UNIVERSITY OF THESSALY

BACHELOR THESIS

Investigation of property management trends based on blockchain technology

Διερεύνηση των δυνατοτήτων αποκεντρωμένης διαχείρισης και αξιοποίησης ακίνητης περιουσίας με χρήση της τεχνολογίας blockchain

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Declaration of Authorship

I, Stergios KOUTOURATSAS, declare that this thesis titled, "Investigation of property management trends based on blockchain technology" and the work presented in it are my own. I confirm that:

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- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
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"trust (noun) : firm belief in the reliability, truth, or ability of someone or something."

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UNIVERSITY OF THESSALY

Abstract

Department of Electrical and Computer Engineering

Diploma in Engineering

Investigation of property management trends based on blockchain technology

by Stergios KOUTOURATSAS

The buying and selling of residential and commercial property is a complex process concerning itself with legal, economic and technological matters. Real estate is the biggest asset class in the world, a consequence of housing being important and a top priority for most people as well as of the necessity of commercial property for economies to flourish. Despite its importance, the real estate sector is traditionally slow to adapt to technological changes. The current process involves multiple steps and many intermediaries to secure every step of the transaction as property is a high value good. Every professional involved in the process adds to the total costs and time to completion with fees and additional information exchange. Real estate transactions are further burdened in costs and delays by the outdated and inefficient practices employed by land registry authorities around the world. The result is a time-consuming process with the fees being a considerable percentage of the final sale price. This thesis explores the ways blockchain technologies can be applied in the real estate sector in order to enhance the transaction process and whether such expectations are realistic.

Οι αγοραπωλησίες οικιστικών και εμπορικών ακινητών αποτελούν μια σύνθετη διαδικασία στην οποία εμπλέκονται νομικά, οικονομικά καθώς και τεχνολογικά στοιχεία. Η στέγαση είναι άκρως σημαντικό δικαιώμα και βρίσκεται σε υψηλή προτεραιότητα για τους περισσότερους ανθρώπους. Επιπλέον, τα εμπορικά ακίνητα αποτελούν το θεμέλιο πάνω στο οποίο μπορεί να αναπτυχθεί μια ισχυρή οικονομία. Ως απόρρεια αυτών, η ακίνητη περιουσία είναι η κατηγορία περιουσιακών στοιχείων με την μεγαλύτερη αξία. Παρά την σημαντικότητα του, ο τομέας των ακινήτων προσαρμόζεται με αργό ρυθμό στα νέα τεχνολογικά δεδομένα. Η διαδικασία της αγοροπωλησίας αποτελείται απο πολλαπλά βήματα αλλα και πολλούς μεσάζοντες για την διασφάλιση των συμφερόντων των συμμετοχόντων σε κάθε βήμα, καθώς ενα ακίνητο είναι αγαθό υψηλής αξίας με υψηλό ρίσκο. Κάθε επαγγελματίας που συμμετέχει στην διαδικασία αυξάνει τα συνολικά κόστη αλλά και τις καθυστερήσεις αφού περιπλέκει την συναλλαγή πληροφορίας. Οι συναλλαγές ακινήτων επιβαρύνονται επιπλέον απο τις ξεπερασμένες και αναποτελεσματικές πρακτικές που εφαρμόζονται απο τις υπηρεσίες του κτηματολογίου και του υποθυκοφυλακείου ανα τον κόσμο. Το αποτέλεσμα είναι μια χρονοβόρα διαδικασία με τα συνολικά κόστη να αποτελούν ένα σημαντικό ποσοστό της τελικής τιμής πώλησης. Η διατριβή αυτή αποσκοπεί στο να εξερευνήσει τους τρόπους με τους οποίους οι αποκεντρωμένες τεχνολογίες blockchain μπορούν να ενισχύσουν την απόδοση της διαδικασίας των αγοραπωλησίων και αν μια τέτοια βελτίωση είναι ρεαλιστική.

Contents

List of Abbreviations

CRE	**C**ommercial **R**eal **E**state
HVLF	**H**igh **V**alue **L**ow **F**requency
MLS	**M**ultiple **L**isting **S**ervice
MoU	**M**emorandum **o**f **U**nderstanding
PPP	**P**ublic **P**rivate **P**artnership
GDP	**G**ross **D**omestic **P**roduct
API	**A**pplication **P**rogramming **I**nterface
UTXO	**U**nspent **T**ransaction **O**utput
ICO	**I**nitial **C**oin **O**ffering
PoW	**P**roof **o**f **W**ork
PoS	**P**roof **o**f **S**take
PoA	**P**roof **o**f **A**uthority
DoS	**D**enial **o**f **S**ervice
EVM	**E**thereum **V**irtual **M**achine
UI	**U**ser **I**nterface
API	**A**pplication **P**rogramming **I**nterface
DLT	**D**istributed **L**edger **T**echnology
BFT	**B**yzantine **F**ault **T**olerance
P2P	**P**eer **T**o **P**eer
STO	**S**ecurity **T**oken **O**ffering

Dedicated to my family and friends.

Chapter 1

Introduction

1.1 Real Estate

Housing is a fundamental human need and the pillar upon which people build their lives and careers. The lifelong dream of acquiring a house is a driving motivator for many people. Not many people can achieve this dream however, as housing affordability is becoming a rising cause for concern across many countries [56], with costs and consequently house prices escalating. Unsurprisingly, a home is one of the biggest, if not the biggest, purchases a person will make in their lives.

Two consenting parties are not enough for a transaction to take place, as trust needs to be established and every step of the process has to be scrutinized by professionals to make sure no party is subjected to deceit. As a consequence, a real estate transaction ends up being a highly complex, confusing and multi-step process with a plethora of hidden fees, as many having taken part in one can confirm. Contributing to aforementioned fees, is the number of intermediaries involved along with the sheer amount of documents which need to be validated multiple times.

Property or *real estate* is the biggest asset class in the world, achieving a place next to bonds and equities in the stock market [99]. The buying and selling of property is part of the real estate market, which constitutes a very big slice of a country's economy. Consequently, economic growth is directly intertwined with the real estate sector. The real estate market is in fact larger in value than the stock market or other financial markets [29], reaching $8.5 trillion in size in 2017 [84]. Apart from its inherent value, real estate provides the necessary infrastructure for businesses to operate and thus for a modern economy to flourish. It also offers major employment opportunities for architects, builders,engineers and everyone involved in the process of construction. The impact on a country's GDP is indeed tremendous.

1.2 Motivation

There are several problems with the real estate sector today, many of which are a result of outdated practices. The barrier for entry into the market is also remarkably high, prohibiting small players from participating. Real estate transactions are not only financially costly (with fees rising to 11-22 % of property value as per [56]) as mentioned above but also time-consuming, with a figure of one and a half months not being unrealistic. Research into how beneficial an improvement in cost, security and transparency of transactions would be for the industry revealed that there is great demand for a solution that can secure trustworthiness and steadiness of information involved in the transaction [94]. Buyers, sellers, investors and even the government could benefit by taking advantage of new technologies. Real estate, however, is a paper based industry which has been slow to adopt new technologies [99]. Despite that, [29] found that transparency, followed by cost reduction and security are the main motivators moving the industry to technological change.

Blockchain technologies have been a major disruptive force these last few years, especially in the financial sector. Applications of this technology go far beyond the buzz of cryptocurrencies. This relatively young technology seems like a promising candidate for enhancing the process of real estate transactions, as its decentralized nature offers a trustless environment in which it is possible to conduct transactions without intermediaries. Furthermore it is said to provide an immutable and secure way to register ownership, a practice essential to the correct functioning of the real estate sector and usually the responsibility of each country's government.

1.3 Purpose of this Thesis

The purpose of this paper is to examine whether blockchain technology in its many variations and intricacies is ultimately a suitable addition to the real estate sector. The benefits of the technology as well as its shortcoming will be presented. The immediate question of whether the existing real estate sector's infrastructure can harmoniously co-exist with the replacement of outdated practices with blockchain-based ones or if major disruption needs to ensue will also be considered. The parties most at risk from such disruption are enumerated and roles for them under the new functioning are suggested. Finally, real life attempts to apply a blockchain solution to the registration process in various countries are presented and the degree of their success is analyzed.

The rest of the thesis is organized as follows. Chapter 2 discusses the current state of property registration and real estate transactions as well as the major challenges present in these processes. Chapter 3 provides an overview of blockchain technologies and related concepts used later in the thesis. In chapter 4 the main arguments for the use of blockchain in real estate are presented and the viability of such solutions is briefly analysed. In chapter 5, current research and attempted implementations are reviewed and discussed. Finally, chapter 6 concludes the thesis and highlights the points where more research needs to be conducted.

Chapter 2

Current state and Major Challenges

2.1 Land Registration

Land registration refers to the practice of recording property rights by government officials in order to provide evidence of ownership, facilitate transactions and prevent fraud [7]. The land registry is maintained by public authorities, either courts or administrative bodies [37]. A well functioning land registry is a prerequisite for economic development as well as confidence and stability within a country's boundaries [88]. For the government, these records are essential to collect taxes, provide services and establish its territorial authority. For citizens, the status of land rights can affect their access to economic opportunities [7].

2.1.1 Titles and deeds

There exist two different systems for land registration that countries employ. While each country operates with slight differences, two major land registration systems can be distinguished; *registration of titles* and *registration of deeds*. Under the deed registration system, which developed first, the documents required for a land transaction are registered and kept in a government database, usually in paper form. Thus, the land registry consists of a collection of documents which are simply checked for legal validity. Current ownership is not evidently clear in such a system and the chain of transactions has to be scrutinized in order to find the current owner. This system is widely used in the United States [44], Belgium, France, Italy and the Netherlands [37]. On the other hand, title registration involves the examination of legality of such documents and afterwards, the rights to land are recorded directly on the register. The identification of the current owner is faster under this system. Title registration is employed by most European countries including Greece [94]. An abstraction of how the two different systems would exist in a digital registry is shown in figure 2.1.

Cadastre is a term closely linked to land registration. According to [25] a cadastre is systematically organised database containing property data within a jurisdiction. The information is based on a survey of the property's boundaries. It is mainly a technical registration describing where a property lies and how large it is [101]. A cadastral map is a map visually indicating the boundaries of land parcels. A land parcel refers to a plot of boundary-defined land which is meant to be owned by one or more parties. The cadastre is used in conjuction with a registry for land registration.

Title registration was first introduced as an alternative to deed registration by Sir Robert R. Torrens in South Australia who believed that a register should show the actual state of ownership and be guaranteed by the government [25]. This system called the Torrens title system is distinct from other title registration systems such as

FIGURE 2.1: Deeds and titles in a digital database.

Title Unique ID	Owner
9blwN9lZzWy8U4EX	Phillips
7aLsLYuKzaaHqtXS	Davis
ag1N7jJ5pSPrLmfE	Scott

Deed Unique ID	Transaction
ZQ74eo:date	Lee inherited *Land_ID* from Bob
aPN6hn:date+t	Lee conveys *Land_ID* to Jenkins
S0igTS:date+t+t1	Jenkins conveys *Land_ID* to Cole

the English system and the German/Swiss system [101], with the main differences lying in the way parcels are described.

2.1.2 Bundle of rights

A common practice of registration involves a triple of data [94]. The structure essentially consists of: the Object (spatial unit), the Rights (personal rights) and the Subject (title holder connected to the object). Each of the items on the triple can implicate one or more parties. For example, titles can be divided in the case of co-ownership. Co-ownership means that the property belongs to all co-owners equally while in joint ownership shares of the property are owned by the co-owners. Additionaly, subordinate rights exist apart from the right of full ownership. These include the right to use a property, the right to control the property as well as the right to build on the land.

Bundle of rights is a term used in Common Law to describe the complexities of property ownership. [44] narrows the broad spectrum of rights down to three main ones. The right to dispose, the right to possess and the right to use. Disposition means changing the legal status of the property and includes renting it out, selling it and mortgaging it. Possession implies the right to control and physically possess the object. The right of usage or the right to enjoy is the right to enjoy useful properties of the object. Many real life cases are covered by the above abstraction. When a landlord, using his right to dispose, rents the property out to a tenant he temporarily gives up the right to possess and enjoy which are then transferred to the tenant under the conditions of a contract.

2.1.3 Registration Principles

The main land registration principles as described by [94, 101] concern both types of land registration.

Speciality principle: The object (property) and the subject (owner) must be clearly and unambiguously identified in the documents submitted to the registry and consequently the entries in the register itself.

Booking principle: The change in a right, as in a transfer of property, is not legally valid until it is registered in the land registry.

Principle of publicity: The land registry is open for public inspection.

Consent principle: Consent must be given by the subject when a change concerning them is made in the register.

While these principles are not always adopted by all countries, they act as a base for comparison between different land registration systems. [94, 101] present another set of principles which are specific to title registration. Compliance with the following principles is speculated to determine the success or failure of a title registration system. Chapter 4 will analyze whether blockchain technology facilitating a title registry is compliant with these principles.

Mirror Principle: The title register is an accurate and complete representation of the facts regarding a title.

Curtain principle: A potential buyer can completely rely on the contents of the registry and it is the sole source of information he needs.

Insurance principle: Loss suffered due to a fault in the registry is compensated. Accurate information in the registry is guaranteed.

2.2 Transactions

A real estate transaction refers to the complex and regulated process of selling or purchasing real estate property often involving one or more agents. [46] categorizes a real estate transaction as a high-value low-frequency transaction. High-value, because for the majority of people a house or property is the most valuable asset they own. Low-frequency, because excluding professional traders and agents most people will conduct a real estate transaction less than ten times in their lifetime.

The high-value part implicates a big financial risk for the buyer of a real estate transaction as he is is putting up a large part of his wealth on an asset. Furthermore, a property and its features are hard to explicitly define and most people, whether they participate as buyers or sellers will feel the need for assistance by a professional in this long process. Real estate agents are employed by both parties for the information expertise they provide.

2.2.1 Steps of a transaction

[14] presents the transaction process divided into five steps. While these steps differ for every economy and different details appear in the literature, they provide a sufficient general outline of the process.

1. Listing: The seller prepares the property for sale during this stage. They acquire the necessary paperwork, consider the pricing and set up a personal advertisement for the property. If a real estate agent is employed to help with the above decisions, they are rewarded with a commission if the house is sold. The agent now takes on the responsibility of advertising the property and showing it to potential buyers.

An **MLS** or Multiple Listing Service is a database of property for sale operated by real estate agent offices, usually with access limited only to them. Agents can add and view all property listings in an area. As a consequence, property that's not listed with an agent misses out on a large chunk of potential buyers, making real estate agents invaluable to the current process. Thus, the advertising of a property can be done either independently by the seller or through an agent.

2. **Searching:** During this stage, buyers look for houses that fit their needs in price, location, size and features. This can be done independently by contacting sellers through their advertisements posted on newspapers or online services. If the buyer enlists the help of an agent he can benefit from professional advice on the specifics of a particular property as well as gain access to information of MLS-listed properties.

3. **Evaluation:** The high-value aspect of real estate transactions mandates careful consideration on the buyer's side. In this stage the buyer usually examines the property in great detail during a physical showing. The showing is arranged between seller and buyer at a date where both are available.

   An agent makes the process significantly easier on both sides. He can show the property to interested buyers at much more flexible schedules and organize open house events during which anyone interested can attend and walk through the house.

4. **Negotiation:** The buyer, often with the help of an agent, makes an offer for the property he settled on. The seller reviews the received offers for a property and might make a counter-offer to some of them for a higher price, usually under an agent's counsel.

   After both buyer and seller agree on a price, a binding contract is drafted. This is the stage where more professionals are involved in the transaction process. Banks which provide financing for the sale, property appraisers who look for defects that may affect the price and lawyers who are responsible for the contract details as well as title search in the land registry to ensure the title is legal and valid are some of them. These actors are discussed further in subsection 2.2.2.

5. **Execution:** The sale is finalised and the funds and property change hands. The buyer is given a deed (or title) for the house as proof of ownership. This stage is handled by third parties that both the seller and the buyer trust.

[39] describes the Swedish transaction process in 33 detailed steps highlighting the inevitable cross-checking with the Land Registry that happens multiple times within the process and also the loan granting process by the buyers bank. Most of these steps are executed by regular mail, over the phone or in-person meetings. This bureaucratic overhead adds up to a significant time to completion for the sale of a property. [57] reports an average of four months for Sweden. Two months for Hungary, three for Germany and four for Moscow on average are also reported by [38].

2.2.2 Participants in a real estate transaction

A transaction of goods in the general sense happens between two parties, the buyer and the seller. However, as the value of the traded good increases, so does the number of stakeholders involved. A stakeholder is a third party with an active interest in the transaction.

The main intermediary in a real estate transaction is the **real estate agent** who either operates independently or as part of a real estate firm. The terms "agent", "broker" and "realtor" are oftentimes used interchangeably in the literature. There is a difference however, in that a broker can operate independently while an agent can only work under the employment of a broker, who is more qualified [76]. "Realtor" simply refers to a member of a realtors' association, which includes other real estate professionals. As mentioned, the real estate agent can either represent the seller, the buyer or sometimes, both. When working with a buyer, he is responsible for helping him find a property that is most suited to his needs. A seller's agent tries to advertise the property in order to attract as many buyers as possible. They also facilitate the transaction by processing offers and counter offers made by either party as well as providing advice. They are primarily interested in the finalization of a sale as they are paid a commission for it and often don't have the best interest in mind for both the seller and the buyer they represent [28].

Lawyers are necessary on both seller and buyer side to provide security in such a complex process. Representing the interest of their client, the lawyer's main role is to ensure that the agreement of the transaction is properly translated into legal terms. All necessary documents are reviewed before a contract is signed to ensure no legal issues arise in the future. On the buyer's side, the legal professional can conduct searches in the land registry regarding the title and property tax information [66]. The title search process on the property can also be conducted by a dedicated **title company**. In the case of a loan the buyer's lawyer also handles mortgage documents. Counsel on legal details is provided throughout the whole process.

In order to decide if they are making the right decision the buyer can hire a **home inspector** during the evaluation stage. The inspector provides crucial information that cannot be discovered by a simple title search to the buyer such as the physical condition and defects of the property [30]. Depending on the buyer's judgment they may also employ more specialised inspectors who perform more than general checks on the property.

Buying a property requires a large amount of funds. While some buyers complete the transactions with cash the majority need some kind of financing. A **lender** is a person or financial institution that provides the funds needed for housing with an interest rate. The role is usually taken on by a bank that provides a housing loan. The term "mortgage" is seen often when discussing real estate transactions. In a residential mortgage loan the buyer puts the newly bought property up as collateral for the loan [54]. Should the buyer fail to conform to mortgage terms, the lender has a claim to the property and may sell it to clear the debt.

Protecting its interest, the bank will want to make sure that the property is worth lending money for [48]. A **home appraiser** is employed by the bank to estimate the value of the property, its condition and whether the loan amount is appropriate. An appraiser is an independent third party who might get involved in the process even if the transaction is an all cash deal.

An **escrow agent** is sometimes involved in the process as a trusted third party to hold onto the funds or the deed to the property itself until certain contractual elements are fulfilled [35]. The function of an escrow agent can be facilitated by a lawyer, a notary or a title company.

Licensed conveyancers or **notaries** are public legal professionals whose responsibility is to notarize the transaction documents at closing. A notary is present when both seller and buyer sign the various contracts and certifies with his stamp that the signatures are authentic. Furthermore, the notary collects, verifies and stores the necessary documents. Lastly they send the deed to a **registrar**, a public official who updates the land registry, effectively updating ownership [94].

2.3 Challenges in the registration process

A trusted, updated and well-functioning land registry is essential for the real estate market and the economy as a whole. These records can be used to protect owner's rights, prevent fraud and resolve disputes [41]. However, not all countries currently have developed land registries [88], with some countries struggling with fraud and corruption and others not having a land registry at all. Even countries with developed systems are constantly looking for solutions to optimise them.

2.3.1 Limitations of land registration systems

Paper based registration A principle distinction of land registration systems across different countries is whether their records are digitized or held in physical/paper form. Countries with digitized records are much closer to adopting new technologies and increasing their speed and security in registration. Many countries however still keep their records in paper form usually in a centralized location, as is the case with Greece.

An obvious challenge with such systems lies in the difficulty of accessing and navigating the records. A legal professional conducting a title search for their client delays the transaction process considerably if they have to acquire a paper copy of a title or deed from a registrar in-person or by mail. Maintaining paper records can also prove difficult since every title conveyance adds a considerable amount of documents to be held by the registry authority.

Perhaps the biggest issue of single-copy paper records is their vulnerability to degradation and natural or man-made disasters [7]. A prime example of such disaster is the 2010 earthquake in Haiti which completely destroyed government facilities and as a result wiped out the majority of land registry records [2] leaving the country in a chaotic state with ownership disputes and legitimate owners unable to sell their property as ownership could not be proved. Digitization of records in paper-based systems is a big step towards security since digital records can be backed up and kept in different locations.

Centralization Having a single point of failure is always cause for concern as seen above. Land registration records are kept exclusively by government agencies in highly centralized systems. Regional land registries exist to take the load off a huge nation-wide database which would process a huge amount of real estate transactions. The challenge of centralization remains, however, since information about a property can only be found in the regional land registry of its jurisdiction. Such databases are also vulnerable to malicious third-party attacks which can delete or alter records. A centralized system is not inherently disadvantageous, however, it requires a well-functioning and highly-secure infrastructure as well as a trustworthy authority to operate it. Not all countries can afford the "luxury" of trusting the ruling government [91].

Lack of transparency While some countries (127 out of the 190 economies investigated by [87]) keep their land registries open for public inspection, many do not. While this decision is usually made concerning the privacy of individuals whose information is in the register, it makes the process a lot more complicated. An interested party possibly has to go through a legal professional plus a registration officer to get the contents of the registry they are looking for. Not only does this intermediation add to the delays, it is usually done for a fee.

According to [19], under Greek law one has to visit the regional land registry office which covers the area in which the property they are interested in lies. They must then submit a paper application, strictly in Greek, requesting the information. The excerpt can then be received at the registry office or sent by mail in paper form. Each request costs about 12 EUR and must be accepted or rejected within five days of application. It is issued after this procedure is completed. These request are most commonly executed though a lawyer.

Even in countries where the land registry is open to the public, registrations happen during the tail end of a real estate transaction meaning that the majority of the process is opaque until the registry is updated. This is compounded by the fact that it takes even well-functioning registries a long time to update the title from the moment they receive a notarized contract. For Sweden, whose land registry is one of the most efficient in the world, this time is between three to six months [39]. Transparency in land registration systems is necessary to increase the efficiency of the real estate market. It increases public trust in government and promotes more investments in real estate, as costs are reduced.

Fraud, Corruption & Forgery Lack of transparency allows corrupt registration officials to change details on a record [88]. Forgery on land records can have serious implications and often goes unnoticed. [89] argues that incorrect paper records about property burst the US housing bubble ultimately leading to the 2008 financial crisis. During the crisis the Bank of America tried to recover money from mortgages they think they owned but incorrect or fraudulent paperwork regarding property contracts meant they had no right to do so [34]. Third world countries with oral agreements on land ownership and boundaries in the place of official registration are especially prone to fraud and disputes, which cause serious problems to both owners and the government.

The corruption degree of a country is directly correlated with the state of its land registry practices. Corruption can manifest itself in the land registry in the form of bribes to register or verify land information [77]. In fact, one in five users of such land services globally claim to have paid a bribe for them [87]. Bribes of this form decrease trust in the existing system, promote informal ownership agreements and create a barrier for land administration for those not able to pay them. Greece ranks 60th out of 180 Countries in the severity of public sector corruption in an investigation conducted by [91].

Inefficient and unorganized systems All existing registries, whether digital or on paper, contain inaccuracies [23]. These inaccuracies are usually caused by human error and are, for the most part, harmless. Other times owners neglect to register changes with their property. Over time however, these errors pile up to create a register that simply does not reflect the actual situation. Poor management can mean land disputes, missing or outdated information and possibly multiple records for the same property. It should be noted that in the case of renting property, tenant rights are usually not visible in the land registry but only known to the tax authority to whom the rent income is filed by the landlord.

Outdated, time-consuming and expensive practices are prevalent across most countries. In addition, the huge amount of documents that have to be signed can also lead to errors that end up getting rejected by the land registry, thus having to be filed again, doubling the delay [40].

An example of a land dispute caused by an inaccurate land registry causing problems in economic growth is the case of the disused Hellenikon airport site in Athens. An 8 billion EUR investment in the site has been stalled because of disputes between the national forest agency, the government and the contractor [69].

2.3.2 The Land Registry in Greece

FIGURE 2.2: Monetary and time costs for registering a property in major Greek cities. Source: [86].

Location	Registering Property Score	Registering Property rank	Procedures (number)	Time (days)	Cost (% of property value)
Alexandroupoli	46.9	3	11	33	4.8
Athens	46.9	3	11	26	4.8
Heraklion	36.7	6	10	134	4.9
Larissa	47.1	2	11	31	4.8
Patra	47.8	1	11	24	4.9
Thessaloniki	44.7	5	10	130	4.9

Greece's land registry system has been criticised for its severe limitations. In fact, according to [86] Greece is ranked 156th out of 190 countries on the ease of registering property. There are no deeds for land in some parts of the country and the government has resorted to collecting property taxes by adding them to electricity bills. Transactional records are handwritten and identified by last name of owner, instead of a unique cadastral ID. Actually, cadastre maps cover just 7% of the country's total land. [81] states that adding the total area of registered deeds would result in twice the country's total area in an exaggerated way. The cumbersome process is quantified in figure 2.2, assuming an already registered, free of disputes property.

2.4 Challenges in the transaction process

2.4.1 Information asymmetry

A core issue with real estate transactions is information asymmetry. Every stakeholder involved in the process runs into problems with acquiring necessary information. Property information is distributed across many different actors such as real estate agencies, the government and specialists (ie. home inspectors) who hold onto the information with little motivation to share it since they profit each time they provide it, even for the same property. Furthermore, surveyors, engineers and other experts collect huge amounts of information about property without the obligation to ensure its quality [28]. Such vague information can be used by a real estate agent to sway the buyer into going through with the transaction, since his primary goal is the actual sale of the property. After price negotiations are completed, the buyer has a fixed time frame to conduct inspections and acquire relevant information, which increases the pressure on the buyer's side. These factors are to the disadvantage of the buyer who is called forth to make an informed decision in limited time. There is also the issue of owners not disclosing information about the property or possible defects in fear of negatively affecting the selling price.

The agreed price of a transaction is determined by the information available about market trends and the details of said property, among other factors. Inexperience related with the low frequency nature of real estate transactions on both sides and the aforementioned information asymmetry, which usually favors the seller as per [28], prove to be impediments to the formation of a rational price dictated by the trends of the real estate market or in other terms, by the economic theory of supply and demand.

The buyer responds to this information asymmetry by adding a perceived risk component to the transaction. Perceived risk is negatively correlated with the price a buyer is willing to pay. While disadvantageous to the buyer, information asymmetry also affects the seller who loses out on potential profit. The buyer can also try to combat the information asymmetry by hiring a plethora of specialists during the inspection period but this considerably adds to overall costs. The advantage to sellers disclosing asymmetric information is not directly evident to them.

2.4.2 Transaction costs

It's safe to assume that all the intermediaries and their associated fees, the inefficient information exchange and the multiple steps in the process add up to a significant total monetary cost. The figure for a home sold in the US is 10% of the total price in transaction costs [23]. In the Canadian real estate market, one of the more efficient ones, these costs range between 11-22% of the total purchase price. Unsurprisingly, such high fees render housing affordability a major concern in most countries. The cost in the latter market [56] can be broken down into: • Title search fees • Land transfer taxes • Appraisal costs • Lawyer fees • Agent fees • Notary fees. The need to establish trust between participants, partly due to the prevalence of fraud discussed in section 2.4.3, along with the information asymmetry that's typical of a real estate transaction are, of course, factors contributing to the costs.

Cost breakdown. Transactional costs, which include monetary setback, time delays and other difficulties, when acquiring an asset can be distinguished into *ex ante* and *ex post* costs [97]. Ex ante "before the event" costs are related to the establishment of the contract. Ex post "after the fact" costs are related to the verification of the parties involved in the contract. The latter costs are harder to reduce or eliminate because of the lack of trust and access to full information [29]. [38] provides a useful breakdown of the costs in the case of a real estate transaction.

Information retrieval costs The time and money spent by stakeholders trying to find relevant information. Activities include advertisement, comparing prices, searching listings, viewings etc. These costs are driven up by information asymmetry and are a source of revenue for real estate firms who undertake these steps of the process. The commission paid to an agent is between one to six percent the final sale price.

Negotiation costs The cost for communication between parties. As most of the communication is done by mail, phone or in-person this includes travelling as well as the cost for organization of the bidding process.

Measurement costs The cost of assessing the quality of real estate. Many of the qualities of a property are difficult to measure and quantify. Buyers resort to the help of experts while also depending on reviews and the reputation of the developer to feel confident in their decision.

The cost of securing property rights This category includes legal fees for notarization as well as the cost for registering the property rights with the land registry. The cost of interacting with a bank in the case of a mortgage loan as well as the cost for property appraisal conducted by the bank, which burdens the buyer, fit this category. Furthermore, insurance against fraud or the restoration of rights in case of a violation are included.

The cost of opportunism The complex nature of the real estate market gives rise to opportunistic behavior. Stakeholders withholding information, evading contract obligations and generally acting in fraudulent manners creates costs related to mending the consequences.

2.4.3 Scams in a real estate transaction

The real estate market is a major target for all different types illegitimate activities from money laundering to fraud. In fact, real estate fraud is one of the fastest growing types of white-collar crime since the housing crash of 2008 [59]. [38] estimates that 6-8% of real estate transactions show some sign of fraud. When fraud is prevalent in a market it breeds insecurity, driving the costs up and further complicating the processes with added bureaucracy and policies. For the victims the financial damage may be devastating. When there is a will, there is a way, and real estate scams come in several forms.

Title fraud. Title fraud is a rare type fraud in which the scammer transfers the title of a property to their name. This is done by impersonating the original owner, usually having stolen their identity and using false identity documents. The title is then used as collateral for loans that the criminal collects. The owner becomes aware of the fraud much later, when the lender attempts to claim the property for not receiving any funds back. An unlikely variation is that the scammer succeeds to sell the property. Most buyers, however, won't even consider buying a property without inspecting it [63].

Mortgage fraud. Mortgage fraud is a broad category of fraudulent practices that result into the approval of a mortgage loan that the applicant would normally not qualify for. An example is a borrower somehow enticing the third party value appraiser, possibly by bribing, to inflate the value of the property so that they receive a bigger loan. A more serious form of this fraud is when real estate and legal professionals in the loan transaction chain manipulate information, often working within a network, with the goal of stealing funds from lenders or homeowners [21].

Double-ended agent scam. Some countries allow for the same real estate agent to represent both the buyer and the seller. As mentioned previously, offers and counter offers for the sale of a property are usually communicated through the real estate agents of the buyer and the seller. When a fraudulent agent represents both parties they may provide confidential information about current offers (from other buyers and their agents) to buyers they represent so that they can win the bidding by a small margin. In that way the agent has doubled their commission since they have secured that a buyer they represent wins the bidding. This is achieved at the expense of the other buyers and their agents, who might have been willing to pay more than the winning bid. Of course, the seller also misses out on a potential higher selling price [52].

Double selling fraud. Taking advantage of the long delays until a transaction is registered, an ill-intentioned homeowner might attempt to sell a property to two different buyers. Taking advantage of the registration gap, the transaction closings are scheduled really close to one another so neither buyer knows that the property is being sold twice leaving them both in a very complicated legal situation [67].

2.4.4 Illiquidity

Transactions discussed previously were mostly **residential** real estate transactions, that is transactions involving property that is to be used for housing. **Commercial** real estate (CRE) or investment property refers to assets of land that generate a tangible income [99]. Profit is generated either through capital gain as is the case with other investment markets or through rental income. The same issues when transacting in residential real estate are also faced in commercial real estate transactions.

Real estate has become the biggest asset class in the stock market. The main difference however when compared to other assets such as stocks is the high entry barrier and the long term commitment of investing in property [99]. The entry barrier results because of the intense regulations, high transaction costs and the inherently large value of property. The current state of the market makes fractional investments a rare occurrence. A small player investing in real estate rarely has the opportunity to make an investment that would suit his capabilities; ie. buying X square meters of the whole property. The complex transaction process also makes it cumbersome to exit the market or "liquidate" the asset.

All these factors contribute in making commercial property trading an inherently illiquid asset class [65]. This property of CRE is not only to the disadvantage of investors but of the economy as a whole, since the development of real estate projects heavily depends on investments made during the construction phase of the project.

Chapter 3

Background

3.1 Blockchain

Blockchain, famously known as being the underlying technology of Bitcoin, is a distributed ledger technology (DLT) first introduced by Satoshi Nakamoto [64]. A *ledger* refers to a book of records for keeping financial transactions or in the digital case, a database. A distributed ledger is a database that is shared and synchronized across multiple points in a network. Each participant of this network maintains an identical, yet independent, copy of the ledger. In a blockchain network, which is based on peer-to-peer (P2P) topology, the participants are called *nodes*.

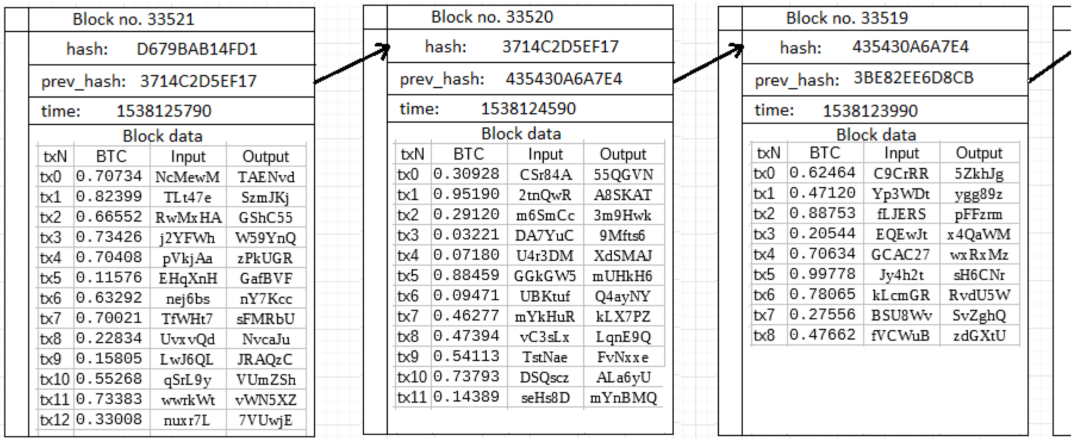
This ledger is not controlled nor kept by a single node in the network. In fact, for a change to take effect in the blockchain ledger, a node broadcasts its desired modification to the rest of the nodes,its peers, and then the whole network votes on whether the change is acceptable and which of the modified versions is the correct one. in a process known as *consensus*. If consensus is reached all the other nodes update their ledger with the new, correct version of the ledger.

3.1.1 Chain of blocks

While a blockhain is a distributed ledger, its data structure differs from that of a typical distributed ledger. As its name suggests the blockchain ledger is structured as a "chain" of cryptographically secured data blocks. A **block** contains a header and block data. The block's data is the information (transactions) that is to be saved on the ledger. The header contains important information about the block such as its position in the chain, its size and a timestamp. Three important values in the header are the cryptographic hash generated by applying a hash function to the whole block, the hash value of the previous block in the chain and the *nonce*, which is simply a number the manipulation of which changes the hash value of the entire block.

The first block in the chain is called the *genesis* block. Subsequent blocks are added by storing the hash of the previous block in their header. Since a small change in the data completely changes the hash of the block the blockchain ledger is tamper-proof as modifying the contents of a block will cause a discrepancy in the headers of the block that succeed it. This hash chain gives the blockchain the property of immutability; once a block is added it is permanent and cannot be changed. If a malicious actor wanted to change a block, they would have to change all subsequent blocks across all the network points which maintain the ledger. Figure 3.1 illustrates how data is structured in a blockchain.

FIGURE 3.1: Connected blocks in a blockchain.



3.1.2 Transactions

Blockchain, being a ledger, is used for recording transactions between users. A transaction is an interaction between users usually involving a digital asset. A user sends their desired transaction to a node and it is then propagated throughout the network. Before sending the transaction to neighbouring nodes, the node verifies the transaction is valid. Then, once a node receives it, it is added to the *transaction pool* which contains all pending transactions and is independently and locally kept by each node. Once there, it is chosen by a node to be *validated*. During validation the node will check if the sender has signed the transaction, whether he actually owns the asset and generally make sure it's valid. The node then adds it to a block along with other validated transactions, calculates the block metadata and tries to publish it. If the block is published all the other nodes check if the transactions within it are valid and if they indeed are, they add the block to their ledger. The block containing the transaction is now part of the blockchain. The state of the blockchain is updated each time a block is added.

A user participating in a transaction does not necessarily have to be running a full node. A user is associated with a pair of public-private keys, just like the ones used in an asymmetric cryptography scheme [53], which they use to manage their digital assets. From their public key an **address** is generated for use in transactions. A user sending a transaction to the network signs it using their private key to prove they are the owner of the address.

The Bitcoin and Ethereum blockchains both contain mostly transactions of their native cryptocurrency in their ledger. A cryptocurrency is a digital asset that is awarded for participation in the network and is used to perform actions, such as sending a transaction to the network. A *transaction fee* is an amount of cryptocurrency offered as a prize to the publisher of the block that it is included in, as an incentive for the publisher to include it over other pending transactions.

Transactions sent to the network consist of the input and output information fields. The input contains the digital asset that goes into the transaction, or roughly, the asset the user wants to transfer. The output of the transaction is what is to be received. These outputs can then be spent by being the inputs of other transactions. Unspent transaction outputs (**UTXO**) are outputs that have not yet been used in subsequent transactions. Tracking these scattered UTXO, the balance associated with an address can be calculated by software also known as a *wallet*.

3.1.3 Permission models

Four distinctions are made on the basis of who can participate in the blockchain network and what the participants are permitted to do [7].

1. In a **private** and **permissioned** blockchain access is restricted to specific authorised users. A central authority controls the permissions of who can participate, view or add to the blockchain. Transactions are validated by nodes authorised by the owner.

2. In a **public** and **permissioned** blockchain everyone can participate in the network and access blockchain data. However, transactions are validated only by authorised nodes.

3. In a **private** and **permisionless** blockchain everyone can add information to the blockchain. However, its contents are not publicly accessible.

4. In a **public** and **permissionless** blockchain any user can connect to the network as a node, add new blocks and view the contents of the blockchain. There are no restrictions on who can add to the ledger, so in order to prevent malicious users from adding blocks and compromising the blockchain, the right to add a new block is reserved to nodes who prove themselves to be trustworthy by completing tests set by the network. These tests are called *consensus* models and make it so adding a new block is a resource demanding process, deterring attackers.

A **hybrid** blockchain utilises elements of both private and public blockchains [37]. A system may keep transactions private and participation restricted to specific users but at the same time use a public blockchain to verify them; for example, by uploading a hash of confidential transactions on a public blockchain like Bitcoin.

3.1.4 Consensus models

The question of who publishes a block is answered by which consensus model is used. Several such models have been developed, such as:

Proof of Work (PoW). Nodes compete with each other in a process called *mining* to solve a hashing puzzle. The first node to solve the puzzle gets to publish the next block in the blockchain and is awarded an amount cryptocurrency associated with that block along with the sum of transaction fees contained therein. The mining nodes or *miners* are motivated by this award to keep validating transactions and keep the network working. The miners have to create a block that when hashed produces a value lower than a limit called the *target*. By manipulating the nonce value of a block header, miners can unpredictably change the hash value of a block. Depending on how small the target is, finding a hash in the accepted range can be very computationally demanding. Verifying whether a solution is acceptable, however, is as easy as calculating a hash value. The winning mining node sends the mined block to the rest of the nodes of the network, who verify it does indeed produce a hash satisfying the puzzle and if so, they add it to their copy of the blockchain. Both the Bitcoin and the Ethereum Blockchain utilize this consensus protocol at the time of writing.

Proof of Stake (PoS). In this model, nodes prove their good intentions by having a stake in the functioning of the network. Nodes stake an amount of cryptocurrency for the chance of being the next node to append a block to the blockchain. This stake is then locked and cannot be spent. The chance of a node publishing a block is proportional to the amount they have staked in relation to the total amount staked by the whole network. A node with a stake in the process is selected according to the specifics of each implementation and is eligible to publish a block. The miner validates the transactions and adds them to a block. If the majority of the network accept the block as valid the miner receives the rewards associated with the block. The stake acts as incentive for the miner to not create or validate fraudulent transactions as they will lose their stake if such a transaction is detected by the network. Various implementations use concepts such as aging in order to prevent nodes with large stakes from monopolizing the block creation process [9].

3.1.5 The Blockchain network

The blockchain network is comprised of equal computer nodes interconnected with no central point or authority. Nodes retaining a full copy of the blockchain are called *full nodes* and can independently verify transactions according to the information contained in their copy. Mining nodes are full nodes that are participating in the mining process. A node joining the network has routing functionality for finding and connecting to peers. Once connected it starts syncing to the current version of the blockchain. Information is passed from a node to its *neighbors*, or nodes it is connected to, eventually propagating throughout the entire network.

All nodes are actively listening for information about transactions and blocks. When they receive information about a new transaction they first verify it. It is then added to the nodes transaction pool and transmitted to the node's neighbors. When they receive information about a new block they verify its validity, verify that the proof of work is provided and then update their blockchain copy. The transactions included in the block are then removed from the node's transaction pool. A mining node receiving an update about a new block signifies the end of the mining competition so it immediately starts mining for the next block.

3.1.6 Forks

Network latency as well as the large amount of nodes competing in the block creation process, especially in permissionless blockchains, might mean that there are different blocks mined at the same time, causing discrepancies in the state of the blockchain at different points in the network. For example, in a PoW Blockchain, two miners might select different transactions from the transaction pool and as a result create completely different blocks. If they both solve the puzzle there are now two different, although correct, versions of the blockchain where in one of them transaction X has not happened.

This scenario is called a *temporary fork*. Most blockchain networks resolve such conflicts by waiting for the next block to be mined and accepting the version this next block was appended to as the official one. A node will immediately start solving for the next block and will ignore the alternate solution that arrived with a small delay. While mining the next block a node will most likely receive a message that a new block has been mined. The node will accept the new blockchain provided it is longer than the version he was working at the time, regardless if the new block was appended to his version or the alternate version he ignored. In other words, the longer chain is chosen and the shorter branches are pruned, with their now invalid transactions returning to the transaction pool. This chance of a transaction being revoked is the reason multiple confirmations, meaning blocks on top of the current one are needed before a transaction is considered complete. Most forks are resolved in the time it takes to mine the next block.

Changes to a blockchain's protocol or rules can also create a fork. A *soft fork* happens when blocks mined under a new protocol are also considered valid by nodes running the old protocol. A *hard fork* makes it so new blocks are incompatible with old versions of the protocol, thus creating two separate competing blockchains with different rules. When a hard fork happens, nodes choosing to participate in the new blockchain have to upgrade the software they use to connect to the network [68].

Consensus attacks. A 51% or "double spend" attack is a malicious attempt to invalidate transactions that have already happened by using a large amount of mining power and creating a temporary fork to the benefit of the attacker. A corrupt miner or group of miners begin the attack by successfully mining a block and not broadcasting it to the network. They continue working on this alternate blockchain, trying to add blocks faster than the rest of the network in order to make the illegitimate fork longer. Once the corrupt chain passes the threshold of length difference to be considered official it is broadcasted, effectively reversing transactions on the original chain [83]. Attackers controlling over 50% of the total network mining power will be able to mine blocks at a significantly faster rate than the rest of the network. As such, more mining nodes in a network mean more security. An attack of this type does not require control of strictly over 50% of the mining power and can be attempted with a lower but still significant percentage. The 51% figure is simply the threshold where the attack is guaranteed to succeed.

In a permissionless PoW blockchain such as Bitcoin, acquiring mining power that exceeds that of millions of miners across the world would be extremely costly and unrealistic. In a PoS blockchain, attackers would need to acquire over 50% of the circulating cryptocurrency associated with that blockchain, which depending on the cryptocurrency is similarly costly [9]. Furthermore, performing such an attack would devalue the cryptocurrency which is not in the best interest of someone supposedly in possession of the majority of the circulating supply.

Blockchain networks that have grown large enough have extremely low chances of suffering such an attack. A 51% attack is more common in smaller networks that are easier to overwhelm and in the scenario of some kind of bug in the blockchain code.

3.1.7 Smart contracts

Most blockchains, including Bitcoin, act as ledgers for recording cryptocurrency transactions. Ethereum consolidated new functionality with the concept of *smart contracts* [96]. Smart contracts are programs written in high level programming language that can be executed by the Ethereum Virtual Machine (EVM), an instance of which runs in every Ethereum node. The bytecode of a smart contract is stored in the Ethereum Blockchain.

Ethereum's virtual machine, EVM, is Turing complete and isolated, meaning it can only access information in the blockchain such as transactions, addresses and their balance. Deploying smart contract code to the network involves a user account sending a transaction containing the contract's bytecode to the network, without specifying any recipients. Once deployed the contract is now associated with an address, called the contract address, through which other users can interact with it. Much like user addresses, contract addresses have a balance, can be the recipients of transactions and even send transactions to the network. A user sending a transaction to a contract address triggers the contract code associated with that address. The code is then run and the results validated in every mining node.

Smart contracts consist of functions and data. Contract data can be permanently stored in the blockchain as persistent contract variables or temporarily in the scope of a function's execution. Storing data on the blockchain is a much more costly operation so as to prevent the size of blockchain data growing uncontrollably. Functions act as the contract's interface meaning they can be invoked by transactions or other contracts. The input required to run the contract is sent along with the transaction triggering it.

Since the EVM is Turing complete and every mining node has to validate the transaction, essentially running the contract code, it is possible to create programs that run indefinitely, effectively performing a Denial of Service (DoS) attack on the network. To deter malicious usage, every contract instruction costs a fee to be run on the network. This fee is paid with *gas*, which is bought with Ethereum's native cryptocurrency called Ether. The amount of required gas corresponds with the workload of the node validating a transaction. The total amount of gas fees in a block is awarded to the mining node that mines said block. Execution of contract code as well as the results are visible to the whole network.

3.1.8 Multisig addresses

Multisignature refers to transactions requiring multiple private keys to be authorized [11]. This practice can be used for joint ownership of cryptocurrency as well as to increase security. An M-to-N multisig address is an address associated with N private keys, of which M are needed to authorize the transaction.

Losing the private key associated with an address means that the funds it holds are lost forever. This single point of failure is not caused by weakness of the technology but rather by human error. Furthermore, the immutable nature of the blockchain means that in the case a private key is stolen, stolen funds cannot be recovered, even if the violation is proven. A 2-to-3 address, for example, provides security against such a scenario since the address requires two out of the three private keys to authorize a transaction and can afford its user the loss of one key. An M-to-N multisig address can be easily generated by a user by providing the public keys of N addresses. The resulting (empty) multisig address can then be used in any transaction sent to the network.

3.2 Blockchain Tokens

3.2.1 Token Value

Ownership of an asset, digital or otherwise, can be abstracted by creating a unique token, possession of which certifies ownership of the asset. While not a new concept by any means, blockchain's immutable and transparent ledger provides the suitable infrastructure to facilitate asset management through the use of cryptographic tokens. According to [44]: "a token is a record in the ledger owned by the user via the mechanism of public-key cryptography". A blockchain's native cryptocurrency can be considered a token according to this definition as it is indeed a record (UTXO) associated with an address. Tokens are a distinct concept from cryptocurrency, however, as cryptocurrency does not represent a separate asset but rather has inherent value as the commodity used to facilitate transactions in the network and motivate miners to keep validating transactions retaining the immutability of the ledger.

Tokens can be used to represent a plethora of assets from a single apple to property rights. It is noted that tokens can represent either divisible or indivisible assets as they can be programmed to be divisible themselves. The value of a token is user defined. Blockchain technology cannot guarantee the connection between the token and real life object but simply provides the certainty that a token will not be replicated and a secure way of transacting the token without the need of an intermediary.

3.2.2 Implementation

A token can usually be created by any user with minimal cost. The specifics depend on how the token protocol is implemented and the blockchain platform used.

Colored Coins. One of the earliest implementations of tokens on the blockchain was the *Colored Coins* group of protocols. In the context of the Bitcoin blockchain, this class of protocols involves using various techniques to add unique identifiers to transaction metadata so as to "color", or mark, small amounts of bitcoin. These coins are now re-purposed to represent an asset while also retaining value as cryptocurrency, although comparatively small to the value of the asset [3]. Taking advantage of unused transaction fields, specialized wallet software operating atop the layer of the blockchain allows a user to create tokens by tagging the output of a simple bitcoin transaction, called the *genesis* transaction. Using the wallet users can track these assets with the underlying blockchain technology offering immutability, non-counterfeitability and transparency to subsequent transactions. The cost of creation and transfer of these tokens is no more than that of sending cryptocurrency transactions to network plus the amount of cryptocurrency being colored. Coins can also be uncolored by removing the metadata during a transaction. The introduction of the `OP_RETURN` transaction opcode, which allows for 40 bytes of arbitrary information to be included in a transaction made the implementation of Colored Coins protocols easier.

Name-Value Storage. Other Blockchain platforms support more direct implementations for user generated tokens. [44] analyzes the *Name-Value Storage* overlaid technology introduced by Namecoin. This protocol allows users insert records in the form of a key,value tuple into the blockchain. The key or name field of the record is unique within the blockchain and only the address associated with its ownership can make changes to its value or transfer it. The author explains how the protocol provides standard database functionality. Updating the value of a record involves the owner posting a transaction requesting a value change to the network. The timestamped nature of blockchain guarantees the audit trail of changes to a record's value or ownership is left behind. Deleting the record and freeing up the key is also done through a simple transaction. The scheme can facilitate asset management but is more expensive than the colored coins protocol since it requires more data to be inserted in the blockchain.

Smart Contract Tokens. Token ecosystems can be implemented and managed with the use of smart contracts. A smart contract can represent a token and all the functions such as transfer, creation or deletion can be programmed as part of the smart contract. A divisible token corresponding to an asset uses a smart contract which stores the associated addresses and the amount of the token they own in the blockchain as contract variables. When invoked by the token owner to transfer an amount of tokens the contract function takes care of all the necessary validations and eventually updates the token amounts registered on the blockchain. All these operations are transparent and performed by the whole network. The smart contract should provide the interface to create the token, check the token balance of an address, the total circulating supply of the token as well as functions to transfer tokens and verify ownership of a token before asset manipulation. The user creating a token has complete freedom as to specifying the rules under which the contract operates, however, certain token standards exist that make the creation and functioning of tokens on top of the Ethereum blockchain a much more standardized process.

Token Standards. These standards dictate the necessary contract functions and the way they operate [4]. The **ERC20** token standard is used for divisible assets that are *fungible*, meaning that two units of the same token have the exact same properties and are interchangeable. This term defines most currencies, as two coins of the same value have no special properties differentiate them. The **ERC721** token standard, in contrast, can represent indivisible, *non-fungible* assets. Non-fungible assets are unique and cannot be copied. The ERC721 token standard is suitable to be used to represent ownership of an asset such as property. The main difference lies in the fact that the ERC20 smart contract tracks the balance associated with every address that holds some amount of the token, with the address being the key of the mapping, while the ERC721 smart contract tracks which address owns every unique token ID, with the token ID being the key of the mapping.

The implementation of a token that is non-fungible but can be divided into fungible parts, always in relation to the parent token, to facilitate crowd-ownership of an asset is possible using a combination of existing standards and the freedom provided by smart contracts. For example, using the ERC721 token which only tracks one owner per unique token we could take advantage of the fact that the owner address can be that of another smart contract that manages the divisions of original token as fungible tokens or that of a multisignature address.

3.3 Data insertion in the Blockchain

Many of the protocols seen above rely on inserting data into the blockchain for immutably recording records relating to the assets. Since every full node retains a full copy of the blockchain and blocks are constantly added, adding information not related to native cryptocurrency transactions or the main purpose of the blockchain is discouraged and taxed. This is of course to keep the blockchain from bloating with unnecessary data which will compromise the efficiency of validating transactions, syncing to the network and the general latency of the network. An example of an attempt to limit the amount of data inserted in the blockchain is seen with Blockchain's 2014 reduction of the `OP_RETURN` transaction opcode's byte count from 80 to 40 bytes by the community [22]. Another indication is Ethereum's high standard gas price for the store instruction compared to any other simple instructions in a smart contract (20.000 gas units vs. 3 gas units for an addition instruction) [98].

As mentioned before, ownership of a token is not enough to guarantee the connection between the token and the asset. Legal documents issued by the government may be necessary to certify that a token does indeed represent an asset. The immutability of blockchain makes it an attractive option for storing legal documents concerning tokens since it guarantees permanency and protection from being corrupted.

Anchoring is a technique used when storing data in the blockchain is impossible due to size or cost constraints. The technique involves using a blockchain as a shared source of truth to prove the validity of data which is stored off the blockchain. The data in question can be a single character string, a legal document or even another blockchain. Publishing a hash of the data, metadata concerning the file or a combination of both makes it easy for parties with access to the data and the blockchain to quickly verify if they are holding a legitimate version. The technique however does not help in the case the original file is corrupted or lost, since a hash does not suffice to recover a file.

Chapter 4

The Case for Blockchain in Property

After examining the functioning of the real estate sector and the intricacies of blockchain technologies it becomes clear that the two cannot be combined without major disruption in the industry. This is the result of blockchain technology being decentralized at its core, despite the fact that there are more centralized models than the public, permissionless blockchain. The real estate sector, in contrast, operates with highly centralized databases which require an authority to operate, many intermediaries who are employed to establish trust between participants and others, whose role becomes unclear in a theoretical blockchain ecosystem. It is important to consider whether blockchain technology in all its forms is a viable solution to mend the shortcomings of the real estate sector before dismissing long-established actors in the field as obsolete.

4.1 Land Registry

At the time of writing, the most prominent application of blockchain technology is registering cryptocurrency transactions without the need of verification by a trusted authority. One application of blockchain technology in real estate is immediately apparent as being used in place of the centralized databases of Land Registration systems. Deed registration from chapter 2 looks a lot like the registration of cryptocurrency transactions with rights to land being the object transacted and physical persons being the blockchain addresses while title registration can be thought of as the resulting world state of such transactions.

4.1.1 Adherence to registration principles

[94] examines whether a blockchain-based solution for a land registry would adhere to the registration principles mentioned in subsection 2.1.3. The entirety of transactions concerning an object are logged on the blockchain. In contrast to traditional land registry systems, a change in a blockchain land registry system would be almost instantly replicated among the participating nodes. A party checking for ownership is presented with an up-to-date and accurate history of transactions. As a result, a blockchain could be used as the official registry for documenting ownership, thus satisfying the **Booking principle**. Depending on the blockchain system in question, the **principle of Publicity** can also be satisfied. Public blockchains are fully transparent to the public, with the consensus method guaranteeing the contents to be immutable and valid.

The **Consent principle** is also satisfied as blockchain systems operate with a strong asymmetric cryptography scheme to prove ownership of an asset. No one but the owner of a private key can authorize a transaction involving an asset associated with the key pair. A public-private key pair, however, is not enough for legal identification required in matters of land registration. Users in public blockchains are mostly anonymous since there is no direct connection between a blockchain address and the physical person. This fact is in violation of the **Specialty principle**, which requires clear identification of persons mentioned in registration documents.

The **Mirror principle** requires the transition to a blockchain registry to be seamless, as the genesis block needs to contain information that accurately portrays the state of ownership at the time of transition. This is not always the case with registries lacking information about third party rights to land. The **Curtain principle** is respected as there is no doubt that the account in possession of an asset on the blockchain is the owner and one has to look no further to be assured of that fact. However, the issue of who the physical person behind the account is makes itself relevant again.

The **Insurance principle** highlights a pain point with the blockchain solution as the liability for a mistake in the process is uncertain with no trusted third party responsible for the registration. In a traditional system the intermediary responsible for drafting the mistake is usually the one liable.

4.1.2 Advantages of a Blockchain solution

While there has not been an established guideline on what the most appropriate implementation of a blockchain registry would look like, independent of the topology or type of blockchain, the advantages over the current system's shortcomings are several.

Disaster Recovery. An obvious advantage of a blockchain database is the implied redundancy. A blockchain solution for land registration means that the registry will be now replicated across a number of nodes, with a backup always being available in case one of the databases gets corrupt or suffers a natural disaster.

Efficient Registry Processes. Reduction of delays is another expected improvement of a blockchain solution. Under such scenario, the verification of land ownership is reduced to accessing blockchain contents; a near instantaneous process. Furthermore, registering or updating property rights would constitute of publishing the information to the blockchain network, which is a process much faster than the current one taking several months. Comparatively, a Bitcoin block takes approximately 10 minutes to be appended to the Bitcoin blockchain [3].

Less paperwork. Most countries' land registry is reliant on paper documents. Even extremely well-functioning and digital land registries have some degree of paper reliance [44]. Blockchain enabled registration has the potential to reduce the total amount of paperwork required even more, as notary related documents and verifications can be performed as part of the block verification process, with the network miners undertaking the role of notaries or other third parties.

Monetary Cost Reduction. An important benefit that may come with a blockchain implementation is the reduction of the currently high fees for registration as mentioned in subsection 2.4.2. Blockchain allows for the execution of concurrent registry operations, such as right transfers and registration, thus increasing efficiency and decreasing costs [90]. Another way costs would be reduced is by the elimination of trust-establishing third parties, each with its respective fee, since smart contracts could provide their service. Last but not least, the aforementioned reduction in paperwork could in turn reduce logistic costs and streamline the process.

Forgery Reduction. The immutable nature of blockchain is also expected to reduce forgery and curb corruption. While access to the system may still be the responsibility of a trusted official, changing the contents of a blockchain entry is an impossible task for a single corrupt party.

Secured ownership. An indisputable record of ownership on the blockchain provides the owner with the security that his property rights are not at risk of being challenged. This of course implies a clean starting state for the blockchain registry, where previous disputes have been resolved.

Intergration with smart city projects. A blockchain-based land registry provides the necessary infrastructure for the development a smart city; an urban area using digital technologies to make its functioning more efficient [18]. A blockchain land registry is compatible with other digital or blockchain-based administrative city functions, providing more possibilities to improve and simplify urban life.

Transparency. Depending on the blockchain system used, registry information can be open for public inspection, reducing information asymmetries and information gate-keeping. In countries with unreliable or corrupt officials, a transparent registry could restore the public's trust.

Enhanced Administration. The government can benefit by having access to a comprehensive database detailing an accurate state of land ownership. Increase in available information per household can be used to more easily enforce taxes or monitor and manage violations.

4.1.3 Types of Blockchain Land Registries

Blockchain systems come in different forms depending on their permission model. The public variant of blockchain is in many ways incompatible with the functioning of land registries today. When considering a blockchain implementation for land registries the question of which model is most suitable arises.

Permissioned Ledger. A permissioned blockchain is closest in function to the centralized nature of land registry systems. In the case a land registry takes the form of a private blockchain, a central authority, not unlike a current land registry authority, would be in control. A selection of trusted validators would comprise the participants of the system, through which consensus is obtained. Registrars, notaries and other intermediaries could assume this role. Depending on the country, this ledger can be open for inspection to the public or not.

A permissioned distributed ledger, while not being distributed to the degree of a permisionless one, would provide some benefits over a centralized database. First of all, participants would have access to the same information on the ledger at the same time and the full audit trail of transactions with a high degree of trust in the contents, since they can verify that they have not been altered using the cryptographic chain. Furthermore, consensus algorithms used in permissioned ledgers such as PoA (Proof of Authority), in which trusted nodes are arbitrarily granted the right to append the next block, are much less resource-intensive than the ones used in public blockchain systems with consensus often being instantaneously reached. The central authority can change the rules of the system at any time, voiding the property of immutability. This can provide the benefit of enforcing court-ordered decisions upon the system or reverse transactions without consent from the owner, who cannot be censored in a public ledger as he owns the private key.

While a slight improvement from the current system, a permissioned DLT system does have a certain degree of centralization. Most of the participants need to be trusted and free of corruption. Regarding security, due to the small number of nodes, such a system has only slightly better resilience than a fully centralized database against attacks.

Permissionless Ledger On the other hand, a permissionless ledger would allow anyone in the world to participate in the network with the visibility of the ledger's contents able to be adjusted to fit each countries needs. The registration of deeds and titles would be a responsibility of the public, driven to validate transactions by personal gain. The creators of the ledger would not be able to intervene and immutability would be a defining characteristic of the registry.

Such a system could restore trust in countries where land registries cannot be relied upon or where government officials are corrupt. The processing of transactions would improve in both efficiency and cost with every transaction being treated as equal. A major impediment in such a system is the element of human error [43]. Immutability means that human errors such as losing the private key that certifies ownership of a property can not be mended. Furthermore, while a blockchain land registry will leave no room for ownership disputes, it would necessitate the resolving of ongoing disputes in the current system for a transition to be made, which is a seemingly never-ending process.

Hybrid Ledger Most of the real life solutions discussed in chapter 5 lie somewhere in between. A hybrid solution using both permisionless and permissioned blockchains in a cross-chain protocol could assume many forms. The technique of anchoring to a public blockchain discussed in chapter 3 can be used where a hash of the whole permissioned ledger or a centralized database is periodically posted to a public blockchain to provide some amount of additional credibility. The actual data remains on traditional or permissioned distributed ledgers with the public ledger being used for accounting purposes. Such scenarios preserve the viability of intermediaries as validator nodes.

4.1.4 Limitations

[43] argues that while a hybrid or permissioned solution can address some of the limitations of the public blockchain variant they cannot be considered blockchain solutions since they are not inline with the creator's definition. According to the author, to the outside view a permissioned DLT is highly centralized and its honest functioning is entirely dependent upon the good will of the administrator. Furthermore, if the contents of the ledger are private, posting a hash to a public blockchain does little to prove legitimacy if the hash is the product of compromised entries.

[37] highlights some of the limitations that exist in implementing a blockchain based land registry, especially in the traditional public and permissionless form of blockchain. In a public blockchain land registry miners validating transactions do so in a technical manner rather than a legal one. A validated entry on the blockchain cannot provide the same legal security that a registrar can. Miners can validate the identities of the participants, the date and whether the claims of ownership made by the participants are factual based on the transaction trail in the ledger. In the case of title registration, the fact of ownership needs to be scrutinized before being added to the registry. This is in contrast to deed registration where the collection of deed documents is scrutinized at a later date when ownership is investigated. This makes a public permissionless ledger a better solution for deed registration as the validation of documents by notaries is limited to formal aspects and can be performed by miners.

Furthermore, land registries use timestamping of documents to determine priority in the case a conflict occurs, as in the case of double-selling a property by taking advantage of the time until the change in ownership is effectuated. In a blockchain ledger transactions are timestamped according to the time the block in which they belong to was added. Transactions in the transaction pool have no priority and are chosen arbitrarily by the miner that gets to append the next block. This gives the seller a chance to double sell the property while a change of ownership is pending in a transaction pool. This scenario further highlights the need for enhancing the process with trustless ways to enforce a transaction such as smart contracts.

Users in a public blockchain system remain partially anonymous. This anonymity can facilitate money laundering and other crimes [43]. In order for legitimate transactions to take place an ID system is recommended by both [37] and [43]. Electronic IDs, provided by notaries and other legal professionals, can be connected to each public address. [94] mentions the alternative of using a side chain for the legal identification of addresses on the main one. [37], in contrast to [43], proposes that a permissioned or hybrid variant of the traditional blockchain system can address some of these limitations.

4.2 Transactions

Apart from the registration of land rights, other steps of the transaction process seem to be fit for applying blockchain solutions. Of particular interest are the use of a blockchain platform where the participants of the transaction process exchange standardized information and the elimination of intermediaries in the transaction process using smart contracts. As seen in chapter 2 real estate transactions are mainly facilitated through real estate agents with notaries, lawyers and other professionals also being present in the process. Information is exchanged multiple times between the participants in the form of physical or digital documents, often redundantly. What is more, during some of these steps parties have to be physically present in order to sign documents.

4.2.1 A Blockchain Ecosystem

A first approach on how to apply blockchain technology in the real estate transaction process would be its use to improve information exchange. A distributed ledger can be used as a way to share relevant documents between the participants of the process. This can be done either by uploading the whole digital document; or for validation purposes by uploading its hash. A party required to sign a document would download it from the blockchain, sign it and then upload the new version that would be immediately visible to the other participants. In the case the blockchain is used for validation purposes that same party would receive the document, authenticate its validity by checking the hash posted on the blockchain, and post a new hash for the signed document before sending it. The audit trail created keeps the history of changes made to the original document. The permission model can vary in the blockchain used and different approaches will be analyzed in chapter 5.

A more sophisticated concept, the blockchain-based transaction ecosystem, as described by [29, 99, 90] would entail current stakeholders participating in the network with any changes in transaction status being logged onto the blockchain. The use of smart contracts can regulate the flow of information and also provide the escrow functions that are commonly provided by escrow agents, with the release of funds being triggered by the change of ownership. This can be either an on-chain event in the case of a blockchain-based land registry or triggered off-chain. The use of a public-private key pair in combination with electronic IDs can simplify the identification of the participants and allow participants to digitally sign documents.

4.2.2 Implications of a Blockchain ecosystem

Multiple sources [29, 99, 90, 28, 56, 17] argue for the improvements a blockchain platform would bring to the process. In particular:

Single platform. The use of a common platform where documents are accessible to all parties reduces the need for parties to be physically present and as a result could speed up the process. This distribution of information can also enable participants to easily check the progress of the transaction and act when they need to, further increasing efficiency. The challenge of information asymmetry is also addressed with an expected increase in the transparency of the process as participants have access to the same version of data. The use of digital documents can reduce reliance on paper processes and thus total cost. A single source of data can reduce data redundancy, a defining characteristic of the current process where the same documents are sent back and forth wasting resources and time.

Smart contracts. The utilization of smart contracts in such an ecosystem is expected to simplify the process. Smart contracts perform the role of establishing trust between participants meaning some intermediary fees can be excluded. More specifically "ex post" costs related to the verification of parties during the transaction are reduced [29]. Delays can also be reduced as smart contracts can execute immediately after triggering. Furthermore, they can facilitate concurrent release of funds and transfer of ownership, severely limiting the time window for fraud schemes.

4.2.3 Motivation & Challenges

In regards to the main motivating factors to adopt blockchain tecnhology in the transaction process [29] used a questionnaire on 1.050 participants of real estate transactions to find out which of the aforementioned benefits are the most compelling. Using SPSS software to analyze the results the authors found that increasing transparency was a key factor. The results, in decreasing order of influence, are shown in Table 4.1.

Composite Factor	Factors
1.Transparency	• Data availability • Reduction of information asymmetry • Transaction verification
2.Security	• Data reliability • Data immutability • Secure encryption
3.Cost Reduction	• Due to elimination of intermediaries • Due to process efficiency

TABLE 4.1: Results as interpreted from [29].

An attempt to transform the transaction process so radically is likely to be faced with challenges. Some of the stakeholders are directly benefiting from the current state of information asymmetry. A major part of their occupation consists of providing information to parties. Similarly, some stakeholders are benefiting from the lack of trust between participants. The adoption of such a system depends on the support of all stakeholders and at first glance, it seems that a blockchain ecosystem is not in the best interest of all of them.

Additionally, documents relating to real estate as well as digital data of property lack standardization. A well-functioning real estate ecosystem would require an accurate and consistent way to represent property data in addition to digital documents in a form suitable to be processed by smart contracts and other software.

4.2.4 Tokenization

The process of property tokenization on the blockchain coupled with techniques discussed above is another way to enhance real estate transactions. Furthermore it could create investment opportunities in a traditionally exclusive sector. Characterized by illiquidity, real estate investing is reserved for affluent investors and dominated by powerful organizations. Reducing opaqueness in the process could make the sector more accessible to new investors. The use of blockchain tokens can contribute to the ecosystem described in the previous section by providing a way to represent property on the blockchain using a digital-physical link. This means that transactions relating to each property will be registered automatically on the blockchain and smart contracts can seamlessly handle escrow and transfer of the token.

ERC 20 or ERC 721 tokens can be used, for example, to divide a property into smaller investment units which can then be traded via blockchain or through a secondary platform, increasing investment liquidity as they can be bought or sold with greater efficiency and less overhead than currently. The development of a real estate project could be funded by way of a security token offering (STO) [17], in which the developer of the project issues a predetermined amount of tokens representing fractional ownership of the finished project. The capital raised during the sale would be used by the developer while the investors can choose to do with the token as they see fit, instead of being locked into the investment until completion. The ease of blockchain transactions and the reduction of intermediaries should also positively benefit the real estate investment process. The reduction in fees and complexity can benefit both investors looking for more flexible options as well as project developers by increasing available capital.

Chapter 5

Research and Development Advancements

5.1 Land Registry

There have been several attempts to redesign and advance land registry systems towards a more digitized state through blockchain technologies with differing results.

5.1.1 Two differing cases

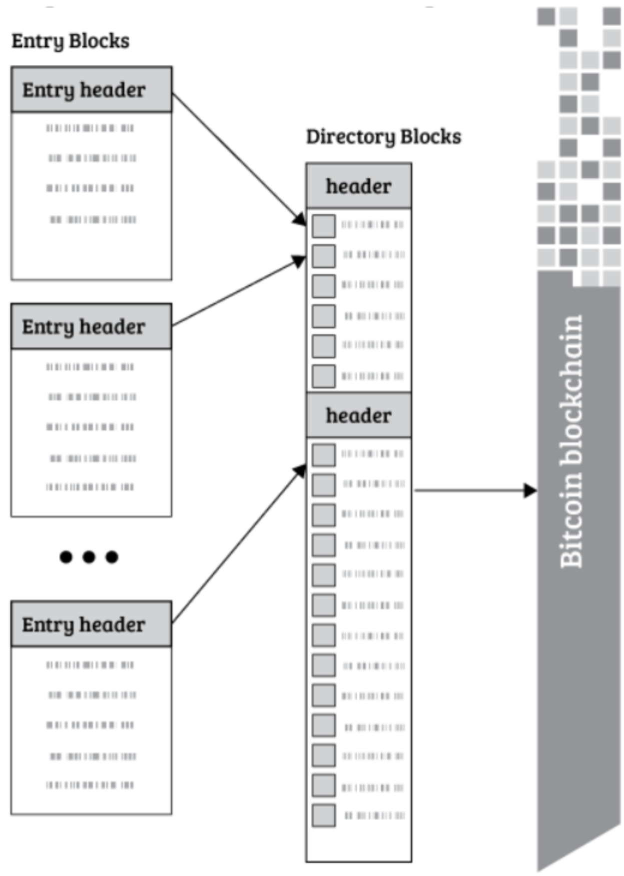
Two such initiatives are presented in [7], whereby two contrasting cases of attempted implementation in Georgia and Honduras are presented. The success of an initiative depends on a variety of factors. This paper introduces the metric of IS readiness, which indicates how well a company will implement an IT solution and derive benefits from it. As is expected, in the public sector, there exists a political component to this metric. A cutting-edge innovation might threaten a certain player's position so of course they would oppose it. When a government lacks the resources to implement such technology, as they often do, they employ the private sector. This concept is called a public-private partnership (PPP) and heavily influences IS readiness.

Honduras
As is consistent with developing countries' registries, Hondura's Land Registry system is plagued with inaccuracies. In fact, only 14% of Hondurans legally occupy properties [7]. Such a system guarantees that dispute and frauds are inevitable. In response, the Honduran government partnering with private firm Factom initiated plans to modernize the Land Registry using a distributed blockchain database. The main challenge was that the records existed solely in physical paper form, which meant that additional costly steps like verification and eventual digitization of records had to be made before they could move onto a blockchain. Factom proposed a blockchain solution layer operating on top of the bitcoin blockchain. Their data structure (figure 5.1) consists of :

- Entries : raw data
- Entry blocks : references to entries
- Directory blocks : Merkle Roots of entry blocks

Factom's server (which consists of decentralized nodes and a currency of its own) organizes the hashes of the entries into Entry blocks. Next, the Merkle roots of these blocks are further packaged in a directory block and that directory block's hash is anchored onto the Bitcoin blockchain every 10 minutes. While Factom does guarantee that a process will be immutably recorded, the validation of an entry must be

FIGURE 5.1: Factom's Data Structure. Source: [49]



done client-side by users and applications. "The rules for real estate transfer are very complex, a cryptographic signature alone is insufficient to fully verify the validity of a transfer of ownership" [80]. In the case of Honduras this is a critical aspect that nonetheless goes beyond the implementation of the technology. Assuring records reliability is one of the major limitations of the proposed solution and, indeed, of any Blockchain-based solution [49]. The project has since stalled denying Honduras the chance of being one of the first countries to implement a blockchain-based land registry. [7] failed to extract a comment from government officials on the matter and argues that the proximity of this project to a presidential election ultimately affected its progress.

Georgia

Georgia's system was similarly problematic with real estate transactions being slow and prone to bribery as a result. However, considerable effort has been put into eradicating corruption which propelled the country from the bottom of the Transparency International's Corruption Perception to the top 50 [78].

Bitfury, one of the largest companies in blockchain technology, has been established in Georgia since 2014 utilizing the country's reduced electricity cost and low taxes to mine Bitcoin. Having already established a good partnership with the Georgian government, a project to design a private permissioned Blockchain to be operated by the Georgian land registry authority was announced in April 2016 [78]. This blockchain would be similarly anchored to the Bitcoin blockchain as was the case with Honduras. Georgia's property registration systems were ranked third according to the World Bank worldwide ranking [26, 70], which means that there is a greater chance that entries uploaded to the blockchain are accurate and valid compared to other countries. As of 2018, 1.5 million land titles had been uploaded to the blockchain [77].

Results

Such a difference in results can be explained in part due to the differing state of land registry records in each country. Georgia's records were already digitized in contrast to Honduran records. There's also a big difference in the efficiency of the existing systems. On average, in Georgia it takes 1 day and 1 legal procedure to register a property. In Honduras it takes on average 29 days and 6 procedures [8]. Another major difference is the complexity of IT infrastructure, which is also a key factor of IS readiness.

Furthermore, regarding the PPP of the Honduran case, there was a misalignment of interests since the government wanted to keep the project under wraps to minimize resistance during pre-election. On the other hand Georgia's partner Bitfury not only had been active in the country, but the Georgian government had already started taking steps to modernize the process and increase transparency before the coalition started. It's evident that technology expertise brought through a PPP is not enough. Adequate IT infrastructure and a harmonious PPP with aligned interest on both ends are necessary to provide the IS readiness required for success.

5.1.2 More early adopters

[88] explores more early adopters of the technology, categorizing countries into three categories depending on how developed their land registry systems are.

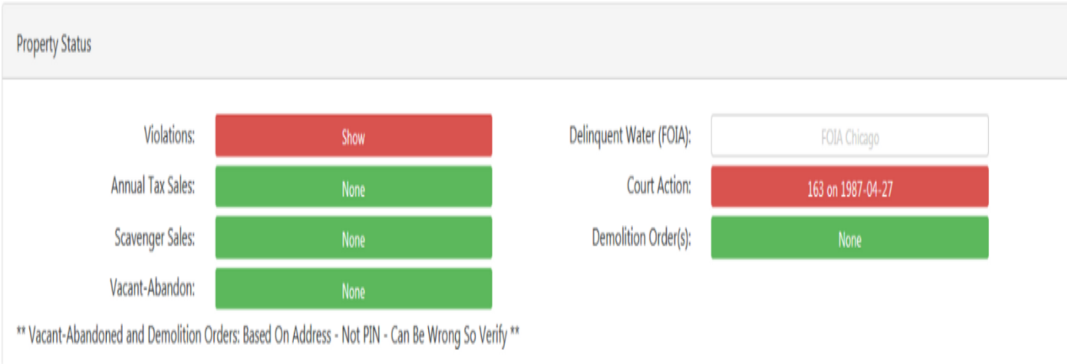
Advanced registries

Dubai aims to become one of the leaders in blockchain technology. Smart Dubai, a PPP to create a smart city announced in 2013, aims to digitize all its services including its land registry. This project as a whole is rumored to result in an estimated EUR 1.2 billion savings per annum [79].

Illinois , Cook County had been experiencing an increasing amount of title fraud, where fraudsters sold property that could not be legally acquired or inhabited without first correcting a defect of some sort. Thus in September of 2016 a pilot program studying how blockchain could be utilized was launched. The aim was to create an all-encompassing database that could be used by buyers of property.

Software firm velox.RE was employed to import Cook county's 190 million existing records and create a blockchain containing every property. Along with ownership titles, info such as building permits, violations, lot size, square footage and a photo from Google Maps was included. Furthermore, a tool for the visualization of the data was created called "Property Health" (see figure 5.2), making it easy for buyers to check if a property possesses worrisome characteristics with simple color coding (green/red). Violations such as unpaid taxes or building code violations caused the entry to turn red, warning buyers to inquire further before purchasing [45].

FIGURE 5.2: Property Health data visualization



Source: https://illinoisblockchain.tech/blockchain-cook-county-final-report-1f56ab3bf89

The pilot proved to be successful, thus this solution is planned to be used as a model for the widespread adoption throughout the state of Illinois. "Make no mistake, a transition from the status quo to a blockchain-powered real estate industry will require a lot of work and education, but the payoff appears to be worth the effort", according to [59].

Sweden 's land registration system was already a well-functioning one. In 2016 a pilot project was launched to investigate whether it could be made more efficient with the use of Blockchain. The Swedish land registration authoriry, Lantmäteriet, partnering with companies Chromaway, Kairos Future and Telia set the project in motion. It is estimated that such solution could save Swedish taxpayers over EUR 100 million per annum by speeding up transactions, reducing fraud and eliminating paperwork [88, 57, 24].

At the time, although the registry was already digitised, the process of signing a real estate sale contract until its registration took approximately 4 months [57]. The project is based on a private blockchain which stores verifications. Moreover, as is consistent with Sweden's publicly visible system and dictated by law, these records are verified on an external Blockchain which is transparent to the public [37]. The process of Swedish land transfer involves many steps, however the Lantmäteriet is involved relatively late in the process. The result is that there is significant delay in the time for the transaction to show up in the registry as well as that the trust generated by the Lantmäteriet is absent for part of the process [57].

Telia, a Swedish telecommunications company, provided a digital ID system solution to be used for signing documents and verification of actors who have access rights to the system [39]. The testbed for this project is built on Chromaway's private blockchain network, which only authorized parties have access to. Furthermore a smart contract application is used to manage the transactions recorded on the blockchain [24]. As mentioned, the blockchain will store verifications of documents rather than the documents themselves, which are to be held by each party creating redundancy. In addition, each party can feel secure in the fact that the verification records are summarized in a public blockchain and they can recreate the chain of events themselves in case of a data breach suffered by the other parties [39]. Refer to figure 5.3 for a visual represantation.

There are also different interfaces for each type of user.

- End users - buyers/sellers

Using an app, these users can see the state of a contract they are part of and be called to take action when it is their turn to.

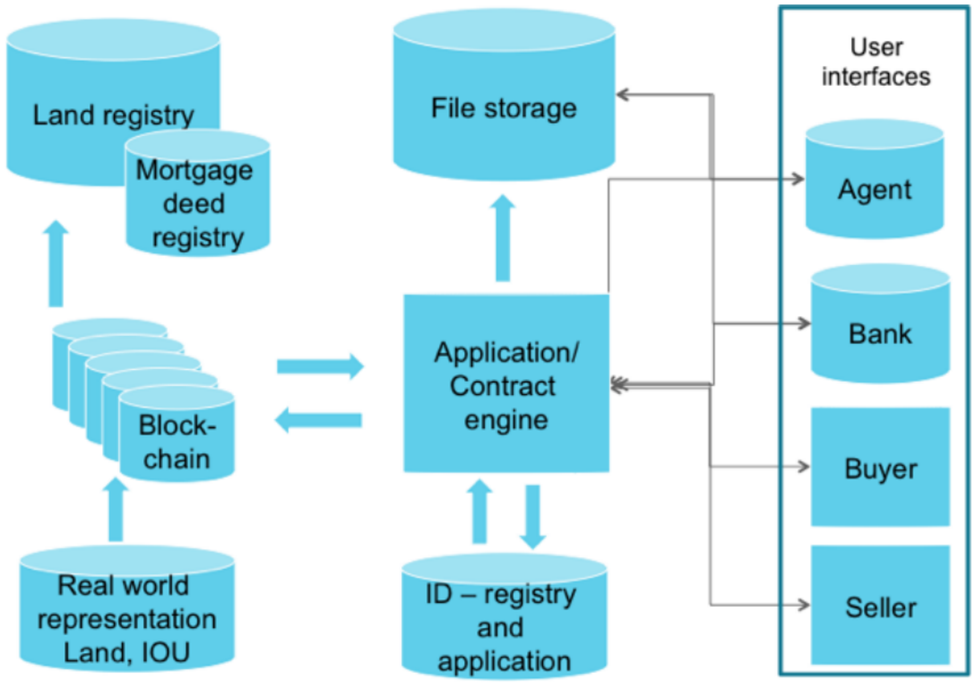
- Professional Users - banks, agents

  The application will ideally be integrated with the organization's own systems. Able to see a contract in a professional interface.

- Contract Administrators - Lantmäteriet and developers

  These users can change, revise oradminister a contract. Changes overseen by all partners running the blockchain.

FIGURE 5.3: Parts of the private blockchain solution

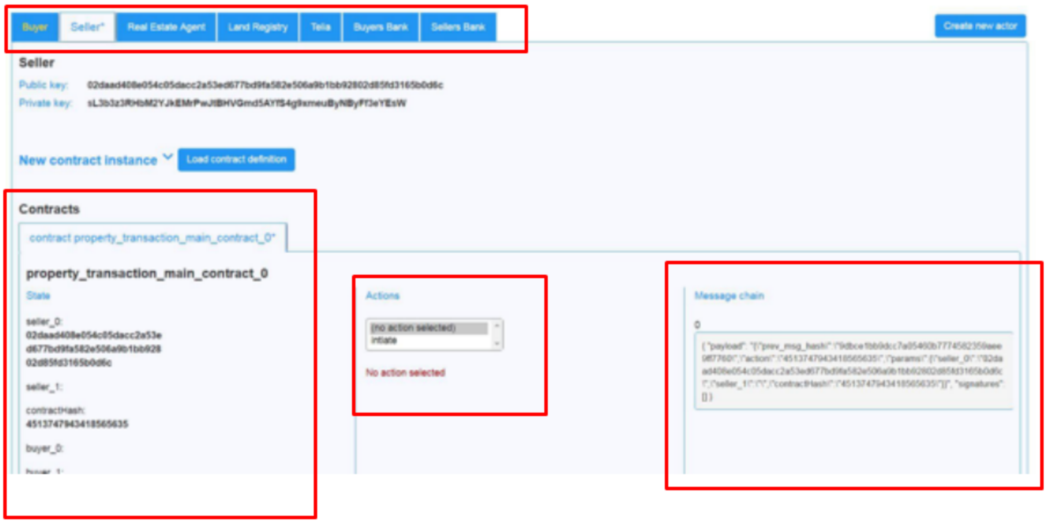


Source: http://ica-it.org

A screenshot of the administrative interface is shown in Figure 5.4. On top, the actors involved, managed by the contract admin can be seen. On the left, there is fixed information about the contract such as date, public keys of actorsa and property ID. In the middle is the action field where actions to progress the process appear. Finally, to the right are the messages that are posted to the blockchain. This project has undergone three stages. Proof of concept, working testbed and a real world property transfer have all been successfully completed [37]. Plans to extend its functionality are now in the works.

The United Kingdom 's HM Land Registry, looking to optimize the way all participants of the property market interact, partnered with software company Methods to investigate the use of blockchain in land registration in a project called "Digital Street"[33]. The project will utilise the R3 blockchain platform Corda [36].

FIGURE 5.4: Administrative interface. Source: http://ica-it.org



In 2019 a successful trial was completed, which involved the sale of a house in Gillingham [55]. Despite this success however, the Digital Street project has given itself a long time window, until 2030, to familiarise itself with likely technologies[10].

Cyprus , is actively looking for an IT solution that will help facilitate a modern cadastre system that enables entities to instantly and confidently identify location, rights, ownership and responsibilities related to land. Such is the case for many well-developed countries without major organizational problems looking to optimize their land registry. [88] strongly suggests that Blockchain is the solution that the Cypriot Department of Lands and Surveys is looking for.

Vermont's welcoming legislature and attitude towards new technology [93] caught the attention of Propy, a California-based blockchain startup, which hopes to change the way the real estate industry works in the future by recording all real estate conveyance documents in blockchain [72]. Specifically Vermont's towns South Burlington and Hubbardton were approached by the firm for a pilot project which was met with an open mindset by the cities' officials [74] .

Propy's vision described in their white paper [73] is to ultimately create a global real estate market with a decentralized title registry. In regards to their registry solution, called Propy Registry, it is hoped that it will initially mirror the state of the official land registry but ultimately become the official ledger on which transfers are legally consolidated. In accordance with a global real estate market vision, Propy Registry will standardize the way data is represented in a registry. This ambitious plan naturally requires several governments to choose Propy Registry as their legally valid ledger.

Propy Registry consists of multiple smart contracts interacting with each other in a microservices architecture manner. Each contract is responsible for a different kind of record in the system and requires Propy Utility Tokens(PROs) to be created. Their function and contents can be summarized with the diagram in figure 5.5 taken from Propy's whitepaper.

- Identity Contract

Contains information about the legal identity of each user.

- Title Contract

  Responsible for storing property data on the blockchain, for which it uses PROs.

- Deed Contract

  Manages escrow information that is essential for facilitating a transaction. Similarly requires PROs.

- Agreements Contract

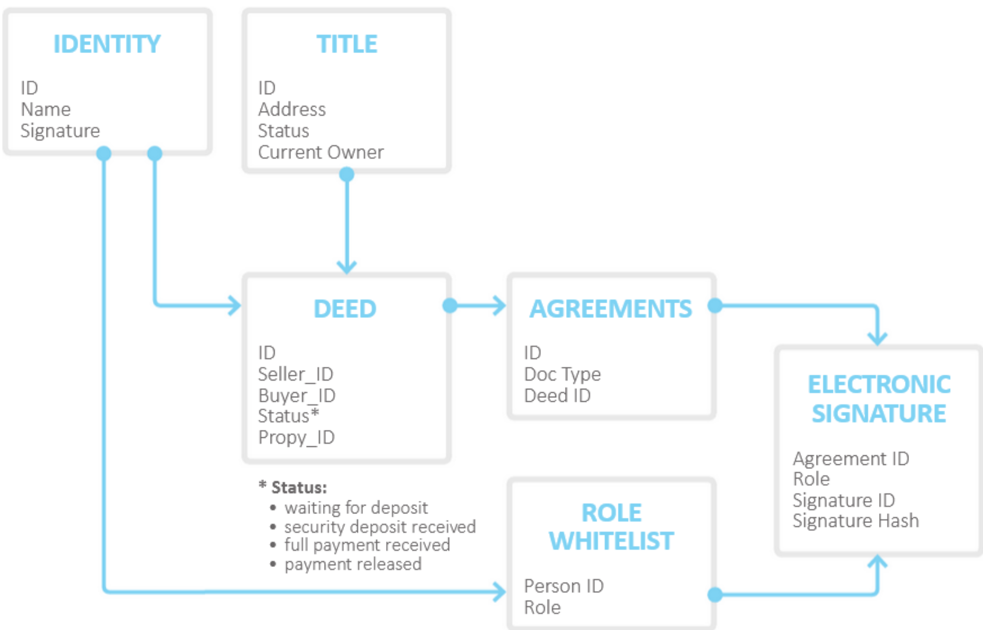
  Stores legal agreements that need to be electronically signed for a deed transaction.

- Electronic Signatures Contract

  Stores and validates the digital signatures in all Propy Registry documents.

Revenue is expected to be genarated by substracting a comparatively smaller fee than the current one for each property sold through the platform. Despite favorable conditions, however, expansion throughout the state and elsewhere has been slow.

FIGURE 5.5: Propy's Smart Contract Architecture



Source: [73]

Less organized land registries

India 's individual States have different ways of handling land records. Due to each Land Department working within its jurisdiction, discrepancies in the information between them is a dangerous possibility. The Digital India-Land Records Modernization Programme has been successful in digitizing records in most States, however, the concern of information discord remains. The need of a trusted and efficient ecosystem is addressed by research done by [85]. The state of Andhra has already moved forward to partner with Chromaway, seen in Sweden's case, for a blockchain-based land registry [61].

[85] suggests that blockchain be used to connect the different Departments in a network, a goal made easier by the fact that records are already digitised. The nodes comprising the network will be the major actors involved in the process of registration and transaction, such as: the seller's/buyer's Bank, Notaries/Court, Cadastre Office, Deed registration office and the main Land Registration office.

A property is represented as an object with attributes such as: address, owner's details, area and parcel ID. When a property is initially registered the information is added to a block along with a hash. When a transaction involving this property is made, the information is updated with the buyer's details (including how much area he wants to buy) a new hash is generated and, along with the previous hash, is stored on the blockchain. Business logic regarding the interactions between actors will be facilitated with smart contracts.

Like other implementations the actual records are stored in digital or physical form in databases outside the blockchain. The authors emphasize that simply recording transactions will not guarantee the preservation of the actual records. A way to relate transactions to records is being considered. Before initiating a blockchain implementation, land parcel boundaries should be updated so that transactions lead to a clear and identified entity or object.

Ukraine , one year after Georgia, whose land registry is in the same category as per [88], decided to turn to blockchain technologies in hopes of amending the state of its farmland registry, whose vulnerability to fraud is the cause of ownership conflict. Land reform is of utmost importance since it's one of the requirements of the International Monetary Fund, Ukraine's biggest creditor [92]. Thus, Ukraine's economy is severely held back. Additionally, a transparent and secure registry is essential for lifting the country's ban on selling farmland. Like in the case of Georgia, a PPP with Bitfury was formed to launch a platform for registering land titles. The project has since been abandoned [43].

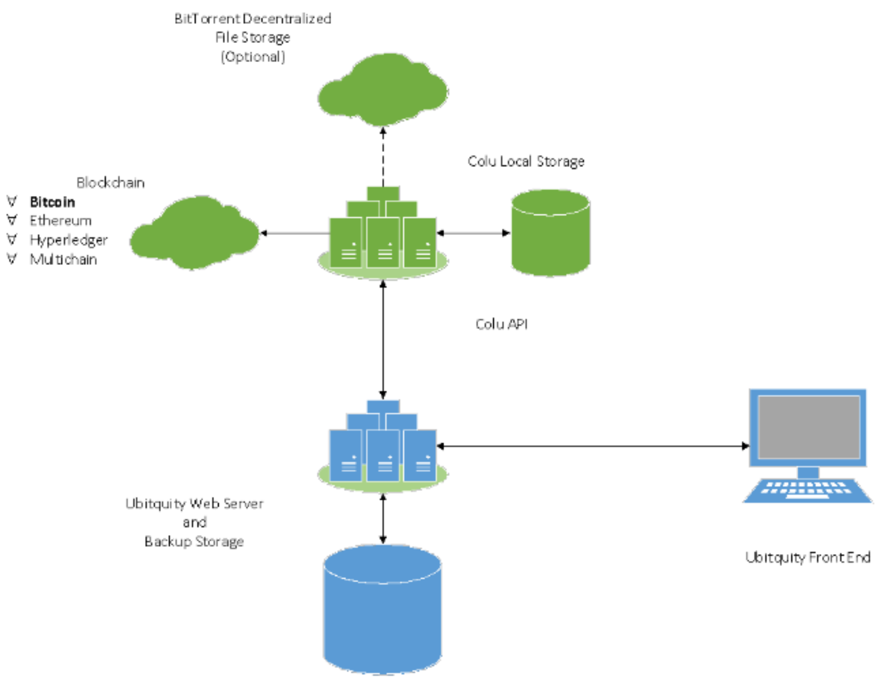
No land registries or inefficient registries

Brazil , just like Honduras, lacks a modern land registry and faces corruption and fraud. Apart from lack of a digitized database, most of the territory is untitled [37]. Furthermore, the process of buying a dispute-free property is quite complex, entailing at least 13 separate steps [50]. Inquiring about the extend of fraud, the National Justice Council discovered that in the state of Pará, land recorded in the registry was twice the area of the actual territory [12].

In the 19th century the Torrens system was adopted but in practice is seldom used, especially in urban areas [12]. Brazil's real estate registry is getting help from Delaware-based startup Ubitquity, branded as the first blockchain platform for real estate record keeping [27], in order to embed land ownership information onto the bitcoin Blockchain. The municipalities of Pelotas and Morro Redondo will take advantage of the platform to embed hashes of information like property address and owner into the bitcoin Blockchain using the Colored Coins protocol [58]. This pilot project is expected to increase transparency and security in the existing system and move away from the current paper-bound system. In fact, a piece of land was already successfully recorded and registered using Ubitquity's blockchain in the Brazilian region of Rio Grande do Sul, in April of 2017 [27].

A case study regarding Ubitquity's solution was published by the University of British Columbia, focusing on the pilot in Pelotas. According to [50], the blockchain will be used to ensure the authenticity of the information on the registry and guarantee that a particular property actually belongs to a particular person.

FIGURE 5.6: Ubiquity's solution architecture



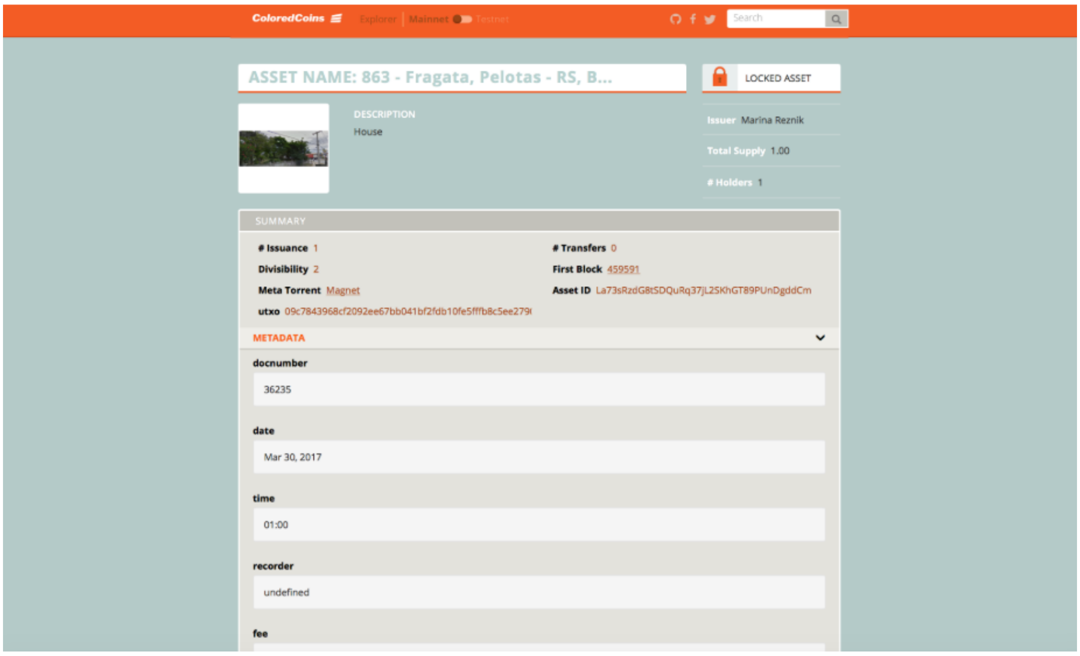
Source: [50]

The solution, as seen in figure 5.6, uses Ubiquity's blockchain Platform and Colu's API. Information is taken from Brazil's general real estate registry, which contains information about the property such as the address, ownership, certificates as well as images, and displayed on the frontend web application. Ubiquity's backend server contains images of the property as well as other documents relating to the property in PDF format.

Ubiquity's web server communicates with the Colu API which translates information about a property or a transaction entered in the FrontEnd into a format suitable to be recorded on the Bitcoin blockchain. This is done using Colu's Colored Coins protocol. As mentioned in Chapter 3 Coloured Coins is a group of methods for representing and managing real world assets on top of the Blockchain. Colu's implementation of the protocol uses the OP_RETURN field of a blockchain transaction to save metadata about a property. The OP_RETURN output field of a Bitcoin transaction allows for 40 bytes of information to be inserted into the Blockchain along with the transaction [3], thus associating the asset with said transaction's metadata. Additionaly, in order for more data to be saved "on chain", a multisig address is used. With multisig more than one parties can control a Bitcoin address and thus, multiple signatures are required to authorize a transaction. In the case that the signature fields are not used, an extra 32 bytes for each signature is available to use in coloring.

Still, metadata can exceed this size, if for example pictures are included and furthermore, using the Bitcoin blockchain for non-financial data storage is a controversial topic in the community. Colu's protocol uses torrent files containing the metadata, whose SHA-1 or SHA-256 hash is then recorded in the blockchain using the aforomentioned fields, in a similar manner as seen in other anchoring implementations. Using the Colored Coins search engine, it is then possible lookup a title by providing the Asset's ID and retrieving all transactions involving that asset.

FIGURE 5.7: Colu Colored Coins search result



Source: [50]

In figure 5.7 depicting a search result, the utxo field which is a bitcoin transaction output's hash, can be used to search for the transaction in the Bitcoin blockchain and verify its validity. Ubiquity's solution is blockchain platform agnostic, meaning that some other blockchain platform instead of Bitcoin could be used in the future. Colu's server is located in Israel, and since Brazilian land details are stored in the platform's metadata, Ubiquity is actively looking for a provider based in Brazil in order to adhere to ethical data localization practices, in the event that such laws emerge in the future.

Ghana 's majority of landowners lack the proper title deeds for their property as most of the land is held by oral agreement. In reality, this percentage is over 80% [62]. Registering property is no easy feat either since Ghana's Land Registering Index ranks 111 out of 190 according to World Bank's report [86]. Lack of transparency and accountability seems to be a major challenge for the development of the Ghanaian land registry[16].

These factors naturally contribute to an environment of immense fraud and constant land disputes, with ill-intentioned parties claiming titles to land they want to illegally acquire. The ongoing Land Administration Project has been trying to solve such disputes for the last 21 years but the public sector is so entrenched in corruption that consolidating the land title system is beginning to sound like an unfeasible plan [1].

Several actors have tried to undertake the project of solving the inefficiencies with the land registry. Namely Bitland, a Ghanian startup is helping farmers register their land online with the use of a public blockchain which in turn will help them and their families be granted loans and mortgages by the bank, which requires a title as capital. However, since land is held by oral agreement Bitland's surveyors have to manually inspect the parcels and interview the owners and their neighbours to figure out the boundaries of each one [62]. Apart from no digital records, the initiave has to face the problem of unreliable infrastructure, since parts of Ghana regularly go without electricity for 24-48 hours at a time, which poses a great risk for a server operating in these parts [1].

Bitland's team is using the OpenLedger platform to host their protocol and also issuing a digital token called "Cadastrals" which will act as the entry token for their blockchain platform [47]. The team has allotted 20 million Cadastrals to be used in an ICO to help kickstart the pilot. Despite some ICOs' having a controversial past, Bitland's support from the governemt means that investors will not be taken advantage of [62]. The token will also facilitate a voting system allowing holders to take part in decision making in the community.

More recently, a memorandum of understanding, a non-binding agreement of alignment of interest, between the Ministry of Lands and Natural Resources and technology company IBM. This memorandum, signed by the Ghanian government in 2018, outlines the adoption of a blockchain based land registry [16]. [16] notes, that despite the time elapsed since the inception of such initiatives, an effective output is yet to be seen. In order for a technology solution to be effective it is imperative for the existing system to undergo broad reform. Furthermore, the issuing of blockchain-related policies and regulations is pending.

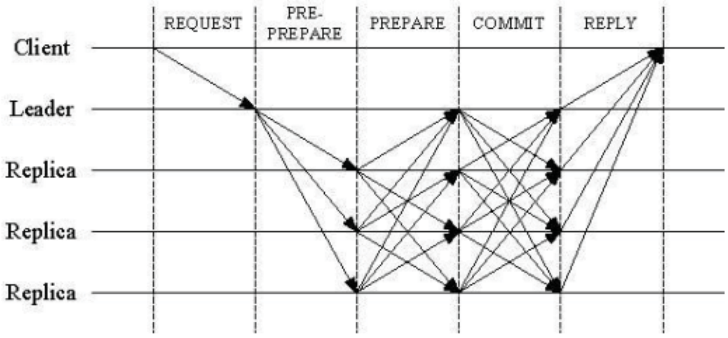
Similar attempts are being made in other countries such as Kenya [62], Japan [37], Russia [38] and Estonia [20].

5.1.3 Proposed Implementations

Byzantine Fault Tolerance Consensus

Byzantine Fault Tolerance Consensus is a consensus algorithm usually used in permissioned blockchains. According to [15] the model works under the assumption that some of the nodes of a blockchain network will produce faulty/malicious messages (Byzantine Faults). A node is chosen as the leader, while the rest of the nodes constitute the backup nodes. A service request by the client is first sent to the leader node who then broadcasts the request to the backup nodes. After the request is executed, the nodes communicate with each other with the goal of all honest nodes coming to an agreement on the state of the system. The client finally awaits f+1 different replies, where f is the maximum number of faulty nodes. The majority of honest nodes decide the resulting system state. The leader is then changed in round robin fashion. The majority of honest nodes can also replace a faulty leader with the next one. The model assumes that an equal or less than 1/3 of the total nodes are going to be faulty, which in permissioned systems with already-established trust does not create any issues. The algorithm's flow is shown in figure 5.8

FIGURE 5.8: PBFT algorithm flow. Source: [13]



Using Hyperledger Fabric

[20] provides a DLT solution that addresses Sri Lanka's manual land registration inefficiencies. Unlike most title registration solutions described above, the authors hope to preserve the properties of deed registration which is dominant in most of Sri Lanka's regions. They chose a permissioned blockchain ledger where the validating nodes comprise of the Notary, Surveyor and Regional Land Registry. These are also the main validators of a land transaction recognised by the Government in the current system.

The ledger consists of: **World State**, which stores the state of the ledger at any given time, and the **Transaction log**, which stores all the transactions which have contributed to the current World state on blockchain. The World State provides access to the latest values without the need traverse the entire transaction log to retrieve them.

The content chosen to be included in the ledger, is the content of the current registration system, modified to fit the needs of a DLT system. Hash values of the deed and plan are included similarly to other solutions. Land ID, Location of land, Boundaries of land, Extent, Hash of plan, Hash of deed and owner are also some of the contents.

Queries	Transactions
queryLand	changeLandOwner
queryAllLands	forkLand
getHistoryForLand	createLand/deleteLand

TABLE 5.1: Queries against the ledger, as interpeted from [20].

Actions against the ledger are shown in table 5.1. queryLand returns the latest values for provided LandID. queryAllLands retrieves details for all lands on the ledger, which could be useful for land registrars at a Regional Land Registry. Intuitively, getHistoryForLand returns the full transaction log for a given LandID. A client can request a changeLandOwner transaction to change ownership or a forkLand to split existing land and update the newly created lands with new owners and boundaries. createLand and deleteLand are used in the implementation of forkLand.

In Sri Lanka each Regional Land Registry is concerned with transactions within its terrain and maintains a different ledger than other regions. Two abstract models are given, one addresses the current system while the other one implements a single land ledger for the whole country. In the second scenario Regional Land Registries with low transaction volume work to validate transactions in other regions, sharing the workload. A client submitting a transaction to the network needs to provide copies of deed and plan. The system generates the hash values before sending the transaction to the validating nodes, which then perform the validation based on these values.

Hyperledger [31], an open-source, permissioned DLT platform and more specifically its framework called Fabric were used for the implementation. A Hyperledger Fabric permissioned blockchain uses the BFT Consensus, explained in subsection 5.1.3. Some definitions specific to the Hyperledger platform and the implementation in general before proceeding:

Chaincode: The main element in a Fabric network, it dictates the rules to be followed by network participants. It is isolated from the shared ledger and runs directly on the peers' processes usually in Docker containers (explained below). Chaincode executes transaction against world state data [6].

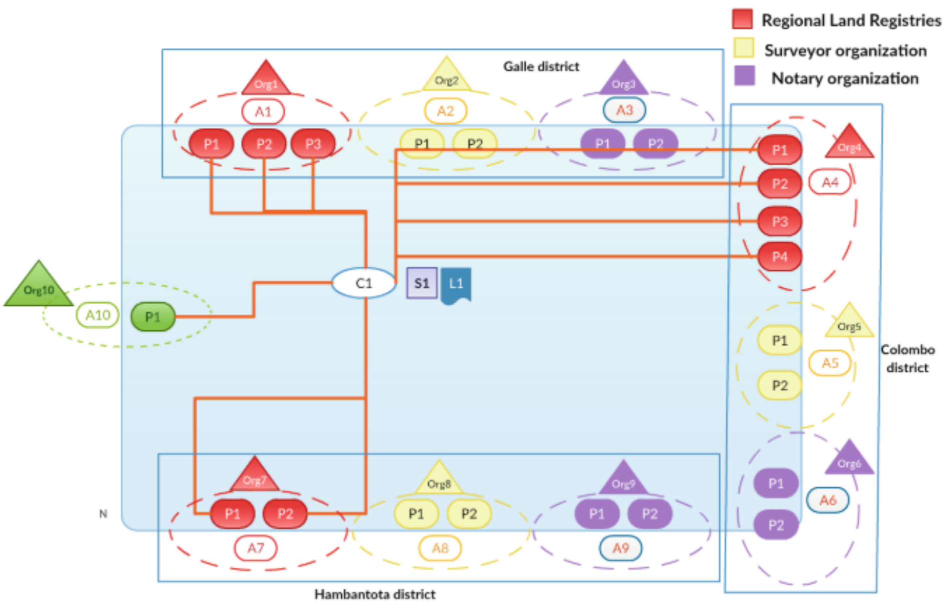
Channels: Channels allow the communication of specific network participants [6].

JSON: A way to represent data in human readable form [95].

CouchDB: A NoSQL database. Supports complex data queries against the whole blockchain data, making it suitable in such implementations [6].

Organization: Grouping of network peers.

FIGURE 5.9: Hyperledger Architecture. Source: [20]



Chaincode for modifying the assets is written in Go. Land assets are modelled as JSON data where LandID is the key and the rest of the attributes constitute the values. CouchDB was used as the state database, while the CouchDB JSON query language was used for data queries on the ledger. Only the second model, which is more in line with other implementations, will be analyzed. The architecture is seen in figure 5.9. The diagram shows peers (P) from three different districts participating in the network with a shared ledger. There are 21 peers in the network grouped in organizations (Org). There is a single channel (C1) to which all Regional Land Registry nodes are connected to. The chaincode (S1) is shared as well as the ledger (L1). The orderer node in green is responsible for executing the consensus protocol.

Perfomance evaluations were conducted and found that the throughput (rate at which transactions are commited to the ledger) of the second scenario where all registries share a ledger was higher. Latency, defined as the time from a transaction being broadcasted to being commited, was higher in the first scenario due to the bottleneck created at Regional Land Registries with high transaction volumes. The requirements of the model were satisfied by using Hyperledger Fabric and thus the authors conclude that the features provided are suitable to provide a distributed land ledger solution for Sri Lanka.

Using Chromaway Postchain

[100] also provides an implementation for Sri Lanka's land registration system. Their solution, called AcreSense consists of the following components.

A Decentralized Blockchain. Ledger for record-keeping and property transactions.

A Smart Contract. Registry which will enforce transaction rules.

Land valuation. Prediction module using machine learning.

A Geographic Information system. For displaying registered land parcels.

The end product is a web platform that will serve as an e-Land Registry. For the blockchain ledger, Chromaway's Postchain was used [71]. Postchain provides a framework for building permissioned blockchain solutions. Blockchain data is stored in an SQL database and transactions can be defined in terms of SQL code. For the consensus mechanism the Practical Byzantine Faut Tolerance(PBFT) consensus is also used.

Successful registration provides the user with a public/private key pair. The smart contract layer, makes sure that all transactions are signed before being commited. An authorized user submits a new deed through the platform that is then sent to three parties for approval. The granter, the grantee and finally the assigned notary sign the deed using their public keys in that order. The steps of the signing process are recorded in a side chain with a different blockchain id. A transactional block is added to the blockchain after the approval of all involved parties is granted.

The platform will also include the land valuation module. Analyzing the transaction details recorded on the blockchain the module will provide information about land valuation in specific areas, giving sellers, buyers, investors and banks alike an idea about current land prices. Finally, the GIS module will provide information about all registered land parcels as well as allow for interested parties to view and inspect the parcels without physically visiting them.

5.2 Real estate transactions

5.2.1 Information quality

One way of enhancing the process of a real estate transaction is improving the quality of the information needed to facilitate it. This information is scattered among the different involved parties and is oftentimes in different formats. Consequently, this lack of transparency in the real estate market causes a state of information asymmetry [51]. In the example of a transaction involving an office building, [99] emphasizes the lack of transparency and perceived unreliability of the data used. The process of an office building transaction is divided into four steps:

1. **Preparation.** The owner gathers related information with the goal of presenting the building in its best light.

2. **Marketing and pre-due diligence.** The owner analyzes his property related information.

3. **Due diligence.** With the help of advisors, the buyer analyzes the information and assess the risk.

4. **Completion.** An agreement is drafted and negotiated.

Validation and verification of the data is carried out multiple times throughout the process, a clear indicator of the existence of information-related issues. A proposed blockchain solution is presented by [99]. The data required is divided into 2 categories:

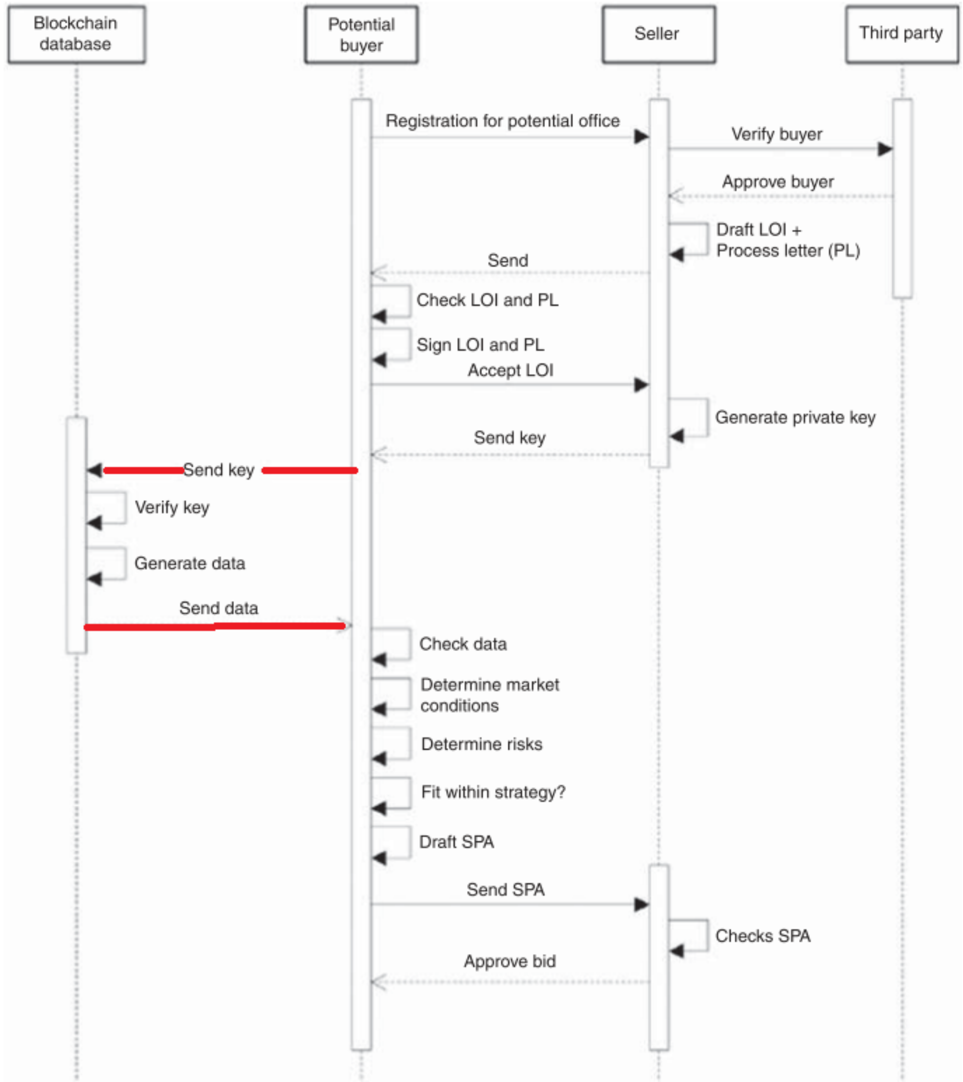
- Physical elements - technical related, such as: square meters, address, pictures
- Contractual - commercial, legal and financial documents

Essential validation information will be uploaded on the blockchain while the original files will be stored on the servers of the involved parties. Any adjustment made to the original files will be kept by the blockchain audit trail. Furthermore, if the data is standardized, it will be possible for this record keeping system to be linked to external databases and be automatically validated, without the need of validating nodes. Lack of standardization of data, however, is a major challenge that exists in the real estate sector today. Without it, the proposed solution could be used just as a way to store and share original files.

The proposed transaction process is shown in figure 5.10. The buyer pulls required data from the blockchain and caches it locally, as is indicated by the red arrows. The illusion that the data was stored locally all along is given. It looks similar to the current process but it can be assumed that the time spent on the stage of due diligence and negotiation will be drastically reduced due to the increased security and reliability between parties the blockchain will provide. Last but not least, a clear, digital representation of a property and its qualities is one of the requirements for property tokenization. The authors argue that recording physical and contractual property data on the blockchain will pave the way towards a property blockchain token.

Information asymmetry in real estate transactions, characterized previously as HVLF transactions, is also recognized by [28] as a major factor which decreases trust. According to the authors the average buyer, who is not a Real Estate trader, is significantly disadvantaged in a transaction as the information asymmetry usually benefits

FIGURE 5.10: Enhanced transaction process. Source: [99]



the seller. This is due to the usually limited experience of a buyer in the field as well as the reluctance of the seller to disclose information which might negatively affect the price.

Stakeholders involved in a transaction include the seller, the buyer, specialists in charge of checking and validating the information the buyer receives, legal representatives for both the seller and buyer, an agent through which the seller will operate and the government. Analyzing the effect that implementing information exchange on the blockchain will have on the main stakeholders of a transaction, their research found that seemingly only the buyer and the government will benefit. The buyer enjoys reduced cost in the due-dilligence process and an increased amount of reliable information. The government also benefits from access to detailed information into each household.

However, the authors argue that increased transparency will also benefit the seller. Balancing asymmetric information will decrease perceived risk for the buyer and will possibly have a positive effect on the price, as buyers tend to build a margin in the price to offset risk. There's also motivation for the specialists in the case they are consulted by the sellers before submitting their asset data to the blockchain.

A permissioned blockchain ledger is recommended for implementing the practical platform, while also deploying a personalized database for sellers to add detailed information to the ledger.

5.2.2 Fees & Fraud

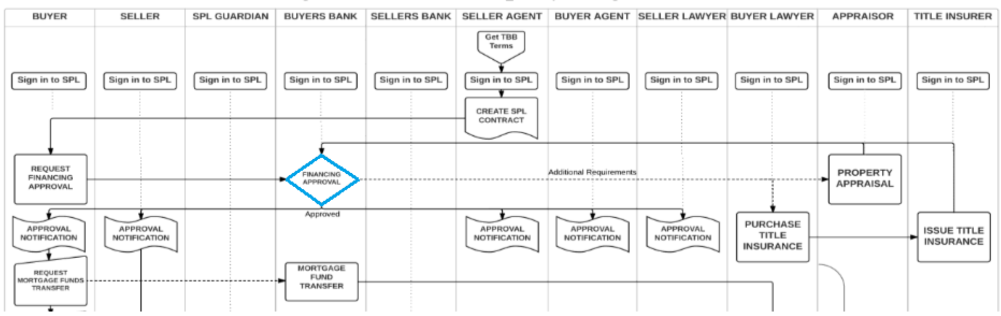
Addressing the challenges of high transaction costs and fraud in the Canadian real estate market, [56] recommends two preliminary blockchain systems. Like most countries, Canada's transaction process is a complex one. As mentioned in chapter 2 the fees in each step of the process pile up to a considerable amount. A quick overview of the most common types of fraud plaguing the market is given. In the first one, the criminal pretending to be the owner of a property, takes out credit against it and flees with the funds. A more uncommon type is when a criminal may get to complete a sale of a property they do not own [63]. According to [52] another type of fraud is when ill-intentioned real estate brokers represent both the buyer and the seller of a transaction. The fraudulent broker can then withhold bid information from the seller to earn a second commission from buyers they represent, which lowers the price the seller receives.

TBB. The current bidding process is paper-based and offers are communicated through agents. The authors introduce the Transparent Bidding Blockchain Process. Bidding information will be collected independent of the seller's agent by capturing the bids on blockchain. The seller receives real-time information about bids on his property while, for the purpose of reducing the aforementioned type of fraud, certain information might be withheld from the seller's agent until the bidding is closed. The buyers might also benefit from such a system. Sellers could broadcast the winning bid, giving buyers the oppurtunity to post a second offer. The buyers could also check the status of their bid directly through the system without communicating with the seller agent.

SPL. The manual transimission of data throughout the many steps and the numerous participants of a real estate transaction takes a long time. Updates about the status of the transaction are also given through the intermediaries executing each step. The proposed solution (Smart Property Ledger) is built upon a blockchain ledger with smart contract functionality, while also making use of the colored coins concept. Relevant data will be broadcasted to all approved users in real time. When conditions on smart contracts are met, the smart contract will execute and then notify the users that have to take action. The execution of a smart contract is demonstrated in 5.11, a snapshot of the transaction process using the proposed blockchain system. The light blue conditional block represents a smart contract which will execute as soon as a financing approval is issued by the buyer's bank. Following that, notifications are generated to the users and particularly to the buyer who is called to take action regarding the mortgage funds. Using the colored coins protocol, it will be much easier to look up the complete history of the property being sold, to ensure it is free of defects and legally owned, further saving time on the process.

MLS [46] also provides suggestions on how the process could be improved using blockchain technology, starting with the early step of searching for properties through a Multiple Listing Service. MLS hosts generally own all the rights of listed

FIGURE 5.11: SPL snapshot. Source: [56]



information. This very centralized way of operation allows hosts to prioritize or alter the information. Additionally, data could be distributed among more than one such platforms, making the process of searching inefficient. Moving the MLS system on the blockchain is suggested.

Property data is initially registered on the blockchain by the owner through a smart contract. This creates a digital ID for both the owner and the property. A block representing this data is added to the chain. The possibility of spam entries is prevented by peers of the network deciding whether or not a block will be added depending on the consensus protocol. Suggestions are also given regarding the stages of due-dilligence and finalization. While optimistic that blockchain technologies will revamp the industry, the research lacks details on the type of blockchain to be used, consensus protocols and other important technical aspects.

5.3 Property tokenization

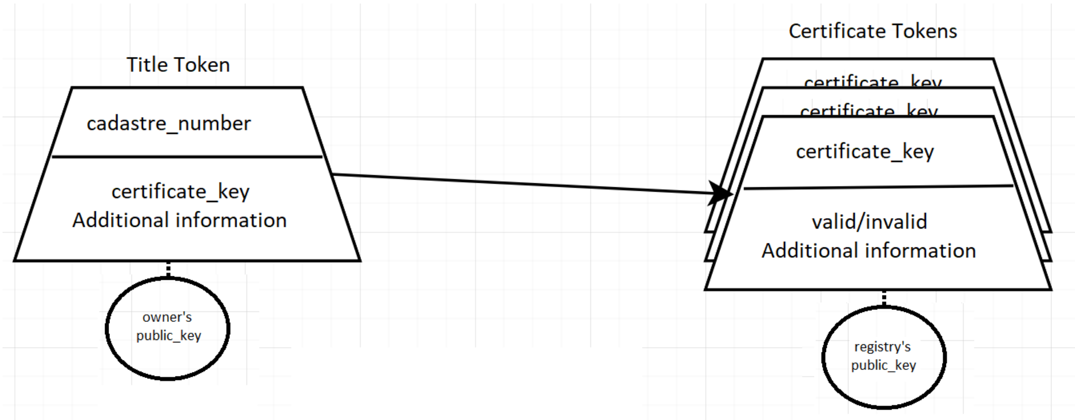
[60] presents a solution which can facilitate seamless property transactions using the concept of colored coins. The solution can be implemented on a layer atop the Bitcoin blockchain. Coloring a coin begins when a property is first associated with a transaction output. The receiver of this transaction, called the genesis transaction output, is identified as the owner of the property. When the property is transferred or sold the transaction output associated with it is spent and the property is now associated with the new transaction output that belongs to the receiver of this transaction. Looking up the current owner involves finding the genesis transaction and tracing the colored outputs up to the most recent unspent one. The owner can prove his legitimacy by signing a message with his private key.

This lightweight implementation makes use of Bitcoin's established network security. Furthermore, it allows for Bitcoin to be used as the transaction currency. This means that a single transaction sent to the Bitcoin network can facilitate both the payment and the transfer of ownership, without the need for intermediateries. The necessity of a property registry is made clear when we consider the validity and uniqueness of a colored coin. A trusted property registry is needed to guarantee that a transaction output is uniquely associated to a property. The author recognises the difficulty of moving away from the current model of centralized registration but attempts to provide ways to minimize reliance on trust. He proposes that the entire list of records is transaparent and accessible to anyone. Anyone interested can search the blockchain for a list of valid (property identifier - genesis transaction output) tuples in messages signed by the registry's private key. However since blockchain space is valuable, the registry will only publish a hash of its records to the blockchain, while providing the records directly to interested parties who can check their validity using the hash.

The registry is associated with a Bitcoin address. Someone who registers their property proceeds to the registry with all documentation necessary to prove they are the owner. The registry will then create a genesis transaction with the owner's Bitcoin address as the receiver using the registry's address for the input. The OP_RETURN field of these transactions contains a string tagging the transaction as a property association transaction plus a hash of the registration entry. The original registration entry containing the link between the property identifier and the genesis transaction output could be provided to users through an API that receives hashes and fetches the original data. The output assigns the colored coin to the property owner. Issues arise with the immutability of the blockchain. Ownership change can be court ordered as a result of a case decision. Additionally, private keys owned by a single entity can be lost or stolen with dire consequences.d

[44] also finds blockchain tokens suitable for facilitating both title registration and deed registration systems. While an owner can create a certain amount of tokens to represent their property, a potential buyer has to rely on the seller's honesty that the tokens do actually represent the property and that other such tokens do not exist. Furthermore, private keys owned by a single entity can be lost or stolen with dire consequences. Quoting the author the involvement of a third party may be a "necessary evil". The following concept is designed to address issues such as disputes and losing access to an asset.

FIGURE 5.12: Title token certified by third party. As interpreted from [44].



Using the Name-Value storage token protocol (Chapter 3) the owner creates a record, which the author calls title token, declaring a title. The unique key is the title's cadastral number. The registry authority creates another record, called certificate, certifying the validity of the property's ownership. The value field contains among other information a flag displaying whether the title token is active or not. The title token contains the unique key of this certificate as a reference (see figure 5.12). If the private key for managing the property is lost the owner can contact the authority to update the flag to invalid and then issue a new token pair. Someone inquiring about a token's ownership can trace the link and check its validity.

This link to authority permits enforceability of the law. In the case of a dispute the court order can be easily executed. The owner is now able to freely transact with the token without the need of registering transactions with the land registry as the link between the token and the registry remains and the blockchain itself acts as an irrefutable transaction ledger. In the case further authorization is required to complete a transaction such as acknowledgement by a notary or permits for reconstruction the above schema can be expanded to include more certificate tokens. These third parties also create a token which contains metadata and hashes of the reports or legal acts required for a valid deed. The owner includes references to these certificates in his title token and is then able to perform a lawful deed.

"Smart laws" introduced by the same author in [42] are implemented as smart contracts provided by the government acting as filters. These smart laws establish rules that reflect current paper regulations. Each new block is checked for non-compliant transactions. Every user running a node with these filters will get a version of the blockchain database containing only valid transactions. The registry thus exists as a layer above the blockchain, which contains both valid and invalid transactions. A user attempting to publish a deed will not be allowed to proceed with an invalid transaction, provided he is also running a node with the smart contracts in place. Being a public database, he can omit the smart law framework and add a non-compliant transaction to the blockchain with no effect.

5.4 More projects in progress

5.4.1 ATLANT Platform

The ATLANT platform is a project aiming at providing a system for conducting peer to peer real estate transactions while bypassing intermediaries. Tokenization of real estate rights and p2p rental are two of the functions offered by the platform, built on top of the Ethereum network.

According to the whitepaper [82] the process of tokenization goes as follows. All the legal documentation relating to a property is digitally signed by an approved local authority. The signed files are stored on the platform's Distributed Data Store while their hashes are recorded on the Ethereum blockchain. Property tokens are issued by an EVM contract, deployed in the Ethereum network, in exchange for ETH and ERC20 tokens. ATLANT nodes who helped facilitate the tokenization receive a fee in the form of the newly issued property token. The tokens are then put up for sale under a Property Token Offering. They can then be traded on the platform using ATLANT's decentralized exchange service. ATLANT is currently waiting for approval from authorities supervising the financial market. At the moment, real estate tokens cannot be legally traded. However, the platform is ready and has a working demo [5].

5.4.2 Imbrex MLS platform

Imbrex is a peer to peer Multiple Listing Service and real estate transaction platform built on Ethereum with the goal of connecting vendors, buyers and real estate agents over an open network [43]. [32] provides a universal listing portal where data is transparent and shared between all participants. Real estate firms that previously had their own MLS platforms, will be able to participate in the data exchange as independent imbrex nodes. This gives them the ability to control their data, have access to new curation feeds as well as benefit from participating in the network. Every non-spam listing that is contributed to the network is awarded with native imbrex tokens.

Imbrex then hopes to also establish a universal property ID system. Starting with their listing platform, each property will be given a unique ID which will be accessible to anyone. This will lay the foundation for a wide ecosystem that also includes transactions. The platform will also offer an escrow service to track information flow during the transaction process. Transaction participants can upload their documents through imbrex's smart contract. The contract will then produce a private key that the uploading party can distribute to the other participants. Participants can track the progress of the transaction as well as what other documents are pending in real time, similar to the proposed solution in [99] as seen in 5.2.1. The platform is unique in that it can benefit brokers and firms, traditionally intermediaries, for posting quality listings through its Listing Rewards system.

5.5 Critics and Skepticism

While many of these projects seem to be on a fast track to mass adoption, not everyone agrees. The initial buzz surrounding blockchain for property registries seems to have been replaced with a more level outlook. These pilots reveal that property rights are quite complicated, governments are slow to change and a technological solution is not a cure-all for deeply rooted problems. A first look would reveal that less-developed countries are in much greater need of the technology to solve their corruption and opaque registries.

GIM's International conference [70] compares the differing cases of Honduras and Georgia and argues that land administration is fundamentally a governance issue, that is compounded not by non-secure systems but rather bad recording practices. Honduras' pilot stalled because of issues in documenting rights and resolving boundaries along with issues with the PPP itself. Georgia is a more exciting opportunity according to the author since its registry already enjoys almost complete coverage of land, alongside a generally very efficient registry.

[75] uses the term "pilot-itis", to describe the state of successful small scale implementations but lack of further adoption. The main reason for such state are the wrong conditions under which the projects are applied. Instead, favorable conditions like an already digitised registry and political will, are key for a successful pilot. [23] proceeds to list the following impediments that caused some of these projects to stall.

Fragmented land systems. The US is an example of that since property databases function at the county level. In the case of Vermont, the management of property is at the municipal level, which means over 3.000 different ecosystems with different laws and procedures. This is also the case in Brazil where land is registered by 3,400 privately-managed cartorios.

Paper land records. Uploading paper records on a blockchain is a severe limiting factor. Usually officials who are most eager for a registry revamp are those whose countries are the least suitable for a blockchain solution. Such is the case for both Honduras and Vermont, who lack digital records.

Resistant professional communities. It is only natural for actors in the trust business to be apprehensive about a disruptive solution. Brokers, title companies, escrow agents and notaries among others must be convinced that blockchain technology is merely a tool, rather than a threat.

Enthusiastic but unprepared decision-makers. This pertains to the issue of little understanding of the technology despite willingness to adopt it. Governments might not know how to properly apply a solution that was developed by a private firm without them having the expertise.

Closing on a hopeful note the author urges for careful consideration on whether a blockchain solution makes sense on a case-to-case basis. In a similar vein, research [43] finds that, perhaps, no technological revolution is on the way despite media news hailing a major disruption. Referring to the failed example of Honduras the author argues that countries in need of blockchain to solve their corruption issues ultimately fail because of no political will, creating a vicious cycle. Additionally, the author raises the question of why countries that prosper would want a change. Chromaway's pilot in Sweden uses a permissioned blockchain which arguably mimicks the existing system since it does not shift to a distributed architecture but is a rather centralized one.

That is the main point of the research; many of these pilots use a permissioned or hybrid blockchain along with hashing of registry records. Such ledgers are different from the idea of blockchain as was originally conceived and may not be the significant disruption in government processes presented by other research. The practice of submitting a hash on a public blockchain is a method to increase transparency on a permissioned system. However, the author is concerned that the practice does not facilitate the tokenization of property neither does it change the way of bureaucratic land registration. He suggests that blockchain be used in parallel with a conventional registry with the option for citizens to choose where they want to manage their property rights and calls for more empirical research.

The temptation to use a blockchain registry for developing countries is also recognized in the article by the European Land Registry Association [94]. The initial phase of recognizing title rights in order to form a blank state, or rather the Genesis block, is a difficult process in countries where land rights are unclear. This initial phase will not be realised by using blockchain since there is no initial trust in the records.

Challenges to form a Genesis block exist even in well-functioning registries such as in the Netherlands, where the owner that is mentioned in the registry is not always the real or current owner. This is because it is not mandatory to register cases of property prescription (the right to use the property of another). Another problem arises due to the fact that blockchain does not use complete identities but rather accounts/addresses. Thus, someone using the registry cannot be sure who the owner of the plot actually is. This comes in contrast with one of the fundamental principles of a land registry. The use of an electronic ID system like in Sweden's case could possibly amend this problem.

Additionally, liability when using a blockchain registry is uncertain since there is not one single point of failure. In a deed system, in case the wrong person is mentioned in the deed, the notary who drafted the deed will be liable for the mistake. Regarding errors in the blockchain source code, which often requires updates, responsibility lies on the developers. The author suggests an insurance system paid by all participants be put in place to address the liability challenge.

The mining process introduces the risk of information that does not represent the actual situation, as the process may take up to 10 minutes. In the case of a fork the period to resolve is even longer. Confusion as to who the owner of a parcel is when multiple title-holders appear is a rare yet serious concern. This is not the case with classical land registration where timestamps provide the necessary certainty.

Moreover, limited block size makes storing cryptographic hashes on the blockchain a viable solution. The authors agree with [43] on the fact that storing hashes of records does not protect the system in case the records are lost like in the case of a natural disaster.

The author states that the complexity of the legal system should not be underestimated and disagrees with the enthusiastic opinion that such techniques will easily replace legal professionals. In contrast, legal expertise is needed for a blockchain implementation. The best course of action would be for lawyers to make use of new technology and become familiar with using it as a tool to simplify or speed up certain procedures. The conclusion that unless the role of the lawyer is completely circumvented, a new technology cannot be regarded as disruptive and that at the current time land registers are too important to be replaced by a technique that does not seem suitable is reached.

[37] also addresses the challenges with using a public blockchain. Namely, the validation of a transaction by miners is not a legal validation but rather a technical one. In agreement with above criticism, it is noted that there are issues with the priority of transactions, as the order they are added in the transaction pool is not necessarily the order that new blocks are added. Further questions regarding liability and the lack of official ID, which were mentioned by [94] above, are raised. The complexity of rules governing land registration makes it impossible to be represented by a simple database. Blockchain technology could be a good fit for land registration if the technology is modified accordingly. The author suggests limiting the access to the blockchain system and having miners fulfill certain qualifications. The examples of Sweden and Georgia, who used a private blockchain as a complementary tool to a digitised and well-functioning registry are brought up.

Chapter 6

Synopsis and Prospects

This thesis examined the ways in which blockchain technologies can enhance the functioning of the real estate sector. From using blockchains for the registration of deeds and titles, facilitating peer to peer trustless transactions using smart contracts, tokenizing real estate to make property a more accessible and more liquid asset to combining these use cases to transform the entire sector to an entirely digital blockchain based ecosystem. The legislature governing the real estate sector is complex and vastly different from country to country. Well functioning ecosystems were found more apt to adopt a blockchain solution than unprepared or unwelcoming ones.

Blockchain is a relatively new technology with limited established real life applications. Furthermore the term encompasses a wide range of systems with differing permission models. Most of the land registry implementations examined chose to use the permissioned version of blockchain which is arguably not an extreme disruption in recordkeeping compared to permissionless public blockchains. A hybrid version utilizing both permission models seems to be a good first step towards improving the accuracy of land records as well as the public's trust in them. A major prerequisite for such transition was found to be whether the country's records were already digitized combined with government willingness to adopt new technological solutions. A technological solution however, whether it be blockchain or another, seems unable to provide resolution to governance challenges such as existing ownership conflicts and missing ownership files.

A major limitation of the concept of a completely decentralized ecosystem seems to be that a trusted third party cannot be easily eliminated with the use of a public permissionless blockchain in place of a land registry. Nevertheless, a well functioning land registry can be the foundation upon which smart contract transactions can be implemented in order to make the heavily convoluted process of real estate transactions much more efficient and less costly. Improving the challenge of information opaqueness by using a blockchain platform to distribute the information necessary in a transaction, reducing intermediaries by making use of smart contracts and especially transacting property with the use of tokens certified by authority are all avenues of great value and worth exploring further.

Further research needs to be conducted on ways to include physical person identity on the blockchain as well as ways to harmonize a blockchain solution with the the complexities of rules governing each country. Going forward, implementations and their designs need to be carefully considered on a case to case basis. In conclusion, blockchain technologies seem to be a promising way of providing a much needed improvement in the slow and costly real estate market as well as a motivator for countries with poor infrastructure to start moving towards a more digitized state. However, the hype and excitement generated by media needs to be replaced with a sober outlook as real estate is far from an intuitive candidate for the application of blockchain.

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