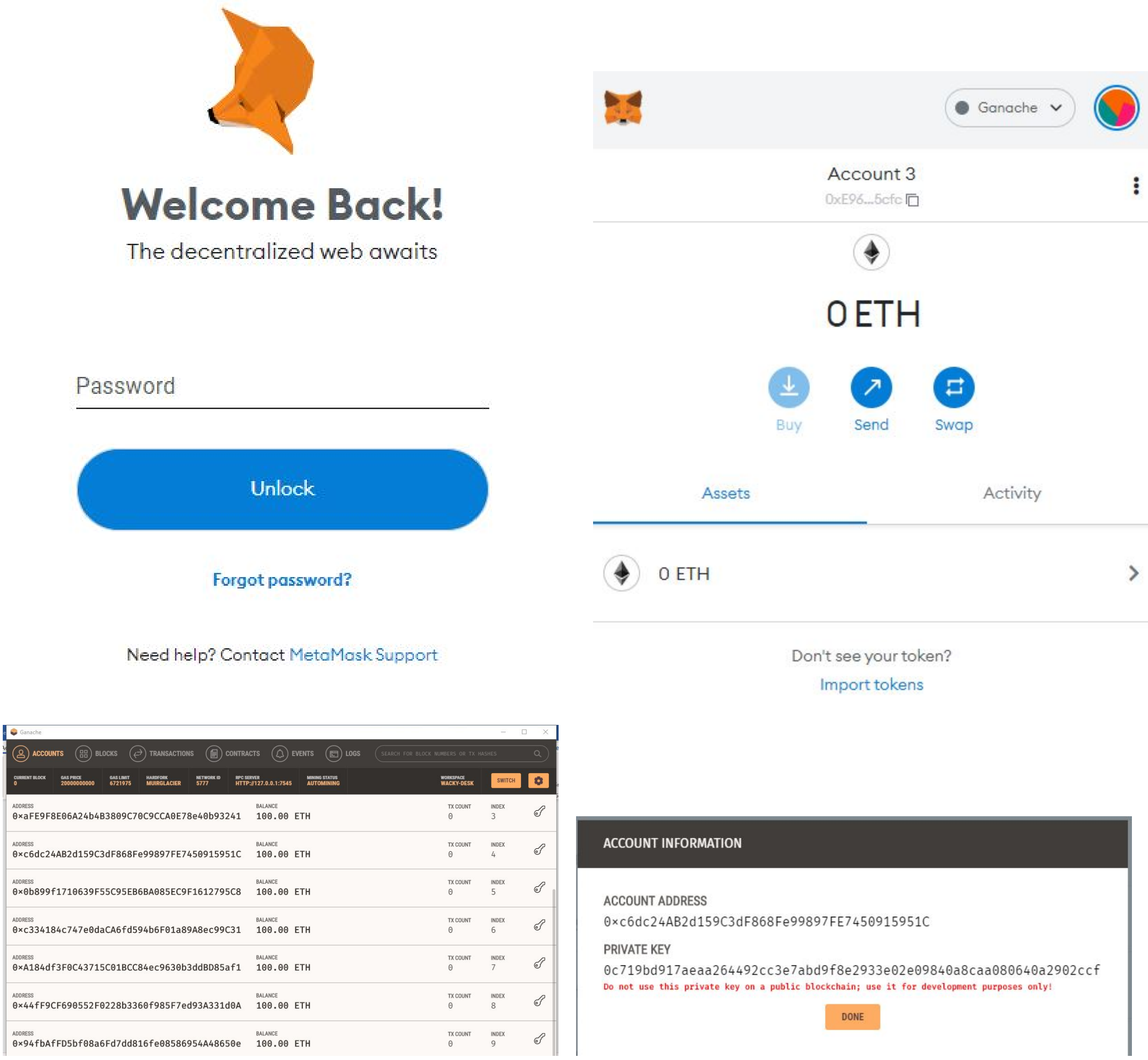



Figure H.1: MetaMask Account

# Appendix I

# Figma Prototype Design(Con't 2)

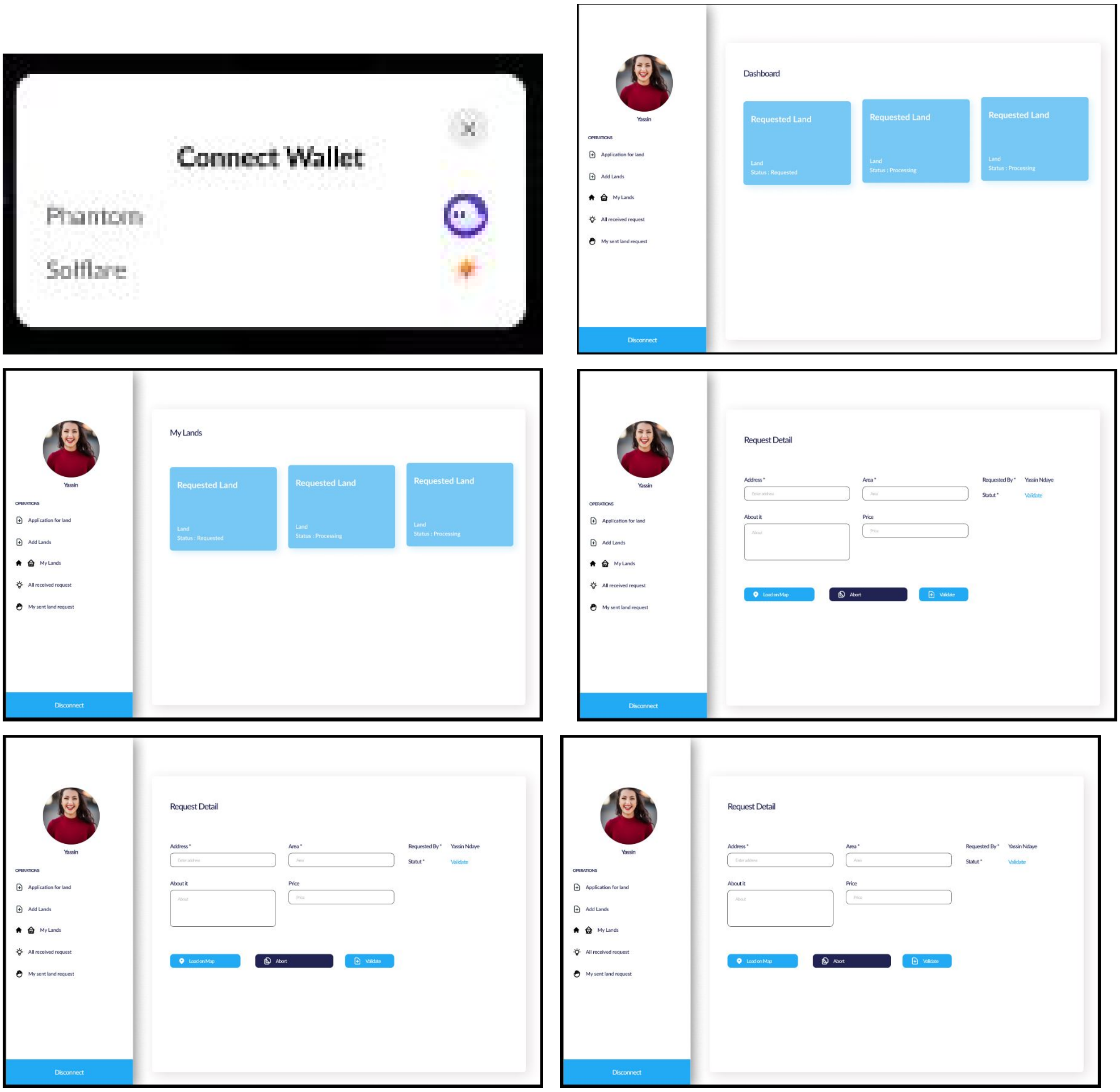



Figure I.1: Lupango Platform

# Appendix J

# Figma Prototype Design(Con't 3)

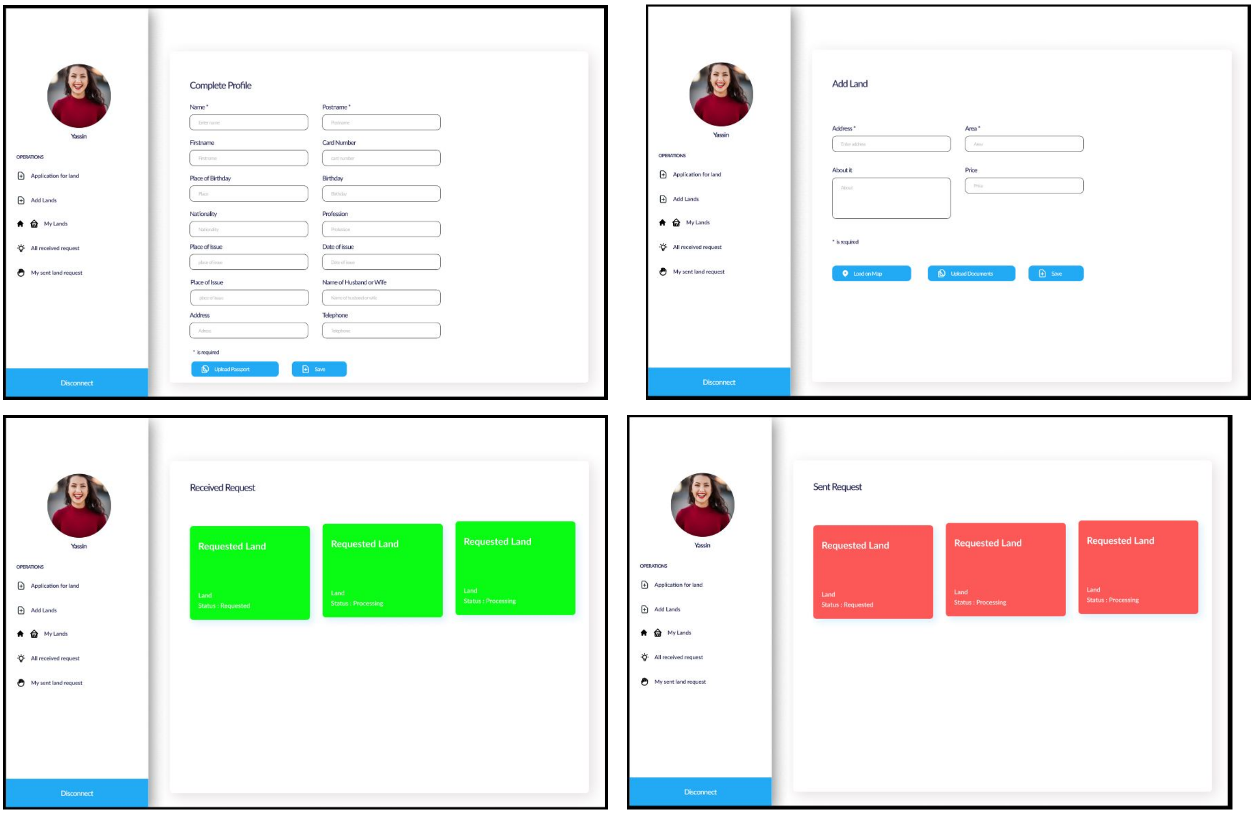



Figure J.1: Lupango Platform 2

# Bibliography


2021, C. P. P. 2. M. (n.d.). What are the 4 different types of blockchain technology? https://www.techtarget.com/searchcio/feature/What-are-the-4-different-types-of-blockchain-technology

Aldweesh, M. A. A., & v Moorsel, A. (n.d.). *Blockchain-based smart contracts: A systematic mapping study of academic research (2018)*. https://www.researchgate.net/publication/333748177_Blockchain-based_Smart_Contracts_A_Systematic_Mapping_Study_of_Academic_Research_2018%20Access%20:%2018.05.2022)

Ali Syed, T., Alzahrani, A., Jan, S., Siddiqui, M. S., Nadeem, A., & Alghamdi, T. (2019). A comparative analysis of blockchain architecture and its applications: Problems and recommendations. *IEEE Access*, *7*, 176838–176869. https://doi.org/10.1109/ACCESS.2019.2957660

Anastasiia Lastovetska – November 12, 2. (n.d.). Blockchain architecture basics: Components, structure, benefits  creation. https://mlsdev.com/blog/156-how-to-build-your-own-blockchain-architecture

Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., Christidis, K., De Caro, A., Enyeart, D., Ferris, C., Laventman, G., Manevich, Y., et al. (2018). Hyperledger fabric: A distributed operating system for permissioned blockchains. *Proceedings of the thirteenth EuroSys conference*, 1–15.

Angers, M. (1997). Initiation pratique à la méthodologie des recherches. *Casbah université*.

Aquib, M., Dhomeja, L. D., Dahri, K., & Malkani, Y. A. (2020). Blockchain-based land record management in pakistan. *2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)*, 1–5.

Aruna, H. Y. L. M. M. A. T. K. J. G. S. (n.d.). *Blockchain-based smart contracts-applications and challenges*. https://arxiv.org/abs/1810.04699%20Access:%2018.05.2022)

Baliga, A. (2017). Understanding blockchain consensus models. *Persistent*, *4*, 1–14.

Baudry, P., Blanchet, A., & Gotman, A. (2010). L'entretien: L'enquête et ses méthodes.

Benbunan-Fich, R., & Castellanos, A. (2018). Digitization of land records: From paper to blockchain.

Bloor, M., & Wood, F. (2006). Phenomenological methods. *Keywords in qualitative methods*, *129*, 131.

Bradbury, D. (2013). Bitcoin's successors: From litecoin to freicoin and onwards. *The Guardian*, *25*.

Bragagnolo, S., Rocha, H., Denker, M., & Ducasse, S. (2017). Smartinspect: Smart contract inspection technical report.

CAMPRENHOUDT, L., & QUIVY, R. (2011). Manuel de recherche en sciences sociales, 4 e édition.

Chakraborty, P., Maitra, S., Nandi, M., & Talnikar, S. (2020). Centralized systems. *Contact tracing in post-covid world* (pp. 31–70). Springer.

Chen, L., Xu, L., Shah, N., Gao, Z., Lu, Y., & Shi, W. (2017). On security analysis of proof-of-elapsed-time (poet). *International Symposium on Stabilization, Safety, and Security of Distributed Systems*, 282–297.

Chohan, U. W. (2021). *Non-fungible tokens: Blockchains, scarcity, and value.*

Combessie, J.-C. (2010). *La méthode en sociologie*. La découverte.

ConsenSys. (n.d.). *A 101 noob intro to programming smart contracts on ethereum*. https://medium.com/@ConsenSys/a-101-noob-intro-to-programming-smart-contracts-on-ethereum-695d15c1dab4%20[Last%20Access%20May%2009,%202022]

Consulting, E. (n.d.). *What is cryptography in security?: Asymmetric symmetric and hashing*. https://www.encryptionconsulting.com/education-center/what-is-cryptography/%20[Last%20Access%20May%2009,%202022]

CryptoCompare. (n.d.). *What is the "gas" in ethereum?* https://www.cryptocompare.com/coins/guides/what-is-the-gas-in-ethereum/%20[Last%20Access%20May%2009,%202022]

De Rossi, L. M., Abbatemarco, N., & Salviotti, G. (2019). Towards a comprehensive blockchain architecture continuum. *Proceedings of the 52nd Hawaii International Conference on System Sciences*.

Delmolino, K., Arnett, M., Kosba, A., Miller, A., & Shi, E. (2016). Step by step towards creating a safe smart contract: Lessons and insights from a cryptocurrency lab. *International conference on financial cryptography and data security*, 79–94.

Driscoll, K., Hall, B., Paulitsch, M., Zumsteg, P., & Sivencrona, H. (2004). The real byzantine generals. *The 23rd Digital Avionics Systems Conference (IEEE Cat. No. 04CH37576)*, *2*, 6–D.

Driscoll, K., Hall, B., Sivencrona, H., & Zumsteg, P. (2003). Byzantine fault tolerance, from theory to reality. *International Conference on Computer Safety, Reliability, and Security*, 235–248.

Elmaghraby, A. S., & Losavio, M. M. (2014). Cyber security challenges in smart cities: Safety, security and privacy. *Journal of advanced research*, *5*(4), 491–497.

Fielding, N. (1993). Ethnography. *Researching social life*, 154–171.

Gatteschi, V., Lamberti, F., Demartini, C., Pranteda, C., & Santamarıa, V. (2018). Blockchain and smart contracts for insurance: Is the technology mature enough? *Future internet*, *10*(2), 20.

Gayte, A. (n.d.). *Nft*.

Goragandhi, D., Shah, J., Doshi, V., & Nanade, A. (2021). The application of blockchain as a distributed ledger and smart contract for property registration. *2021 International Conference on Disruptive Technologies for Multi-Disciplinary Research and Applications (CENTCON)*, *1*, 152–157.

government launches blockchain strategy 2021 — coin telegraph", " (n.d.). Available%20at:%20https://cointelegraph.com/news/ua-government-launches-blockchain-strategy-2021

Goyal, R., & Mittal, N. (2021). E-governance through blockchain technology. a review. *2021 2nd Global Conference for Advancement in Technology (GCAT)*, 1–4.

Gupta, N., Das, M. L., & Nandi, S. (2019). Landledger: Blockchain-powered land property administration system. *2019 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, 1–6.

Gururaj, P. (2020). Identity management using permissioned blockchain. *2020 International Conference on Mainstreaming Block Chain Implementation (ICOMBI)*, 1–3.

Huston, P., & Rowan, M. (1998). Qualitative studies. their role in medical research. *Canadian Family Physician*, *44*, 2453.

Irfan, K. M., Jawaid, I., Ahmad, A., Saddam, H., Amerah, A., & Sajid, U. S. (2022). Blockchain-based land registration system: A conceptual framework. *Applied Bionics and Biomechanics*, *2022*.

Islam, M. S., Iqbal, F. S., & Islam, M. (2020a). A novel framework for implementation of land registration and ownership management via blockchain in bangladesh. *2020 IEEE Region 10 Symposium (TENSYMP)*, 859–862.

Islam, M. S., Iqbal, F. S., & Islam, M. (2020b). A novel framework for implementation of land registration and ownership management via blockchain in bangladesh. *2020 IEEE Region 10 Symposium (TENSYMP)*, 859–862.

Kalodner, H. A., Carlsten, M., Ellenbogen, P., Bonneau, J., & Narayanan, A. (2015). An empirical study of namecoin and lessons for decentralized namespace design. *WEIS*.

Kaspersky. (n.d.). *Cryptography definition*. https://www.kaspersky.com/resource-center/definitions/what-is-cryptography%20[Last%20Access%20May%2009,%202022]

Kiayias, A., Russell, A., David, B., & Oliynykov, R. (2017). Ouroboros: A provably secure proof-of-stake blockchain protocol. *Annual international cryptology conference*, 357–388.

Kirk, J., Miller, M. L., & Miller, M. L. (1986). *Reliability and validity in qualitative research*. Sage.

Kitzinger, J. (2006). Focus groups.

Kuznetsov, A., Lutsenko, M., Kuznetsova, K., Martyniuk, O., Babenko, V., & Perevozova, I. (2019). Statistical testing of blockchain hash algorithms. *CMiGIN*, 67–79.

Liang, Y.-C. (2020). Blockchain for dynamic spectrum management. *Dynamic spectrum management* (pp. 121–146). Springer.

Lin, I. C., & Liao, T. C. (2017). *"a survey of blockchain security issues and challenges".*

Majumdar, M. A., Monim, M., & Shahriyer, M. M. (2020). Blockchain based land registry with delegated proof of stake (dpos) consensus in bangladesh. *2020 IEEE Region 10 Symposium (TENSYMP)*, 1756–1759.

Mangnani, R. S. Y. G. E. K. J. T. B., & Achhra, N. (2021). *Digital land registry system using blockchain.*

Manocha, P. M. S. S. K. (sep 3-4, 2021). Blockchain as an instrument for land ownership and authorization of services. *ICRITO*.

Mathijs, V. L., & van der Haar Gemma. (2014). La gouvernance foncière comme un moyen de renforcement de lÉtat au niveau local dans l'est de la rdc.

Mattila, J., & Seppälä, T. (2018). Distributed governance in multi-sided platforms: A conceptual framework from case: Bitcoin. *Collaborative value co-creation in the platform economy* (pp. 183–205). Springer.

Mays, N., & Pope, C. (2020). Quality in qualitative research. *Qualitative research in health care*, 211–233.

Meva, D. (2018). Issues and challenges with blockchain: A survey. *International Journal of Computer Sciences and Engineering*, *6*(12), 488–491.

Mizrahi, A. (2015). A blockchain-based property ownership recording system. *A Blockchain-based Property Ownership Recording System.*

Mohaghegh, M., & Panikkar, A. (2020). A decentralised land sale and ownership tracking system using blockchain technology. *2020 5th International Conference on Innovative Technologies in Intelligent Systems and Industrial Applications (CITISIA)*, 1–8.

Mugangu, M. (2009). La crise foncière à l'est de la rdc.

Natarajan, H., Krause, S., & Gradstein, H. (2017). Distributed ledger technology and blockchain.

ownest. (n.d.). *Nft month the science behind nfts.* https://ownest.io/en/news/nft-month-science-behind-nfts%20[Last%20Access%20Mai%2009,%202022]

Pacific, A. (n.d.-a). *An introduction to smart contracts and their potential and inherent limitations.*

Pacific, A. (n.d.-b). *An introduction to smart contracts and their potential and inherent limitations.*

Pérez Jiménez, C. (2018). Analysis of the ethereum state.

Poelstra, A. et al. (2014). Distributed consensus from proof of stake is impossible. *Self-published Paper.*

Pope, C., Ziebland, S., & Mays, N. (2000). Analysing qualitative data. *Bmj*, *320*(7227), 114–116.

Pranteda, V. G. F. L. C. D. C., & Santamaria, V. (2018). *"to blockchain or not to blockchain: That is the question," it professional.*

Quick, J., & Hall, S. (2015). Part two: Qualitative research. *Journal of perioperative practice*, *25*(7-8), 129–133.

Razali, S. H. S. H. O. M. N., & Mammi, H. K. (2021). *Secured data storage framework for land registration using blockchain technology,in 2021 3rd international cyber resilience conference (crc).*

Rosado, A., Ribeiro, R. A., Zadrozny, S., & Kacprzyk, J. (2006). Flexible query languages for relational databases: An overview. *Flexible databases supporting imprecision and uncertainty*, 3–53.

Sakibul, I. M., Shahriar, I. F., & Muhaimenul, I. (2020). A novel framework for implementation of land registration and ownership management via blockchain in bangladesh, 859–862.

Sen, S., & Wang, J. (2002). Analyzing peer-to-peer traffic across large networks. *Proceedings of the 2nd ACM SIGCOMM Workshop on Internet measurment*, 137–150.

Sheth, H., & Dattani, J. (2019). Overview of blockchain technology. *Asian Journal For Convergence In Technology (AJCT) ISSN-2350-1146.*

Sofaer, S. (1999). Qualitative methods: What are they and why use them? *Health services research*, *34*(5 Pt 2), 1101.

Spradley, B. W. (1980). Managing change creatively. *Journal of Nursing Administration*, 32–37.

Suganthe, R., Shanthi, N., Latha, R., Gowtham, K., Deepakkumar, S., & Elango, R. (2021). Blockchain enabled digitization of land registration. *2021 International Conference on Computer Communication and Informatics (ICCCI)*, 1–5.

Suryanarayana, G., Diallo, M. H., Erenkrantz, J. R., & Taylor, R. N. (2006). Architectural support for trust models in decentralized applications. *Proceedings of the 28th international conference on Software engineering*, 52–61.

Suryanarayana, G., & Taylor, R. N. (2006). Tref: A threat-centric comparison framework for decentralized reputation models. *Institute for Software Research, University of California, Irvine, Technical Report UCI-ISR-06-2*.

Syed, T. A., Alzahrani, A., Jan, S., Siddiqui, M. S., Nadeem, A., & Alghamdi, T. (2019). A comparative analysis of blockchain architecture and its applications: Problems and recommendations. *IEEE access*, *7*, 176838–176869.

Szabo, N. (2018). The idea of smart contracts. nick szabo's papers and concise tutorials. *URL http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool20*

Vasin, P. (2014). Blackcoin's proof-of-stake protocol v2. *URL: https://blackcoin. co/blackcoin-pos-protocol-v2-whitepaper. pdf*, *71*.

Vilatte, J.-C. (2007). Méthodologie de l'enquête par questionnaire. *Laboratoire Culture & Communication Université d'Avignon*.

Wang, W., Hoang, D. T., Hu, P., Xiong, Z., Niyato, D., Wang, P., Wen, Y., & Kim, D. I. (2019). A survey on consensus mechanisms and mining strategy management in blockchain networks. *Ieee Access*, *7*, 22328–22370.

Williams, C. et al. (2007). Research methods. *Journal of Business & Economics Research (JBER)*, *5*(3).

Zheng, Z., Xie, S., Dai, H.-N., Chen, X., & Wang, H. (2018). Blockchain challenges and opportunities: A survey. *International Journal of Web and Grid Services*, *14*(4), 352–375.

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017). An overview of blockchain technology: Architecture, consensus, and future trends. *2017 IEEE international congress on big data (BigData congress)*, 557–564.

Zhou, W., Simpson, E., & Domizi, D. P. (2012). Google docs in an out-of-class collaborative writing activity. *International Journal of Teaching and Learning in Higher Education*, *24*(3), 359–375.

Zurawski, R. (2014). *Industrial communication technology handbook*. CRC Press.