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Exploring the Potential of Blockchain Technology in Real Estate: A Systematic Literature Review

Ana Sofia Lourenço Alves

Master in Computer Science and Business Management

Supervisor:
Doctor Catarina Ferreira da Silva, Associate Professor with Habilitation,

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TECNOLOGIAS
E ARQUITETURA

Department of Information Science and Technology

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Resumo

Nos últimos anos, a tecnologia *Blockchain* tem vindo a surgir em várias indústrias, demonstrando a sua utilidade através de um número crescente de soluções, que permitem principalmente maior transparência nas transações, redução de custos de intermediação, e melhorias de eficiência na manutenção, rastreabilidade e auditabilidade de registos. No entanto, apesar do interesse crescente, o potencial desta nova tecnologia na indústria imobiliária é, ainda, um tema por desenvolver. Assim, esta investigação visa fornecer uma compreensão clara deste tópico e, consequentemente, produzir um sumário do estado do conhecimento sobre a adequação da tecnologia de livro-razão distribuído, em particular, a tecnologia *Blockchain*, no setor imobiliário. Este objetivo foi atingido através do desenvolvimento de uma revisão sistemática da literatura, que envolveu a análise de 129 artigos científicos. As principais conclusões indicam que a tecnologia *Blockchain* tem potencial para atingir benefícios significativos em algumas áreas imobiliárias, como o registo de detalhes de propriedade ou a transação de acordos de propriedade. Ainda assim, as conclusões também sugerem múltiplas barreiras tecnológicas e societais em aberto relativamente à implementação mais abrangente de *Blockchain*; exemplos destas barreiras incluem segurança, privacidade, escalabilidade, usabilidade, integração com outros sistemas, e questões regulamentares e de aceitação. Finalmente, esta investigação conclui que, apesar da tecnologia *Blockchain* ter várias perspetivas de aplicação benéficas à indústria imobiliária, existem várias barreiras que limitam a sua adoção que, como qualquer outra nova tecnologia, deve ser cuidadosamente investigada e apenas aplicada se for a abordagem apropriada, e não apenas porque é nova ou tendência.

Palavras-Chave: Tecnologia *Blockchain*, Imobiliário, Revisão Sistemática da Literatura

Abstract

In recent years, blockchain technology has been emerging in several industries, demonstrating its usefulness through an increasing number of solutions, which mainly allow for greater transparency in transactions, reduction of intermediation costs, and efficiency improvements in record keeping, traceability and auditability. However, the potential of this novel technology in the real estate industry is still an undeveloped topic. Then, this research aims to provide a clear understanding of this topic and, consequently, produce a summary of the state of knowledge about the suitability of distributed ledger technology, in particular blockchain technology, in the real estate field. This goal was achieved through the development of a systematic literature review, which involved the analysis of 129 scientific articles. The main findings indicate that blockchain technology has the potential to drive significant benefits realised in some real estate areas, like the registration of property details or the transaction of property agreements. Yet, the findings also suggest multiple technological and societal open barriers concerning the wider implementation of blockchain; examples of these open issues include security, privacy, scalability, usability, integration with other systems, and regulatory and acceptance matters. Finally, this research concludes that despite blockchain technology having several beneficial application prospects for the real estate industry, there are several barriers constraining its adoption which, like any other novel technology, should be carefully investigated and only applied if it is the appropriate approach, not just because it is new or trending.

Keywords: Blockchain Technology, Real Estate, Systematic Literature Review

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Abbreviations

DLT	Distributed Ledger Technology
DPoS	Delegated Proof of Stake
EC	Exclusion Criteria
ERA	Excellence in Research in Australia
IC	Inclusion Criteria
IT	Information Technology
P2P	Peer-to-Peer
PICOC	Population, Intervention, Comparison, Outcome, and Context Criteria
PoS	Proof of Stake
PoW	Proof of Work
QC	Quality Criteria
SJR	SCImago Journal Rank
SLR	Systematic Literature Review

Contents

CHARTER 1

Introduction

This chapter introduces the context and motivation of this research, defines the main research question that it intends to answer, highlights the core research contributions, and briefly describes the structure followed.

1.1. Context & Motivation

Nowadays, global digitalisation powered by the advancements in technology allows us to get information increasingly faster; this has been driving emergent technologies like blockchain to actively develop and penetrate many areas of activity [1]. In particular, blockchain technology was firstly applied in 2008 through Bitcoin, a peer-to-peer (P2P) cash system for electronic transactions without relying on trust, with the potential to revolutionise the financial sector [2]; since then, it has emerged as a disruptive technology in several fields and industries, including education [3], healthcare [4], energy [5], supply chain [6], and others [7], by helping to accelerate the business processes to bring more efficiency, safety, and transparency into the market [8]. Although blockchain is a relatively novel technology, the number of studies on it has increased considerably [9] and, consequently, blockchain is currently considered the most well-known and used distributed ledger technology (DLT), where its core innovation is the distributed append-only ledger on which transactions can be permanently recorded [10]. Essentially, blockchain has been expanding due to its features of trustworthiness, immutability, and transparency that are become crucial with the rapid development of the digital field [11]. For that, blockchain technology ensures a new paradigm shift for trust through a decentralized structure that removes the dependency of a central authority, while also provide transparency and immutability of data that are chronologically ordered and available to all nodes in a blockchain network. These characteristics have led blockchain to be considered a technology that helps to provide trust, especially in an environment in which the parties interested in a transaction do not know each other, and in which they want to complete transactions without a central authority control [12]. Also, the decentralized feature of blockchain technology has drawn great interest in future global networks, as a way to incentivize the maximization of information sharing between stakeholders [13].

Moreover, based on the high demand for digitalisation, governments are encouraging digital systems and digital transactions to bring more transparency [14]; accordingly, businesses

cannot escape from the digital transformation taking place across the global economy [15], where vital documents like passports, birth records, medical record, land records, and event transactions are being digitalised. This transformation has not just been improving security but also has been reducing the time and effort to maintain all records [16]. In particular, recent publications have created a perception of success in the use of blockchain technology for the real estate industry, through land registration, protection of titles, and property rights, mostly as tools for transparency and means to fight corruption [17]. Therefore, research on this topic is crucial because misleading concepts may bury the idea of blockchain use [18].

Traditionally, the real estate sector has been designated as an inefficient market that suffers from a lack of transparency, high transaction costs, and slow transaction processes [8] [17] [18]. This is often due to its extensive paper-based inefficient management, manual approach prone to errors, and fraudulent activities happening in the field (e.g., claiming ownership over the same piece of land) [16]. Also, most countries' administration following a centralized paper-based system has been dealing with time-consuming processes in accessing, validating, and maintaining information. Thus, such countries should focus on exploiting available technologies to reduce corruption, enhance transparency, and provide authenticity of data as, although the legal framework differs between regions, the aim of having a reliable property administration system remains common. Several aspects of this system's procedures, such as property sale prices, sale history, lease rental rates, market valuation, and so on, expect as a trusted environment a larger demand for transparency, data integrity, and security [19], to reduce disputes during title transfers, improve the ability to prove ownership, and develop trust in the government [20]. As a result, credible property record management requires a system where the properties' details accurately reflect the legal owner and permit an efficient and trustworthy transfer of rights [21].

On the other hand, real estate is considered the largest asset class in the world, characterized by high value compared to other assets (i.e., it is one of the primary needs in human life, as everyone requires a place to live [22]). In accordance, the sector is one of the top global sectors that are driving the economic growth of any country [19] [23], with significant impacts on the economy, country development, and civil society [24], which is reflected in strict formal requirements envisaged in law, relating to transfer or establishment of real property rights [25]. Accordingly, this industry is known to be resistant to change, and seemingly averse to the adoption of new technology [26] [27]. Furthermore, given the primary characteristics of real estate assets as indestructibility, heterogeneity, and immobility, the market for buying real estate tends to be illiquid, localized, and highly segmented, with privately negotiated

transactions, and high transaction costs due to the involvement of a vast amount of third parties [17] [23].

Hence, as a possible solution path, developments in technology, such as the emergence of blockchain, have triggered new ways of improving the land administration processes through automation [28], to increase property market transparency, improve liquidity and bring lower transaction costs, which could have a positive impact on the value of investment assets [29]. In particular, real estate may represent a fitting use case for blockchain technology, which has garnered significant attention recently for building more reliable and transparent record-keeping systems [30], due to the current complex process of real estate transactions, which centre on protecting title ownership [31]. Consequently, blockchain technology can have a positive impact on the value chain in real estate, which includes thinking about efficiency, transparency, ownership, value transfer, automation, and service [32]; but the main aspect here is focused on the added value of blockchain as a secure data distribution mechanism, which could add value by creating a safer way of sharing data [17].

However, given the early stages of the development of blockchain technology, there is still little research on the possibility of using blockchain technology in the real estate sector [17] [33] [34]. Also, the development of real applications and practical cases based on this technology is still in its infancy period [1] [35], as well as e-government applications related to real estate management are still in their early stages too. Even though, it is estimated that the introduction of blockchain technology in public administration will increase the efficiency of public services while ensuring the reliability of data and reducing the level of corrupt practices [10]. Additionally, despite the attention of government entities to leveraging blockchain technology to enable public services and bring them closer to citizens [36], there is a lack of blockchain frameworks or reference architectures policies that address government services in literature [37]. Consequently, despite the recently rising interest in the potential of blockchain in land administration [38] and while there are several reviews regarding blockchain technology itself, the literature lacks a systematic review focused on the property sector that provides a clear and holistic understanding of how blockchain can be a technology of choice, with meaningful use of its potential, particularly for this sector and their stakeholders.

Therefore, this gap was the main driver for conducting this research. As this topic is an immature field, the present research aims to point out missing data and call for empirical research at the right point in time [39] by developing a comprehensive systematic literature review (SLR) that can further provide a better-established definition and understanding of the research field. Therefore, this review is less hypothesis-driven, and more strongly focused on

synthesizing the basic foundations of the research topic and providing valuable insights [40]. This research also takes into thoughtful consideration that there is a tendency to overhype and/or overuse most emerging technologies, like blockchain, as many projects will attempt to incorporate the technology, even if it can be unnecessary; this is a result of the technology being relatively new and little understood, which leads to the technology being surrounded by misconceptions and the fear of missing out [41]. As a result, the hype over using blockchain technology may unclear the key question of what benefits blockchain actually offers over a non-DLT approach [28]. Then, to address this risk, a rigorous and unbiased methodological approach is followed to assess this research topic while conducting the literature review.

1.2. Research Question

Based on the continuous growth of blockchain technology research, the novelty of this dissertation is based on addressing the need to systematically clarify and summarize the available evidence of the current state of the art about the usage of blockchain technology in the real estate field. Therefore, the main objective of this study is to comprehensively assess the state of knowledge of research papers that approach this emerging topic. In this context, the goal of this research is guided by the following main research question:

RQ. *What is the state of the art regarding the potential of blockchain technology in real estate?*

Additionally, to get a better understanding of the scope of the study, this main research question is divided into sub-questions presented later in the dissertation.

1.3. Research Contributions

With this study, we aim to contribute toward a detailed understanding of the potential of blockchain technology specifically for the real estate sector. Accordingly, the main contributions achieved with the development of this dissertation can be summarized as:

- Identify the benefits of the usage of blockchain technology to address core issues and vulnerabilities in the real estate domain, according to the blockchain's main features.
- Identify thematically the research streams of blockchain technology, particularly in the real estate domain, to highlight the growing interest areas of this research topic.
- Identify the overall limitations and barriers involved in the potential adoption of blockchain technology in the real estate industry.

1.4. Outline

This research is structured and briefly described as follows:

- **Chapter 1 – Introduction.** Introduces the context and motivation of this research, defines the main proposed research question, as well as the resulting key research contributions.
- **Chapter 2 – Theoretical Background.** Presents a short-term definition and contextualization of the relevant theoretical concepts about DLT, blockchain technology, and the real estate industry.
- **Chapter 3 – Related Works.** Presents a rapid literature review of works related to blockchain technology and real estate fields, to highlight the gap in the literature that motivates this dissertation.
- **Chapter 4 – Research Methodology.** Motivates and introduces the research methodology used throughout the development of this research and the protocol steps that need to be performed.
- **Chapter 5 – Results.** Describes the results of conducting the literature review based on the identification of studies from literature and bibliometric analysis of the research evidence gathered from the published papers.
- **Chapter 6 – Discussion.** Summarizes the main findings and discusses comprehensively the insights of the results obtained to answer, in detail, the proposed research question of this research.
- **Chapter 7 – Conclusion.** Highlights the achieved concluding remarks of the research, points out the limitations of the development of the study, and proposes paths for future work.

CHARTER 2

Theoretical Background

This chapter presents a brief definition and contextualization of the relevant theoretical aspects of distributed ledger technologies, in particular, blockchain technology, as well as about the real estate sector.

2.1. Distributed Ledger Technology (DLT)

As the designation suggests, DLT can be defined as the technology that allows to record and to share synchronized data, through the distribution of copies of a ledger over a network of P2P computer nodes, that agreed on a consensus protocol and are possible located across multiple dispersed locations [42] [43] [44]. Then, transactions are executed directly between connected peers using security features, usually based on public key cryptography, and verified consensually using algorithms over the network. As a result, one of the main goals of DLTs is the ability to interact and exchange information across different consenting parties, who do not necessarily trust each other, without the need for a central trust authority or record-keeper [45].

There are several different DLTs (e.g., Blockchain, Tangle, Hashgraph, Sidechain [45]), and each distinguishes itself by a particular design using different data structure models and technologies (e.g., linked lists, directed acyclic graph) [44], but all are based on the core idea of operating in a mistrust environment. For that, a DLT is commonly based on public key cryptography to establish secure digital entities with public and private keys, distributed P2P networks to avoid a single point of failure and to prevent a group takes over the network, and consensus mechanisms to allow all nodes to agree on a unique version of the truth, without the need of a trusted third party [45]. The most widely recognized example of DLT is a blockchain, where data is grouped and stored in a particular structure, through “blocks” that are connected to each other using hash codes in a sequential append-only “chain”, to build the distributed ledger. This technology, in particular, is discussed in detail in the following subsection.

2.2 Blockchain Technology

As referred to before, blockchain is the most well-known DLT, where signed transactions are chronologically grouped and recorded in an append-only chain of cryptographically connected blocks, on a decentralized P2P network, as an immutable and secure ledger made of a linked list of blocks [41]. Each node of the network holds a replication of the ledger and agrees on a

consensus protocol to append a new block. Each block of the ledger is a data structure that enables the storage of the integrity of several digital assets – called transactions – such as the hash of property rights, certificates, and others. The structure of the block (**Figure 1**) is composed of the block header, which contains the hash of the header of the previous block, a timestamp of the block creation, a Nonce (i.e., a unique arbitrary number), and a Merkle root hash (i.e., the hash of all the hashes of all the transactions of this block), and by the block body, that include the transactions data [44]. As each block references the previous block in the chain makes it tamper evident after validation and undergoing a consensus decision, since any change of a block will invalidate all the successor blocks [45]. The consensus protocol (e.g., Proof-of-Work (PoW), Proof-of-Stake (PoS), Delegated-Proof-of-Stake (DPoS) [46]) ensures block integrity and consistency by defining that all network nodes in the network agree on the state of the distributed ledger and how to add new blocks to the ledger. This protocol employs incentive mechanisms to encourage the players in the system to act honestly [47]. Thus, the consensus mechanism is used to establish trust in the accuracy of the data in the distributed system. Traditionally, trust can be established by an intermediary or an administrator in a centralized system.

The application of blockchain technology was originally introduced, by an anonymous author called Satoshi Nakamoto [2], with Bitcoin, as a P2P electronic transaction network that allows for direct financial transactions without the need for traditional financial institutions. Yet many new applications have been introduced since then, also built outside the financial sector, because blockchain has been rising as a reliable technology to provide trustworthiness, transparency, cost reduction, efficiency, auditability, and traceability without central trusted authorities.

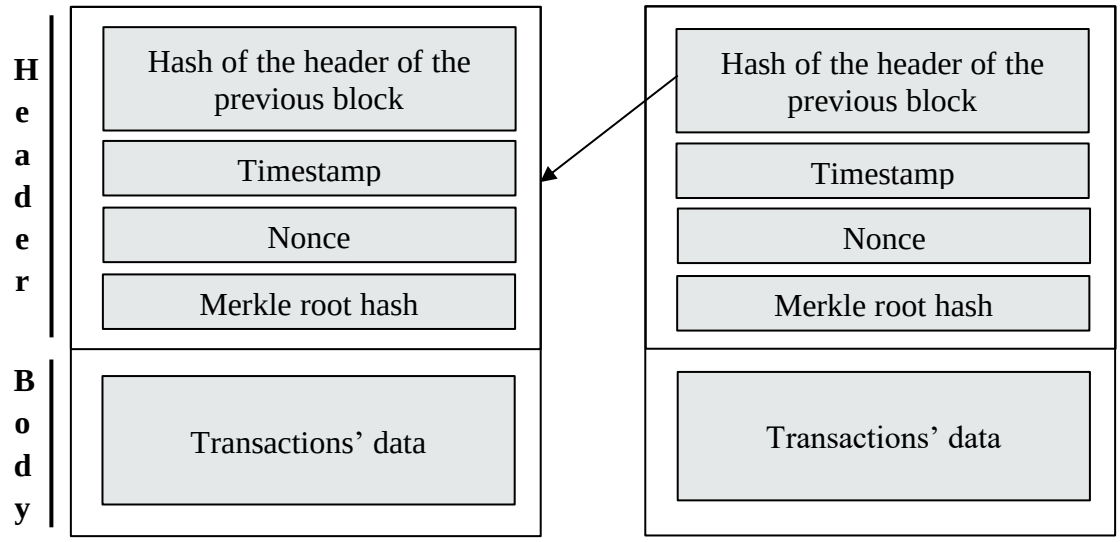

Figure 1. Structure of blockchain connected blocks, adapted from Yaga et al. [41].

2.2.1 Categories of Blockchain Technology

The classification of the blockchain types is not consensual among researchers, some authors [48] categorize it in public, consortium/hybrid, and private access. Others use a more granular terminology between public and private access that can be further distinguished into permissionless and permissioned [43]. We follow the last and more granular categorization, where there are several types of blockchain architectures based on the governance permission model adopted, according to (1) the permissions to participate in the distributed ledger by transaction validation through the consensus mechanism, also known as write permissions (either permissionless or permissioned), and (2) the permissions for access and join in the transactions network (public or private), also known as read permissions [43] [49]. Therefore, as shown in **Table 1**, four main types of blockchain can be distinguished based on this terminology. The public permissionless blockchain (e.g., Bitcoin[1] or Ethereum[2]) is entirely decentralized by allowing anyone to join or leave the network without any access control, as all have equal rights to read and write on the blockchain; consequently, information is considered public, although some can be encrypted. The public permissioned blockchain (e.g., Ripple[3] or Ethereum) also allows anyone to access and participate in the transacting, but only a restricted group of nodes can validate transactions through the consensus mechanism. The private permissioned blockchain (e.g., Hyperledger[4]) is partly decentralized because only authorized/invited nodes (e.g., belonging to an institution) can join the network, and equal rights on the blockchain may not be granted, as the owner of the blockchain system determines who can participate in the blockchain system and which nodes can participate in the consensus mechanism. The private permissionless blockchain (e.g., LTO Network[5]) restricts a group of selected nodes to join the network and who can participate and access transactions, but the consensus mechanism process is open to anyone.

Additionally, the type of blockchain implemented may also impact other aspects of the blockchain, like the consensus mechanism. For example, the consensus mechanisms in a public permissionless blockchain network usually promote non-malicious behaviour by rewarding the nodes that participate in the generation and/or validation of blocks and transactions, consensus findings, and maintenance of the distributed ledger, in order to have protocol-conforming blocks [43]; this approach for malicious behaviour prevention may not be a requirement for

[1] Bitcoin Blockchain – bitcoin.org
[2] Ethereum Blockchain – ethereum.org
[3] Ripple Blockchain – ripple.com
[4] Hyperledger Blockchain – www.hyperledger.org
[5] LTO Network Blockchain – www.ltonetwork.com

private permissioned blockchains, as permissions are more controlled and restricted to only authorized/invited nodes.

Table 1. Classification of blockchain technology categories, based on the governance model adopted. Adapted from Allessie et al. [49] and Kannengieber et al. [43] terminologies.

		Read Permissions	
		Public Anyone can access and join the transacting network	**Private** Only selected nodes can access and participate in the transacting
Write Permissions	**Permissionless** Anyone can validate transactions through the consensus mechanism	e.g., Bitcoin, Ethereum	e.g., LTO Network
	Permissioned Only selected nodes can validate transactions through the consensus mechanism	e.g., Ripple, Ethereum	e.g., Hyperledger

2.2.2 Blockchain Technology & Smart Contracts

In opposition to the emergence of blockchain technology, smart contracts are not new, these were defined by Nick Szabo, in 1994, as an automatic protocol that executes the terms of a contract, a common agreement between two or more parties [50]. In practice, smart contracts are event-driven computer protocols written in code (e.g., Solidity, Go, Java), that execute specific rules based on the state of the system or a transaction that occurs, facilitating the verification or execution of the terms of a contract [44]. However, the rise of blockchain technology brings a new environment of authenticity and uniqueness for smart contracts, by allowing the performance of mutually agreed contracts that are deployed using cryptographically signed transactions on the blockchain network automatically, without the intervention of a third-party authority [50]. Therefore, the self-executable code can automatically be triggered when the predetermined conditions in the contract are verified and then the results of execution are recorded on the blockchain after being propagated by the P2P network [51] [50]. Thus, the code, being on the blockchain, is also tamper resistant and can be used as a trusted third party. In practice, the combination of blockchain technology and smart contract concepts enabled a new form of transparent thrustless transactions [52].

In addition, smart contracts can be further divided into deterministic and non-deterministic smart contracts [53]. The deterministic smart contracts do not depend on outside information other than information on the blockchain to be triggered and work effectively. The non-deterministic smart contracts do not have sufficient information on the network; thus, an

external party is needed to bring reliable information from outside a system to make decisions, which is usually called an oracle [47].

2.3 Real Estate Industry

In simple terms, real estate refers to the earth's surface, everything below and above it, plus all that is attached to it [54], which is usually also defined as any physical property in the form of land or buildings, or both, with related resources and rights. Moreover, the designation of real estate is also generally known as land or real property, but these terms have subtle differences in their meanings; the land is commonly seen as the earth's surface but also includes existing resources (e.g., minerals, trees, water), the real estate is land plus human-made additions, and real property is real estate plus the legal rights associated with ownership of the land and improvements [54]. Then, the business of this industry covers a variety of specialized services related to properties, including brokerage, appraisal, management, development, counselling, financing, and education; but centres around the ownership, possession, and transfer of real estate [54]. As a result, real estate transactions occur very frequently, for example, when a commercial leasing firm rents space in a shopping mall or the owner of a building rents an apartment, if the bank lends money to a business to expand its office and manufacturing facilities, or when a family sells its home and buys a new one [54]. Conventionally, real estate has always been classified as a sector that is traditional, cyclical, and strongly influenced by economic trends, with slow evolution, a strongly illiquid market, lengthy processes, and high costs [55].

Furthermore, the real estate market involves a complex structure of stakeholders [56], namely, brokers and agents that act as a point of contact between two or more people in negotiating the leasing or buying/selling of properties, real estate developers that buy land, build properties on it, and sell it to interested parties, building/property managers that act on the owner's behalf and deal with day-to-day tasks of maintaining properties (e.g., finding new tenants, collecting rents, ordering repairs), and appraisers who assess the value of properties before they can be sold. In addition, support staff, office managers, real estate attorneys, loan officers, government entities, and, of course, the citizens are essential players in real estate transactions.

On the other hand, unlike many assets, real estate has unique characteristics that affect its use based on a variety of reasons, such as its structure, age, and location [55]. These characteristics of land are (1) immobility, (2) indestructibility, and (3) heterogeneity as the

geographic location of any given parcel of land cannot be changed because is the earth's surface, and even if some of the substances of land are removable, two parcels of land are never the same, because every parcel differs geographically. All of these characteristics affect the potential investment and competition for a specific parcel of land [54]. Furthermore, according to the purpose of land, there are several categories of real estate, designated as (1) residential, the most common, used for housing, whether in urban, suburban, or rural areas (e.g., family apartments), (2) commercial used for business buildings that produce income (e.g., shopping, hotel, theatres), (3) industrial for manufacturing buildings and warehouses used for research, production, storage, and distribution of goods (e.g., warehouse, factories, power plants), (4) agricultural (e.g., farms, orchards, ranches), and (5) special purpose properties (e.g., churches, schools, cemeteries) [55] [54]. Because of these characteristics, the rights to use it are controlled by the laws of the state in which it is located, likewise, real estate markets tend to be local [54] and most countries currently use land registration systems (and similar) to manage the legal records usually maintained and controlled by the governmental authorities. These systems contain all the relevant information about any property, for example, ownership, possession, or other rights in land to provide evidence of title, facilitate transactions, and prevent unlawful disposal [9] [57]. The goal of these systems is to simplify land transactions by recording and disseminating real property rights to interested parties. Therefore, every country has its own process and requirements to deal with its territory, which is one of the reasons why cross-border transactions are difficult to accomplish, even with the several projects that try to do so (e.g., European Land Information Service (EULIS)) [12].

Additionally, the real estate industry is an important driver element of the economy, and the value of the real estate market depends on tangible income generated by lands or buildings, referred to as ownership or to a series of rights over the property itself [55], however, as investing in real estate is out of the scope of this research, this matter will not be developed.

More recently, the phenomenon PropTech has appeared as the implementation of emerging technologies within the real estate sector, including virtual reality, building information modelling, artificial intelligence, the Internet of Things, blockchain technology, and others [58]. All these relatively recent innovations have the potential to improve productivity and competitiveness, increase resource efficiency and effectiveness and, hence, enable more efficient interoperability of property information, and introduce new business models for real estate management and trade [30]. Therefore, those emerging technologies have the potential to promote the protection of the environment and provide opportunities for developed and

developing countries to achieve economic growth and sustainable development in line with the 2030 Agenda for Sustainable Development Goals [15].

CHARTER 3

Related Works

This chapter presents a rapid literature review of works related to blockchain technology and the real estate domain, in order to guide this research and highlight the gap in the literature that motivates this dissertation.

3.1 Rapid Literature Review

As pointed out before, despite blockchain technology being primarily recognized in the financial domain by Bitcoin [2], their broad application to several areas has been increasing a growing interest by the research community, and industry as well, which led to the publication of multiple studies on this topic. Some examples are briefly reviewed and described below.

Broadly, Casino et al. [7] propose an SLR of blockchain-based applications across multiple general domains that investigate the state of blockchain technology and provide a framework to determine the suitability of blockchain per application domain. Other reviews focused on specific sectors, such as education [3], healthcare [4], energy [5], supply chain [6], and others [59]. In detail, Loukil et al. [3] developed a survey of blockchain applications in the education field, by classifying the outcomes according to several categories, namely, certificate registration, access control of educational data records, employment recommendations, exchange of educational credits between institutions, and supporting online lifelong education; thus, provided a better understanding to the benefits and challenges concerning blockchain adoption within education for future research projects. Tandon et al. [4] focused discussion on the ramifications of blockchain technology adoption, as well as specific challenges and areas for improvement for advancing the healthcare field, suggesting by the findings that the application of blockchain technology is undergoing a conceptual evolution in the healthcare industry with significant value through improved efficiency, access control, technological advancement, privacy protection, and security of data management processes. Andoni et al. [5] provided a comprehensive overview of blockchain initiatives for the energy industry, where opportunities, potential challenges, and limitations for several business cases are discussed, including emerging P2P energy trading and IoT applications, decentralized marketplaces, electric vehicle charging, and e-mobility. Chang & Chen [6] explored the status, potential applications, and future directions of blockchain technology in supply chain management pointing to major issues that are critical for future orientation like traceability and transparency,

stakeholder involvement and collaboration, supply chain integration and digitalization, and common frameworks on blockchain-based platforms. Also, as traditional supply chain activities involve several intermediaries, trust, and performance issues, the authors suggested that the potential of blockchain can be leveraged to disrupt supply chain operations for better performance, distributed governance, and process automation.

Moreover, at the time of writing, the review studies specifically about blockchain technology and the real estate domain are, on one hand, based on grey literature, such as news articles [60], technical reports [61], or thematic reports [62]; on the other hand, there are also some scientific review works published. Santana et al. [27] used an SLR to review the use of blockchain technology in real estate, yet the research is mainly restricted to identifying the main advantages and disadvantages of the use of blockchain technology specifically in a particular process, the land registry; in addition, it is focused on identifying the specific countries which already have implemented pilot projects of this technology in some stages of their land registry process. Then, as suggested by the authors, a study about how blockchain can impact the entire real estate area, not just the land registry process is needed. Similarly, Kiu et al. [13] performed a systematic review with a mapping process included to identify the potential areas blockchain technology could disrupt the construction industry and future research direction of blockchain in the construction industry. The findings showed that real estate management was one of the areas mapped, however, this was only briefly outlined and analysed. Bennet et al. [52] explored the potential for the applying of smart contracts, implemented using blockchain technology, for the particular land dealings inherent to land administration, to comprehend the potential role, benefits, and disadvantages of blockchain technology within the land sector. However, the review work is limited to a comparative analysis of findings from three specific proof-of-concept studies undertaken in Sweden, the Australian State of New South Wales, and the Canadian Province of British Columbia. Ooi et al. [28] also discussed the promises and perils of blockchain for land transfers, but the study is only focus on the English conveyancing system and similar systems. Lastly, from a perspective closer to the industry, Averin et al. [1] reviewed real estate practical solutions based on blockchain technology, but only focused on defining the main commercial purposes and tasks in the field of real estate and cadastral registration.

Then, as grey literature represents information that does not necessarily go through the traditional scientific publishing peer-review process and the scientific literature is specific to one angle of analysis, we can conclude that a gap in the literature exists of a study that holistically approaches this topic from a systematic and scientific perspective. Therefore, this is the primary driver for the research, and we expect to contribute to the body of knowledge

with the development of an SLR about the potential role and impact of blockchain technology in the real estate industry, as an overview of the state of the art on this technology for real estate processes. Besides, we also expect to contribute by instigating gaps and open issues as future research avenues for this topic.

CHARTER 4

Research Methodology

This chapter identifies the scientific methodology followed in this research and describes the phases of the procedures followed to accomplish the research goal

4.1 Methodology Design

Existing literature is the building block of all types of academic research activities, then literature reviews are a crucial foundation, as they provide a source of knowledge development and have the capacity to stimulate new ideas and directions for a particular field of research [63]. As secondary studies, literature reviews are particularly useful when the aim is to evaluate the state of knowledge on a certain topic based on existing studies.

Therefore, as the aim of this dissertation is to assess the available and relevant evidence of research papers about the application of blockchain technology in the real estate industry, the research methodology followed is the systematic literature review (SLR) based on the guidelines of Kitchenham [64] and complemented by Webster and Watson [65]. This methodology allows for a rigorous and unbiased evaluation of a research topic to summarize previous work, identify unexplored gaps, and consequently provide a basis for potential future research [66].

In this sense, the structure of the literature review process covers three major phases which are described below: planning the review, conducting the review, and reporting the review (**Figure 2**). Although the stages listed below may appear to be mostly sequential, some activities involved iteration, for example, it is expected that the research questions need revision during the protocol development, as the understanding of the problem increases; or the data extraction and synthesis procedures may need to amend to address the research questions [67]; or although the selection criteria are defined during the protocol definition, this may be refined during the search process as well [64]. Therefore, these possible iterations are recorded in conducting the review stage to stay reliable with the procedures of the review performed.

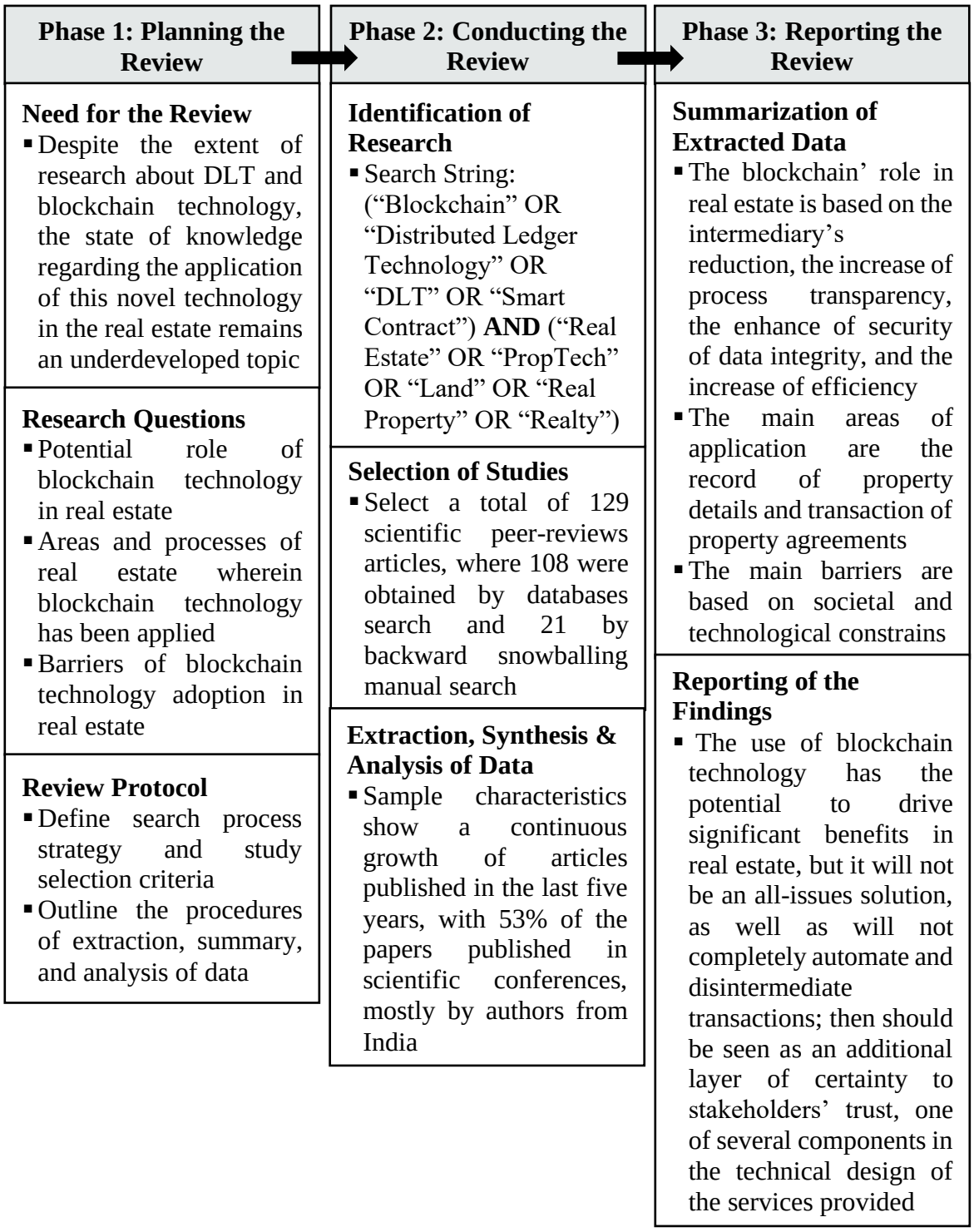

Figure 2. Description of the phases for the SLR, based on the Kitchenham' guidelines [64].

4.2 Phase 1: Planning the Review

The planning stage represents the first phase of the SLR methodology and should ensure the reproducibility of the research process. For that purpose, this section identifies the need to

conduct the review, the research sub-questions that the review will answer, and the definition of the review protocol.

4.1.1 Need for the Review

The identification of the need for a SLR results from the demand to objectively summarize the body of knowledge already available about a research topic. In this case, despite the increasing developments using blockchain technology, due to the extent and diversity of research, there is little discussion in peer-reviewed literature and only recent studies have integrated this novel technology with the real estate area [68]. Consequently, the practical application of this emergent topic is still in the preliminary stages of adoption [34] [35] and, even with limited research done, the meaning of blockchain technology for real estate needs to be studied [33], especially given that blockchain technology may be seen as a novelty rather than a trend [68]. For this reason, to achieve a comprehensive understanding of how blockchain technology can be explored in real estate, an SLR is performed through an in-depth analysis of all available and relevant peer-reviewed published studies in this field.

4.1.2 Research Sub-Questions

The research questions drive the entire systematic review methodology by influencing the search process, data extraction process, and data analysis process [64]. Staples and Niazi [69] recommended limiting the scope by selecting clear and narrow research questions and clearly defining the unit of analysis of a systematic review. In this review, we follow the Population, Intervention, Comparison, Outcome, and Context criteria (PICOC) shown in **Table 2** to formulate the sub-questions that we aim to answer, which are presented in **Table 3** with the respective goals. To formulate these sub-questions a few quick exploratory searches were performed in order to help us to narrow our focus on clear and specific questions.

Table 2. Description of PICOC criteria to define the research question elements based on the guidelines of Kitchenham [64].

Criteria	Description
Population	*Who is interested or affected by the intervention?* Industry group of real estate stakeholders, such as citizens, government, banks, agencies, notaries, and others, as well as researchers and companies interested in the blockchain technology application
Intervention	*What or how technology, tool, or procedure is under study?* Application of blockchain technology in real estate processes

Comparison	*The intervention is compared to what technology, tool, or procedure?* Conventional or commonly used technology and procedures of real estate (also referred to as "control")
Outcome	*What is trying to accomplish/improve?* Improved reliability and efficiency of real estate processes
Context	*Which is the context in which the comparison takes place?* Publish scientific literature focused on blockchain technology applied to the real estate industry

Table 3. Description of research sub-questions and goals, that arise from the main research question defined previously in the introduction section.

Research Question	Question Goal
RQ1.1 *What is the potential of blockchain technology to address core issues in the real estate?*	This research question aims to discuss the overall potential of blockchain technology to address core issues in real estate, by establishing a relation between the benefits enabled by blockchain technology's key features and the main problems faced by the real estate industry, including the discussion and proposal of design steps to exploit the full capability of blockchain technology
RQ1.2 *What are the main processes and application areas of the real estate sector wherein blockchain technology has been applied?*	This research question aims to identify and thematically classify the current main processes and application areas, in the context of the real estate sector, where the blockchain technology has been used as an improved approach; including a brief functional and technical comparison of the proposed practical studies that implement those processes with blockchain technology
RQ1.3 *What are the current barriers that the literature posits to blockchain technology adoption in real estate?*	This research question aims to identify and categorize the general main adoption barriers and limitations of blockchain technology in the real estate industry and, if possible, suggest action steps on how they can be overcome

4.1.3 Review Protocol

The review protocol is an essential element in conducting a SLR by establishing in advance how the review should be conducted [67], in particular, because it has a critical role in decreasing the prospect of research bias [64]. Accordingly, the protocol must define the procedures of the search strategy and selection criteria to find relevant research studies related

to the relation, integration, and development of the blockchain technology in real estate; then, the protocol should ensure that the extracted data and analysis procedures will properly address the research questions. The entire review protocol is represented in the **Figure 3**.

For the search process strategy, the protocol must begin with the keywords appropriately derived from the research questions to formulate the search string. Then, that string is used to search for research papers published in journals, conferences, and book chapters available in scientific databases. It is important to note that, to avoid selection bias, several analogous keywords and several scientific databases should be used to include as many articles as possible. Also, to avoid publication bias and focus on peer-reviewed publications, only scientific databases are used. Therefore, the scientific databases considered relevant sources of information to search articles related to our research questions are the following ACM Digital Library[6], EBSCO[7], IEEE Xplore Digital Library[8], Scopus[9], Springer [10], and Web of Science[11]. Additionally, as some researchers advocate the use of manual searches, a complementary search is performed to identify new papers to include through a backward snowballing manual search [70], based on the references list of the previously selected studies returned by the databases search.

For study selection criteria, the initial search is done by applying the search string in each referred database applied to all study fields. Then, the first filter applies the search string only on the title-abstract-keywords of the studies. After that, the second filter considers the inclusion and exclusion criteria (**Table 4** and **Table 5**), based on document types, source types, document availability, and language. The third filter manually selects the relevant studies by reading the abstract to verify if the study addresses at least one of the research questions; also, as Brereton et al. [67] suggest that the standard of information technology (IT) abstracts is not sufficient to rely on when selecting primary studies, the conclusions are also analysed. Finally, the defined quality criteria assessment (**Table 6**) is applied to all selected studies, based on quality ranks; although, this quality score is not used to exclude studies, it is used to establish the relevance and representativeness quality of the studies. The inclusion/exclusion criteria, the screening of the abstracts/conclusions and the quality criteria assessment are also applied to the complementary studies obtained through the backward snowballing manual search. A list of the

[6] ACM Digital Library database in dl.acm.org
[7] EBSCO database in www.ebsco.com
[8] IEEE database in ieeexplore.ieee.org
[9] Scopus database in www.scopus.com
[10] Springer database in link.springer.com
[11] Web of Knowledge database in www.webofknowledge.com

candidate studies that were rejected by the manual reading of the abstracts and conclusions in the third filter is kept with the reason for the rejection.

Table 4. Description of study selection inclusion criteria (IC) list.

Criteria	Description
IC1	The study is a peer-reviewed scientific research paper
IC2	The study is published in a scientific journal, conference, or book
IC3	The study is written in English
IC4	The full text of the study is available (including requests by authors' contact)
IC5	If several papers of the same study are available, the most complete is included

Table 5. Description of study selection exclusion criteria (EC) list.

Criteria	Description
EC1	The study is a non-scientific or non-peer-reviewed paper/report – grey literature
EC2	The study is published in a non-scientific publisher
EC3	The study is written in another language than English
EC4	The study's full text is only partly electronically available
EC5	The study is a duplicate of another study
EC6	The study has less than four pages – short paper

Table 6. Description of quality criteria (QC) based on the ranks of journals and conferences.

Criteria	Description
QC1	The study is published in one of the following: ▪ Relevant journal, indexed in SCImago Journal Rank (SJR)[12] – the ranking ranges from Q1 (=best), Q2, Q3, Q4 (=worst) ▪ Relevant conference, indexed in Excellence in Research in Australia (ERA)[13] raking – the ranking ranges from A (=best), B, C (=worst) ▪ Relevant conference, indexed in Qualis[14] ranking – the ranking ranges from A1 (=best), A2, B1, B2, B3, B4, B5 (=worst) Otherwise, the study is considered unranked.

For data collection, relevant data is extracted from all selected studies that properly address the research questions, including the title, the authors, the publisher type (i.e., journal, conference, or book series), the publisher (if published in several sources both will be recorded), the year when the study was published (if published in several sources both dates will be

[12] According to the SJR classification in www.scimagojr.com
[13] According to Excellence in Research in Australia (ERA) criteria in www.conferenceranks.com/#data
[14] According to Qualis criteria in www.conferenceranks.com/#data

recorded and the first date, and respective source, will be used in sample analysis), the quality classification rank, the citations based on Google Scholar, and the keywords.

For synthesis and analysis of the extracted data that appropriately answers the research questions, the information is tabulated (ordered alphabetically by the title) to show the basic information about each study. Tabulating the data is a useful way of aggregating information but then it is necessary to explain how the aggregated data actually answers the research questions [67]. **Table 7** defines the scheme of this process by outlining the base details of each study. The data will be extracted and checked by one researcher.

Table 7. Description of the scheme for synthesis and analysis of the extracted data.

Field	Description
ID	Autoincremented unique identification number of the study
Title	Title of the study
Author	Authors of the study
Year	Year(s) when the study was published
Publisher Type	Publisher type(s) of the study – journal, conference, or book series
Publisher	Source(s) of the study
Score	Score of the study based on the quality assessment criteria
Citations	Number of study citations based on Google Scholar
Keywords	Keywords indexed in the study by authors

For dissemination, the results of this research should be of interest to the information technology community, as well as researchers interested in blockchain technology applied to the real estate industry. For that reason, we plan to report a short version of the results of this research as a paper submitted to a scientific journal or conference.

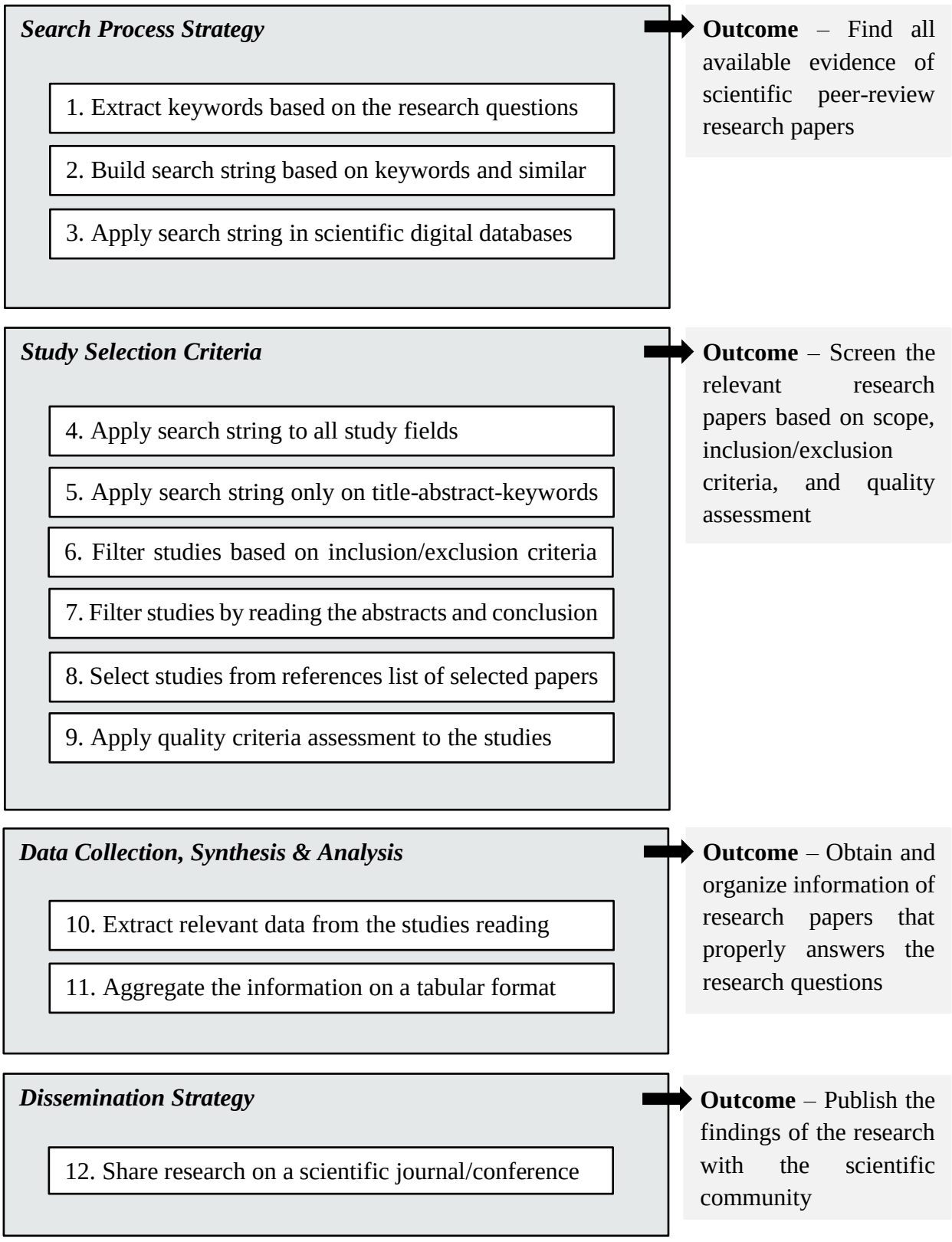

Figure 3. Description of the review protocol, based on Kitchenham' guidelines [64].

CHARTER 5

Results

This chapter shows the results of this research, based on the application of the systematic literature review protocol

5.1 Phase 2: Conducting the Review

The conducting stage represents the second phase of the SLR methodology and describes the application of the review protocol, according to the previous section, as well as the analysis of the extracted data.

5.1.1 Identification of the Research

The identification of the research intends to find as many studies relating to the research sub-questions as possible by applying the previously defined search process strategy [64]. Therefore, the procedures for documenting the search process include the combination of databases and manual searches. For the electronic databases, the following procedures were considered. Based on the defined research sub-questions, several keywords were iteratively extracted and combined to build the search string (**Table 8**). In this research, we focus on keywords related to blockchain technology and the real estate industry, as well as its extended concepts and similar terms. Then, considering the essence of blockchain, a broader terminology was included such as “DLT”, “distributed ledger technology”, and “smart contracts”; for real estate, the terms are vaster, but we only consider terms that unequivocally lead to the real estate scope, like “Land”, “Real Property”, “Realty”, and the term “PropTech”. Once keywords have been established, after iteratively obtain and select the relevant terms, these were combined to build search string expression, which was used to search studies in each scientific database. The search string also needed to be adapted to suit the specific requirements of the different databases search engines, as shown in **Table 9**. For the manual search, a backward snowballing approach was performed based on the references of each relevant study retrieved from the databases search.

Table 8. Description of the keywords, similar terms, and the search string used to search studies in each scientific database.

Keywords	Blockchain Technology & Real Estate

Similar Terms	**Keywords related to blockchain technology, namely**: DLT, Distributed Ledger Technology, Smart Contracts **Keywords related to real estate, namely**: PropTech, Land, Realty, Real Property
Search String	(“Blockchain” OR “Distributed Ledger Technology” OR “DLT” OR “Smart Contract”) **AND** (“Real Estate” OR “PropTech” OR “Land” OR “Real Property” OR “Realty”)

Table 9. Description of the different search string expressions to suit the specific databases' search engine requirements.

Database	Search String
ACM Digital Library	[[All: "blockchain"] OR [All: "distributed ledger technology"] OR [All: "dlt"] OR [All: "smart contract"]] AND [[All: "real estate"] OR [All: "proptech"] OR [All: "land"] OR [All: "real property"] OR [All: "realty"]]
EBSCO	TX (“Blockchain” OR “Distributed Ledger Technology” OR “DLT” OR “Smart Contract”) AND (“Real Estate” OR “PropTech” OR “Land” OR “Real Property” OR “Realty”)
IEEE Xplore Digital Library	(("Full Text Only":"Blockchain" OR "Full Text Only":"DLT" OR "Full Text Only":“Smart Contract” OR "Full Text Only":"distributed ledger technology") AND ("Full Text Only":"Real Estate" OR "Full Text Only":“PropTech” OR "Full Text Only":“Land” OR "Full Text Only":“Real Property” OR "Full Text Only":“Realty”))
Scopus	ALL (("Blockchain" OR "Distributed Ledger Technology" OR "DLT" OR "Smart Contract") AND ("Real Estate" OR "PropTech" OR "Land" OR "Real Property" OR "Realty"))
Web of Science	(“Blockchain” OR “Distributed Ledger Technology” OR “DLT” OR “Smart Contract”) AND (“Real Estate” OR “PropTech” OR “Land” OR “Real Property” OR “Realty”) (All Fields)
Springer	(“Blockchain” OR “Distributed Ledger Technology” OR “DLT” OR “Smart Contract”) AND (“Real Estate” OR “PropTech” OR “Land” OR “Real Property”

5.1.2 Selection of Studies

Once the potentially relevant studies have been found, they need to be assessed for their relevance, then the study selection criteria intend to identify the studies that provide direct evidence about the research sub-questions [64]. In this way, by applying the search string to the article's full text, a total of 89 702 studies was first obtained. Then, the first filter applied the search string only to the article title, abstract, or keywords resulting in a substantial reduction of studies – 2 766 studies retrieved. Then, inclusion and exclusion criteria were used, resulting in 135 studies. Lastly, were obtained 108 relevant articles for this research by reading the studies' abstracts and conclusions. A list of the excluded studies identifying the reason for exclusion is presented in Appendix B, yet the initial electronic databases search results in a large number of completely irrelevant studies (i.e., studies that do not address any aspect of the

research questions or even have anything to do with blockchain technology and real estate), then only are presented records of candidate studies after the irrelevant studies have been excluded as a result of the application of inclusion and exclusion criteria [64]. For reliability of the inclusion decisions, as an individual researcher, it was applied a test-retest approach and re-evaluate a random sample of the studies found to check the consistency of the selection decisions; in addition, the included and excluded studies were also discussed with the advisor of this dissertation until common agreement was reached [64]. Additionally, the selection of studies was complemented by a backward snowballing manual search that aggregates 21 studies, resulting in 129 relevant studies for analysis. Lastly, the quality of the studies was assessed to check articles validity through the quality criteria assessment.

The flow diagram presented in **Figure 5** shows the steps in the selection of studies process through the databases' search and backward snowballing manual search.

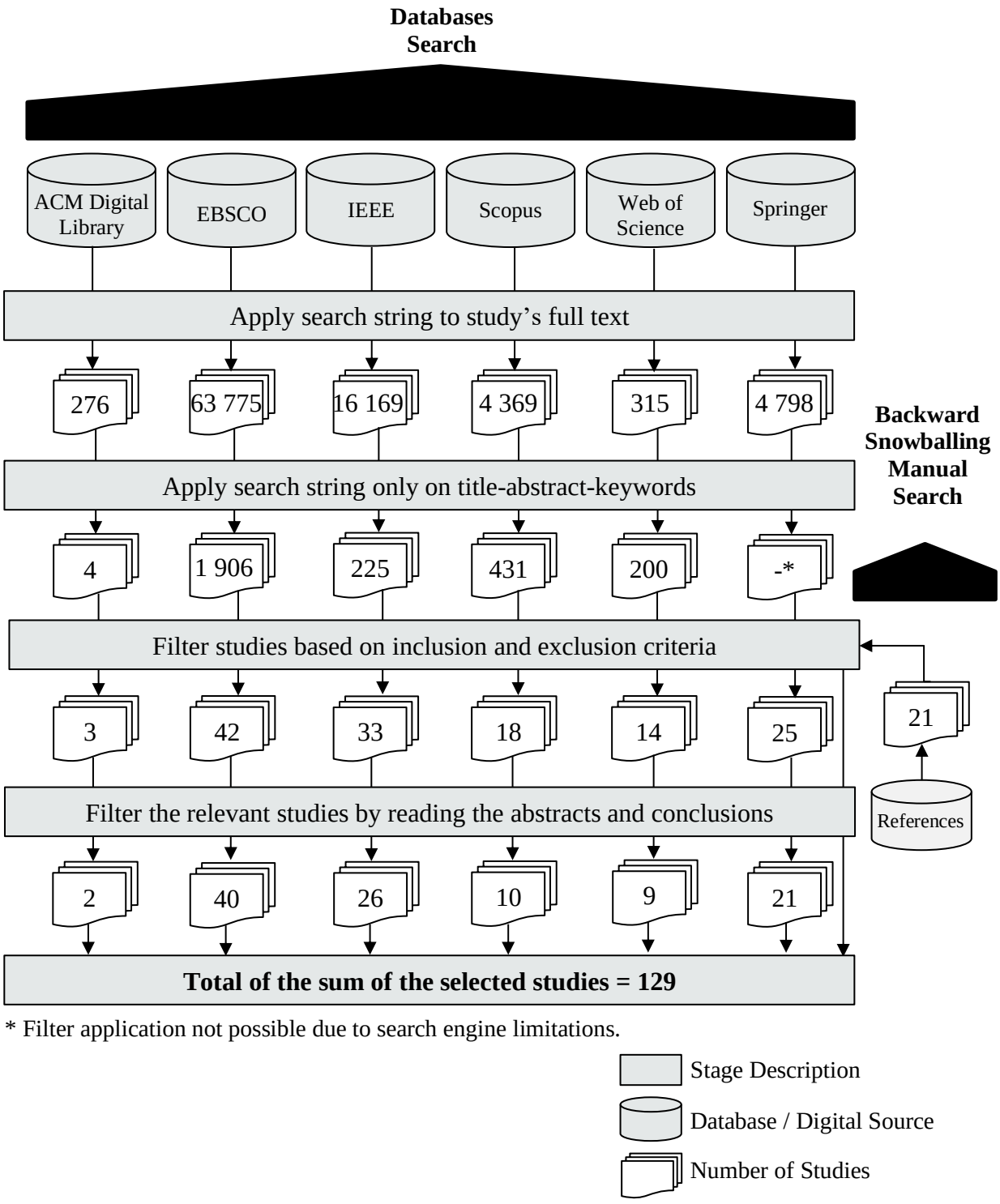

Figure 4. Stages of the study selection processes, through the databases' search and backward snowballing manual search.

5.1.3 Extraction, Synthesis & Analysis of Data

After the study selection process, which resulted in 129 articles, all relevant data were extracted and analysed to accurately record the summarized information of each study. As suggested by Kitchenham [64] and Brereton et al. [67], we have a data extractor and a data checker, although only performed by one reader in this case. Appendix A lists all selected studies tabulated.

As a result, the reviewed articles were profiled to understand the status of research on blockchain technology applications in real estate. In this way, among the 129 articles, the distribution of conference articles is predominant, representing 53% of selected studies, then, about 45% were published in journals, and 2% as book chapters, as shown in **Figure 6**.

On the other hand, although no date criteria were considered in the screening process, it was expected that all the collected articles would have been published after 2008, the year when blockchain technology was first introduced [2]. In this case, all articles were published from 2017 onwards, which indicates the early stage of this research topic (**Figure 7**). Moreover, the evolution of the number of articles published per year shows a continuous increase in publications in the last years (note that 2022 only reflects articles published until February, when the databases search was conducted), which indicates a fast-growing interest in using blockchain technology in real estate.

Furthermore, to recognize the geographical distribution of the members of the research community involved in the study on blockchain technology application in real estate, the countries of the institutions that all the authors are affiliated with were identified (**Figure 8**). The distribution shows that 46 different countries have published papers on this research topic, which indicates a global interest in this area; also, the majority of the articles were published by authors in India (37 studies), Malaysia (7 studies), and United Kingdom (6 studies).

Based on the quality assessment, the distribution of **Figure 9** shows that most articles are not ranked (44%), possibly because these are papers of recent or unranked conferences and book series. On the other hand, the papers published in journals are mainly classified with Q2 and Q3 according to SJR, and the conference and book series papers ranked have a predominant classification of A/B or A2/B1 according to ERA and Qualis classification, respectively.

Lastly, as keywords are a representation of the article content in concise descriptions, we extracted all keywords from the selected articles to generate a word cloud (**Figure 10**), which shows that the primary focus of literature papers retrieved is related to the blockchain (109 times), smart contract (45 times), land registry/registration (31 times), and real estate (30 times), based on the most frequently used keywords.

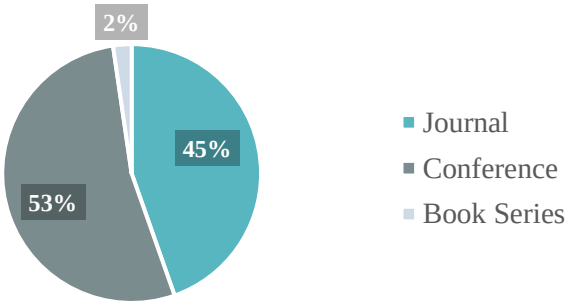

Figure 6. Distribution of selected articles by type of publication source (journal, conference, or book series).

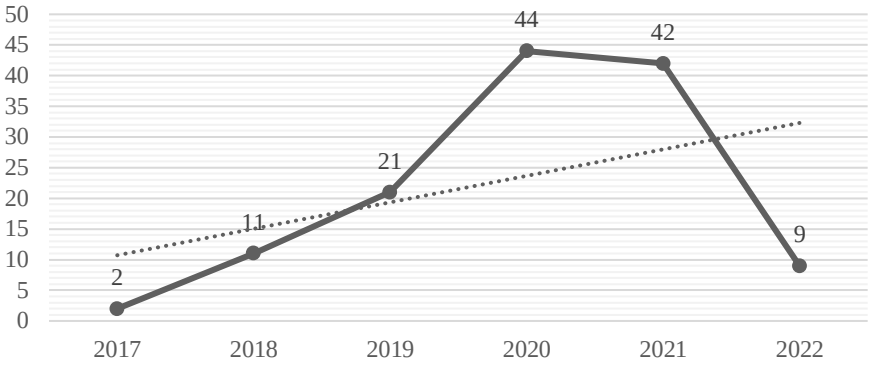

Figure 7. Distribution of the selected articles by year of publication.

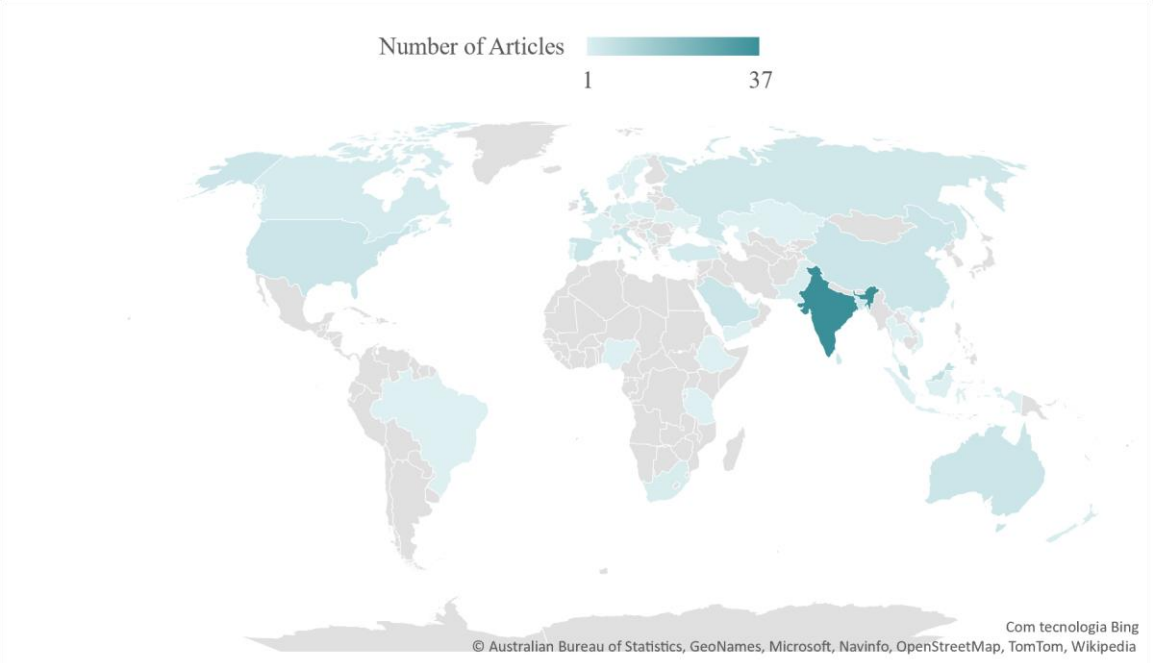

Figure 8. Distribution of the selected articles by authors' affiliation country.

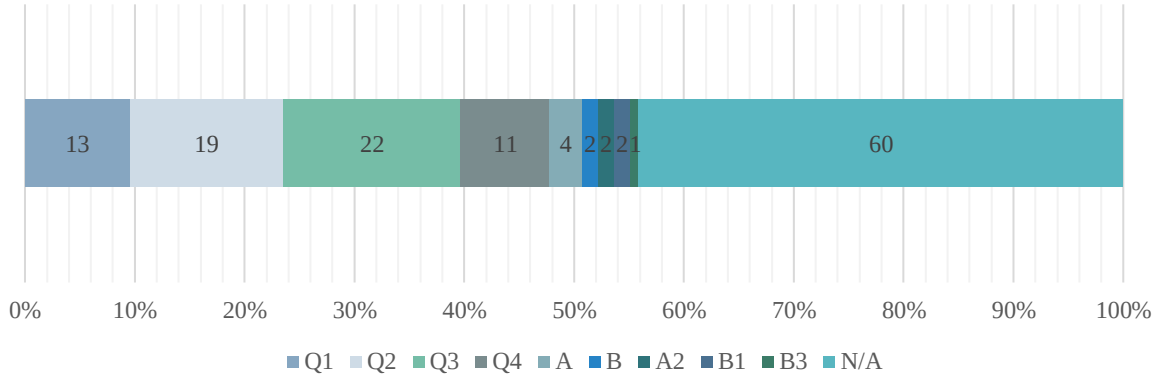

Figure 9. Distribution of the selected articles by rank classification.

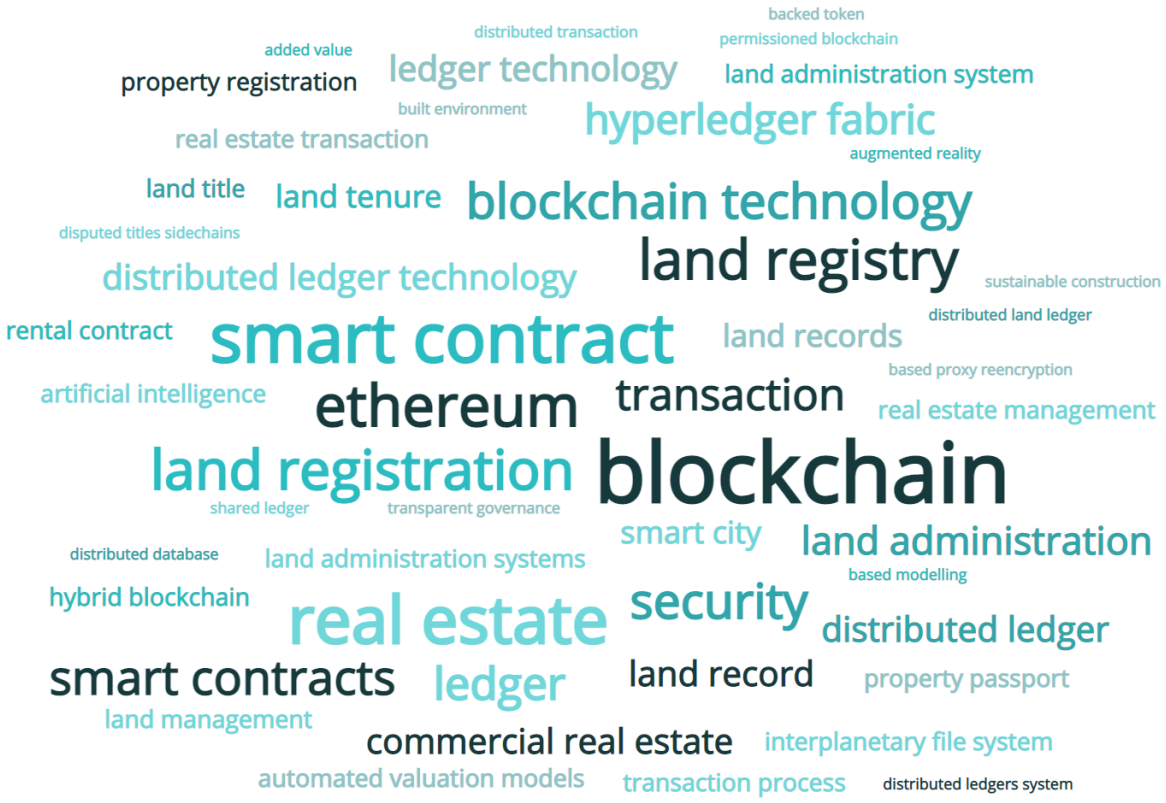

Figure 10. Visual representation of papers' keywords, where size represents the relative frequency (frequency normalized by the maximum value).

CHARTER 6

Discussion

This chapter summarizes the extracted data and discusses the findings obtained to answer, in detail, the proposed research questions of this dissertation.

6.1 Phase 3: Reporting the Review

The conducting stage represents the last phase of the SLR methodology, which summarizes the extracted data and answers the previously proposed research questions.

6.1.1 Summarization of the Extracted Data

The analysis of the selected articles shows that blockchain technology can transform several real estate industry operations, essentially related to land administration, like purchasing, selling, financing, leasing, or management. To first understand and assess this association, **Table 10**, complemented by **Figure 11,** summarizes how the blockchain technology features address core issues in the real estate industry, by establishing a relationship with the potential benefits enabled. The benefits identified are essentially the reduction of intermediaries' role, the increase of process transparency, the security enhancement of data integrity, and the increase of processes efficiency. Overall, these benefits mainly impact positively the reliability of real estate record-keeping. Then, knowing the benefits, it is important to identify the research thematic areas to understand the current exploration of the research field, according to the real estate processes. For that, **Table 11** identifies two main application areas, namely, the registration of property details and the transaction of property agreements. These can include several processes related to the real estate field, like transforming the geographical structure of a property (e.g., making an instalment or division), buying and selling properties, taking a mortgage, and others.

Nevertheless, the implementation of blockchain technology in the real estate industry is not straightforward and like any other emerging technology, several barriers and limitations to adoption arise. These barriers are identified in **Table 12** and classified on a societal and technological basis. According to the references, the main limitations are related to legal requirements compliance.

Table 10. List of the association between blockchain characteristics, resulting benefits, and real estate issues.

Blockchain Characteristic	Benefit	Real Estate Issue	References
P2P Network	- Reduce the role of intermediaries	- High number of parties involved	[19] [37] [71] [72] [73] [74] [75] [76]
Distributed Ledger	- Increase the transparency of the processes	- Information asymmetry	[19] [31] [34] [38] [57] [71] [72] [73] [74] [75] [77]
Consensus	- Increase the transparency of the processes	- Information asymmetry	[19] [72] [73] [75] [77] [78]
	- Enhance the security of data integrity	- Fraudulent activity - Inconsistencies of information	
Decentralization	- Enhance the security of data integrity	- Fraudulent activity - Inconsistencies of information	[19] [31] [72] [73] [74] [75] [77] [79] [78]
Immutability	- Enhance the security of data integrity	- Fraudulent activity - Inconsistencies of information	[73] [75] [77] [78] [79]
Smart Contracts	- Reduce the role of intermediaries	- High number of parties involved	[19] [23] [31] [34] [37] [71] [72] [73] [74] [75] [77] [80] [81] [82]
	- Increase the efficiency of the processes	- Long processing times - High level of costs - Intensive manual physical tasks - Severe paper administration	

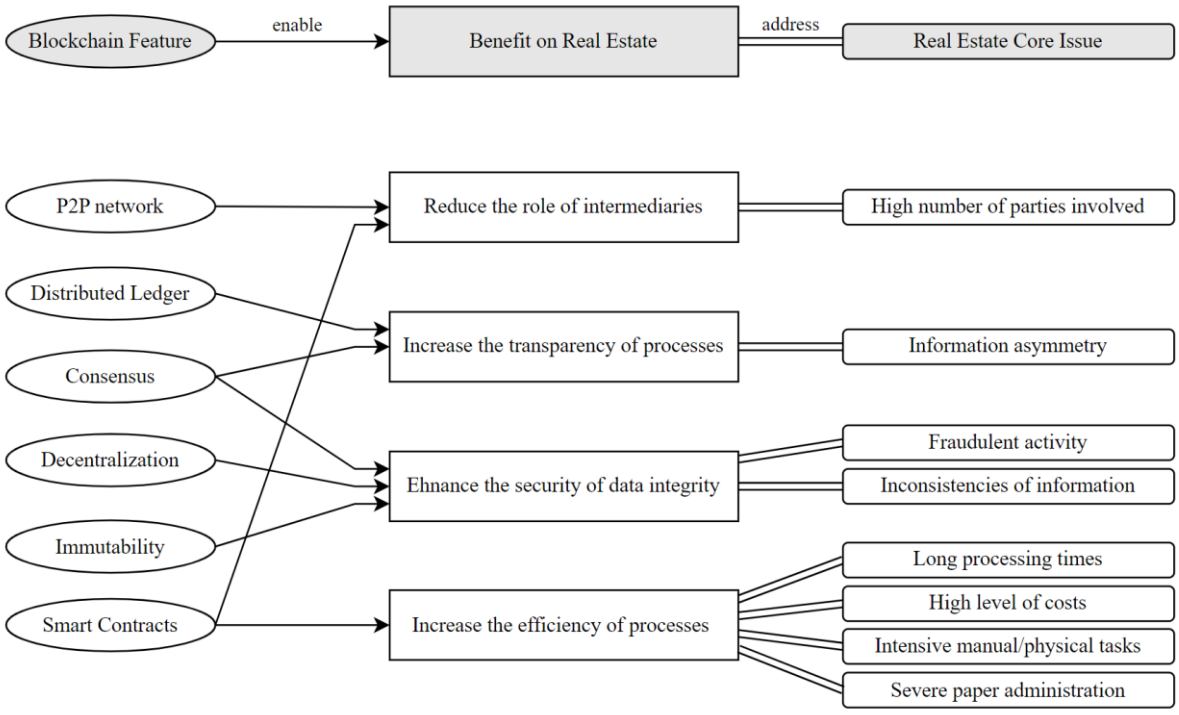

Figure 11. Representation of the relation between the blockchain features and the potential benefits on real estate enabled to address core issues.

Table 11. List of the main application areas and goals of the blockchain technology in the real estate field with the involved processes.

Application Area	Application Goal	Real Estate Processes	References
Registration of Property Details	Facilitate the property-related record-keeping	- Transform property structure - Take a mortgage (loan) - Lien or attachment - Buy & sell property - Lease property	[9] [20] [24] [29] [30] [33] [35] [72] [73] [83] [84] [85] [80] [81] [86] [76] [87] [88] [89] [90] [91] [92] [77] [93]
Transaction of Property Agreements	Facilitate the property-related end-to-end agreements	- Buy & sell property - Lease property - Inherit property	[9] [12] [32] [35] [37] [72] [73] [94] [95] [96] [97] [88] [91] [98] [99]

Table 12. Description of the main societal and technological barriers to blockchain technology adoption in the real estate industry.

Type	Barrier	Description	References
Societal	**Legal Regulation**	There is a lack of a legal standard regulatory framework for the validation of real estate blockchain-based transactions and smart contracts	[12] [20] [27] [30] [31] [35] [56] [73] [100] [75] [101] [102] [103] [104]

	Usability	There is a lack of technology literacy and awareness, given the immaturity and complexity of blockchain technology	[17] [26] [31] [80] [101] [102] [81] [103] [104] [105]
	Social	There is a need for a proper collaboration between stakeholders to engage with the technology as human input will still be essential	[26] [27] [31] [56] [94] [101]
	Lack of Standardization	There is a lack of semantic interoperability and standardization because stakeholders use a different taxonomies and concepts	[17] [27] [26]
	Political	There is a constraint to implementing a solution unless the government has the will to promote it, as real estate strongly relates to public services	[100] [101]
Technological	**Security**	There are several security vulnerabilities, like the leakage or loss of private keys and the exploitation of smart contracts or consensus mechanisms	[17] [27] [29] [52] [31] [94] [100]
	Immutability	Being unable to delete or modify data can lead to wrong and outdated information stored permanently that may mislead stakeholders	[20] [100] [101] [102] [103] [104]
	Anonymity/ Pseudonymity	The identification of blockchain-based transactions by itself is only based on the keys which do not identify the parties	[12] [27] [100] [102]
	Scalability	Due to distributed nature of blockchain technology network, it becomes difficult to execute real-time large volume	[83] [102] [103]
	Privacy	Ledgers are not suitable to store unmask personal information due to privacy concerns, as data is immutable and may be exposed to the network	[27] [100]

6.1.2 Report of the Findings

RQ1. *What is the potential of blockchain technology to address core issues in real estate?*

Despite the blockchain technology may arise as a feasible technology with potential for several businesses, including real estate, a more detailed analysis is needed in order to identify how to improve the current real estate processes and solve core issues, based on the benefits offered by this novel technology. Accordingly, Garcia-Teruel [12] points out that blockchain technology is beneficial when multiple mutually mistrusting parties want to interact and are not willing to agree on a trusted third party, which can facilitate the proceedings in the real estate area where, traditionally, transactions are mainly enabled by several intermediaries or approved by a central authority [23]. Sadkov et al. [106] also defend that the indisputable advantages of this approach are the transparency of information, and the reduction of time to make mutually acceptable decisions, which usually require long-term coordination by multiple parties even

when using conventional electronic document management systems; at the same time, the participation role of some intermediaries during the registration activities carried out by participants in the interaction system may not be required when using the blockchain technology. Also, Mashatan et al. [8] and Bhanushali et al. [18] argue that, if well-designed, a blockchain approach brings a higher level of transparency through a tamper-evident ledger, which can overcome some real estate problems related to fraudulent behaviour, like corruption, fraud, tax evasion, and illegal assets transfers. Similarly, Nijland & Veuger [17] conclude that the implementation of blockchain adds value through the addition of safe and secure sharing, where digital records of real estate assets and the improved re-design of the processes are mentioned as the main positive aspects of a blockchain-based solution. More recently, Stefanovi¢ et al. [24] also identify the double spending in real estate transactions, data tampering, and long duration of the real estate transactions' registration process which leads to incorrectness, as three main issues that could be potentially solved by the implementation of blockchain technology. Therefore, compared with the current systems of real estate, blockchain technology may provide some additional improvements.

Regardless, according to **Table 10** and **Figure 11**, this section analyses in detail the features of blockchain technology to establish a relation between the benefits of this growing technology and the main issues currently faced in real estate processes.

First of all, currently, the real estate chain is a highly fragmented and complex chain with a large number of involved parties (e.g., owners, agents, developers, notaries, property managers, and government authorities), that often share information between several proceedings' stages [33] [84], such as housing and land evaluation, document compilation, document accomplishment, execution of the main contract, money transfer, registration, and others [75]. However, as each involved party usually works independently, with low coordination, different degrees of automation, and many data silos [107], this often results in a long processing time, asynchronous information, and possible inconsistencies that influence the high level of transaction costs [56]. This is increased by the lack of trust and connection among different stakeholders to share data [85] causing information asymmetry and leading to disputes about property rights or illicit activities [19] [80]. This lack of transparency and accountability increases the scope for corruption [73] [78]. Examples of these problems are false listings when properties that are not owned by the lister are announced for sale, and fake documents, when an impostor presents themselves as the owner of a property by exhibiting counterfeit ownership documents [108]. In this sense, blockchain technology as a DLT can benefit stakeholders with a cryptographically protected and organized chain of transactions, recorded on a common

shared ledger of information [12] in real-time and distributed in a decentralized environment across a set of nodes, enhancing the security of data and eliminating the lack of information transparency between interested parties' access [27] [19] [31] [72]. In addition, as DLT is based on a P2P network architecture [19], the several stakeholders involved in real estate transactions, who need to connect and exchange information, can engage in storing, distributing, and uploading transactions directly, without a central authority dependency nor single point of failure [72] [12] [27]. This way, instead of the traditional client-server model, which is vulnerable to corruption and fraud [75], there are no hierarchical positions of privilege, and data is less susceptible to being corrupted or untraceable, which promotes the integrity of the real estate information as more consistent, accurate and available [85].

On the other hand, during real estate transactions, the different parties might not have any relationship, which might as well increase the lack of trust, especially in the digital world where the risk of fraud and impostors intensifies [72]. Then, the blockchain technology can help to improve trust because the transactions can be signed and checked by the network consensus, where nodes compete for the right to create new blocks based on randomness or entitlement, to be stored on the blockchain as immutable (or, at least, tamper-resistant, as it is extremely difficult to change or remove a block of data recorded on the ledger) [12] [101] and distributed among the nodes of the network. Thus, guarantees that data is not subject to a future edition, preventing data security from counterfeit activities [31] [19] [27] (e.g., money laundering, hidden charges, misrepresentation, rental scams, bribery [109] [110]).

Moreover, in theory, real estate processes could be automated and conducted without some of the common intermediaries (e.g., notary, banks, agents) or brokerage fees [19] [29], since the transactions could be independently verified and automatically validated through the execution of smart contracts stored on the blockchain. This disintermediation, as the process of reducing the chain of interaction by diminishing or even avoiding the use of intermediaries between transacting parties [109], is a relevant aspect of the real estate processes because of the costs, risks, complexity, and delay that all these entities add in the process [34] [111]. Even if reducing the role of the intermediaries could have a negative impact on their professional activities, these entities do not need to disappear, as their business value can be transformed, for instance, as a proxy of a stakeholder and maintaining the technological infrastructure, or as an interface between the application and the blockchain node that it represents. Then, the overall benefit for citizens, the economy, society, and the real estate processes efficiency could be much more valuable [34]. This way, if parties can have access to a transaction at the same time and changes are up to date, the role of intermediaries becomes smaller and more transparent [33].

Generally, blockchain technology tends to remove the need for intermediaries through its distributed nature [102]. However, particularly in the real estate field, some authors argue that due to the specialized nature of work and knowledge of some stakeholders, the complete elimination of some third trusted parties is not feasible (e.g., the notary, that is common practice for parties' protection, may continue to be necessary to verify transactions, even with a blockchain [12]) and, although the disruptiveness of blockchain technology reflects in the fact that no intermediaries are necessary, nowadays they are part of the legal framework that is unlikely to be changed soon [102]. Then, their function could change, but the removal of some advisors' participation is necessary [17]. Still, smart contracts clearly enable the reduction of manual tasks, costs, and time consumed to improve the efficiency of real estate transactions through persistent automation in a digital form [19] [27] [31] [100]. With several smart contracts interconnected with the public administration institutions, parties would be able to make, for instance, property agreements, automatic payments related to the contracts, or pay any required taxes, while registering the hash of the contracts permanently on the blockchain [12].

In the last years, given the identified issues in real estate procedures, many countries have migrated their paper-based records to a digital version as, by digitizing land records, physical activities can be minimized, ambiguity can be reduced, facilitates search and retrieval of documents, which can improve administrative efficiency completed safely in the digital environment, reducing red tape and waiting time in land-related transactions [81] [101], but this have only lead to partial success in containing malfeasance [112]. Some authors [73] [85] discuss some attempts to the digitalization of real estate public records that try to minimize the hassle, expenditure, delays, and dishonesty, but argue that solutions based on centralized digital information systems are not enough to solve the out of synchronized data to maintain a single version of land records that, due to discrepancies, results in a lack of real-time transparency and efficiency of procedures [17] [112]. Also, the participation of third parties and brokers still exists, the system did not replace much human work, just made it digitalized [113]. Then, while corrupt actors can exploit vulnerabilities in blockchain systems, they are still more secure than centralized systems [101].

Overall, the ability to enhance the security of data integrity and easier auditability, remove the information asymmetry between real estate stakeholders, re-think the role of possible conveyancing intermediaries [109], and increase operational workflow efficiency by reducing manual tasks, costs, and processing time, give blockchain its potential to success [17] [37] [102] [109]. In addition, the provenance verifiability of blockchain registries and the cryptographic

integrity of transactions support greater trust in the details for the complete chain of custody and property transaction; the smart contract can aid in process automation and streamlining the multiparty processes, which can help reduce complexity and the time needed to fulfil the service to the stakeholders [37]. However, the relationship between blockchain and real estate has not yet been proven in disruptive practice adoption [32]. Looking for adoption, Hoxha & Sadiku [23] study the link between blockchain technology and various important aspects of property transactions; the findings indicate that transparency and cost reduction have the highest influence on the intention to adopt blockchain technology in a real estate transactions system, followed by the safety of transactions.

In this sense, although the blockchain technology can potentially bring several of the aforementioned benefits to address core issues in the real estate field, which can influence the intention to improve the current real estate systems, there is no consensus about a feasible framework based on the application of blockchain technology, especially because there are different types of blockchains with different levels of access. Veuger [32] and Thakur et al. [103] defend that the first step is to build a network infrastructure to improve the interchangeability of information through the standardization and digitalization of real estate data and processes in the existing information systems (e.g., land records, cadastral mapping, land contracts), and only then, blockchain technology can be integrated as an additional layer. This is particularly required as there are currently several countries where real estate procedures are still managed through a manual paper-based approach (e.g., Bangladesh [79]) and, despite a paper-based scheme can be a convenient and a primary method to deal with the transaction of physical assets, like real properties, unfortunately, it has many security challenges, like the lack of traceability, inconsistencies, and transparency [16]. Also, Saull et al. [29] argue that most of the inefficiencies are due to a lack of standardized digital data and a variety of involved parties, and not due to the country-specific systems. Moreover, this approach supports the once-only principle that aims to ensure that citizens, institutions, and organizations only have to provide certain standard information to the authorities and administrations once. Therefore, digital transformation is mandatory, the first goal should be to digitise land registries instead of jumping aboard with blockchain [28], as such funds will be required to digitize land registry records, which can then be used in blockchain recording digital ledger of land interests [114]. In addition, while blockchain systems are secure and trustworthy, their data are only as accurate as what is entered, then without clean records, blockchain's potential cannot be properly achieved [101]. This leads the discussion to the contentious design of a blockchain-based solution. As shown in the following and next sections, some authors propose solutions based

on public and permissionless blockchains, suggesting that permissioned and private blockchain systems cannot be considered a significant evolutionary step in current systems [100], because lose their decentralized open nature to become more centralized [38]. In opposition, some authors argue that the application of a fully decentralized public solution is currently not suitable for the specificity of real estate as the sector is strongly supported by the government [10] [73], who oversees and manages the property register to ensure that taxes are correctly paid and to keep the integrity of the register intact, as discrepancies, irregularities, and incorrect information negatively affect the trustworthiness of the register [115]. Therefore, an institutional infrastructure is indispensable to guarantee real property rights [25] and centralization will remain to some extent, which contradicts the essence of the distributed registry [56]; a viable solution would be a system between the two, not a completely centralized and not a completely distributed system. Also, according to Sekhari et al. [116] an open blockchain network cannot possibly serve the real estate processes needs to maintain the records of rights and to ensure that only trusted members are able to interact with them, so a private chain would be suitable as it would not allow any external unauthorized person to view the property registrations and misuse that data [80] [28]. Mashatan et al. [8] also argue that this design choice is suited because the users interacting with the real estate systems (e.g., citizens) usually have a high degree of confidence in the central authority; in other contexts, the central authority would not be sufficiently trusted for this model to work and, consequently, users of the system may be open to more radically decentralized models of trust. A key advantage of private or permissioned blockchains is a higher speed to process transactions compared to permissionless blockchains [101]. In between, Bennet et al. [52] focused on examining emerging hybrid solutions as those that mix the use of blockchain technology, in particular smart contracts, with more conventional, and pre-existing, databases and technology infrastructures. They advocate that a hybrid approach is an important and necessary step in any scaling process because offer a way to overcome blockers (e.g., legislative and regulatory barriers) by minimizing disruptions, whilst maximizing the benefits of the new technological approach.

Regardless of the type of blockchain design, the distributed and immutable nature of blockchain technology can provide higher security and integrity of the records than most centralized systems offer, however, it is important to note that, this technology will be just a complementary layer that still depends on a traditional storage system. In other words, personal data must always be stored off-chain to ensure privacy compliance, restricting its access to only the ones that have permission to [36], and even if private data could be encrypted and stored

on-chain, this storage approach creates inefficiencies to deal with large data over the network, then, blockchain should only store hashes of real estate records.

According to Nasarre-Aznar [109], blockchain technology will probably not be (at least immediately or in a near future) a disruptive technology in real estate transactions [29], instead, this novel technology has the potential to essentially increase the reliability of public real estate services that use it for record-keeping, which strengthen the relationship between government and citizens in terms of transparency and trust [102]. Also, it is important to note that, according to Castellanos and Benbunan-Fich [84], most of this transformation happens in the background because blockchain is an enabler that does not affect externally visible parts of a business or organization entity, however, it does require the commitment of the involved parties and a sound business process redesign to ensure a successful implementation. This is, adherence to the blockchain land dealing business requirements are not only dependent on technology but broader socio-technical arrangements (e.g., specific legislation) [52] and proper management of the resistance to change of some powerful intermediaries, such as real estate associations and financial management operators.

RQ2. *What are the main processes and application areas of the real estate sector wherein blockchain technology has been applied?*

According to the taxonomy defined in **Table *11***, the main processes of the real estate sector wherein blockchain technology has been applied are related to land and properties administration, in compliance with the existing laws and regulations, to safeguard stakeholders' rights and make land management easier [75] [101], which are provided in most countries, on behalf of the government, by the land registry, mapping, and cadastral services. The land registry provides relevant evidence about property rights like who is the legal owner of a certain property or if there is a share of ownership [57] [117], mapping and cadastre provide information about property location, land use, nature, details about construction buildings, and land value [24] [118]. Therefore, these services must fulfil the land title issuance, due diligence processes, land taxation, land transaction registrations, changes in land use, resolution of land disputes and complaints/corruption handling, and facilitating spatial and land use planning [32] [38] [75]. Accordingly, based on the features provided by blockchain technology, these services can be categorized into the following main application areas **Registration of Property Details** and **Transaction of Property Agreements**. In practice, these areas involve registering real estate hash data on blockchain and including smart contracts in the implementation of real estate transactions (e.g., transfer of property rights) [119]. The big advantages we foresee of these

movements are that the real estate market will become more transparent, the quality of real estate data will increase, and fraud prevention become more effective [32]. Although, there are some procedures in these areas of application that will remain as manual and physical phases, for example, the surveying and mapping services of lands to build geo-referenced maps and models, or the inspection of properties to check details, like construction quality, dimensions, structure, and possible defects in other amenities [19] [38].

In this sense, the following section analyses in detail the application areas mapped to discuss the role of blockchain technology in comparison with the traditional methods.

Registration of Property Details. The main goal of this application area is to increase public confidence in property-related record-keeping, by facilitating the recording and dissemination of information regarding the legal situation of lands and properties [120]. This includes keeping data of the composition, ownership, and charges associated with a particular property resulting, for example, from real estate transactions, when buying/selling, inheriting, mortgaging for a loan, pledging/arresting or other transferring of the charges for a particular property. This is one of the most critical services from the social, economic, and political perspectives provided by governments for its citizens in any country [121], in such a way that the World Bank has been spearheading efforts to improve land registration in several countries, for example, sponsors an annual Land and Property Conference and various land registration projects to improve and modernize outdated registration systems [84].

Currently, as the procedures and requirements for land registry diverge between different regions and countries [80], sometimes the process is carried out entirely within the state institutions, in other cases, it is carried out through a process involving external stakeholders such as notaries and lawyers [9]; thus, most of the literature is based on research developed locally or nationally [85]. As a result, it is not considered reasonable to create a land registration system that can be developed globally [81]. However, despite that the land registration process in every nation is governed by the laws of the constitution, different legal systems for land administration in different countries still share similar problems related to maintaining the correctness of data stored [24]. For instance, the general steps for the current system of land registration can be described, in the situation of selling and buying a property, as follows: the property/land documents are submitted to the appropriate authority within whose jurisdiction the property is located, and the authorized signatures of seller and buyer need to be presented along with witnesses for the registration of the documents [76]. Therefore, while property information varies by country and jurisdiction, and is regulated by specific legal frameworks, the goal is the same – to provide a system for recording titles of ownership and the legal

transference of land property rights. Then, it is common that most land registration methods are known to be a lengthy multistep process [20] since it entails the engagement of multiple stakeholders who will have direct or indirect participation in the recording [87], but that usually does not work synchronously, or even interoperable, for real estate management, which leads to incomplete verification and document forgery [89]. Moreover, there are conflicts in identifying the detailed ownership of property as well as delays in providing the clear title documentation by a manual system [90]. In particular, when the buyer makes the purchase through a mortgage the processing time and costs increase considerably [35]. Also, the limited visibility of land records has created a dependency for landowners and buyers over lawyers upon recurring appointments and rework during land ownership transfer, extending avenues of fraud and ambiguousness; as a result, in the worst-case scenario, can enable land misappropriation or sold illegally [20] [83] [84]. In this sense, data are fundamental at every stage of property registration and investors need information about property operations (e.g., maintenance expenses, potential risks, market assumptions, tenancy schedules), as data need to be transferred efficiently from and to previous and current owners, legal advisors, property managers, and others, but this process is commonly subject to inefficiency and delays [29]. Consequently, verification of land records for ownership is arduous, as authorities must verify many documents and the owner must provide identity proofs to prove his ownership [88] [91], beyond many of these records are either incomplete, tampered, or damaged [92] [82]. As a result, it is difficult to keep track of the actual owner of a property [82]. Overall, the main issues are the identification of the genuine owner, the availability of digital signatures to all the users, and the mechanism of the middleman to verify the transfer [77]. The land registry system involves a massive amount of registration documents to be stored on central databases, this system is prone to various types of manipulation and involves many overheads in the form of time, storage requirements, and cost involved in storing and processing the documents [77].

More recently many countries are moving towards computerization and then gradually leading to an efficient electronic property registering system [20]. Although digitization of records can improve the efficiency of transaction recording, it does not address trust deficiency resulting from cumbersome methods and corrupt practices [92]. Also, while many PropTech companies currently offer digitalized platforms that could contribute to more streamlined property transaction processes, many of them are siloed solutions for specialized problems, which do not take problems of software and data integration into account; as a consequence, the real estate industry is slow at adopting these new technologies [29]. In addition, as land registration methods require complex high-risk security since land is a high-value asset that can

cause a loss of a lot of money because of fraud, it is crucial that the registration of property details become a process more speedy, transparent, and with less hustle [72] [85].

Consequently, some authors in the literature advocate that the introduction of blockchain technology may positively impact property stakeholders to have consistent, accurate, updated, and validated data [86] [72], and there are also several countries that have been linked with trying to use blockchain to solve land registration problems [93]. While the role of certain intermediaries such as real estate agents may be reduced once the system is fully functional, the governmental land registration authority is expected to keep its central role in registration review and in mediating other functions instrumental in rendering the property transaction lawful in the real world [30]. However, property details registration should not be underestimated, it is a rather complex process, including a lot more than only storing a contract or changing the name of the owner of the property [33].

Transaction of Property Agreements. The main goal of this application area is to facilitate end-to-end direct real estate transactions (e.g., buy, sell, or lease properties) for the involved stakeholders, by reducing the distrust between parties in real estate transfers and increasing the speed of transactions. Recently, have been emerging applications allowing P2P transactions, but there is usually a legal limit because of the difficulty to make real estate transactions [98]. Then, despite property agreements do not require the participation of intermediaries, these contracts may be often concluded with the support of a real estate agent and/or an attorney [12]. Having these parties in the process results in the need for complex multiparty transactions, which are usually manual and rely on paperwork, with multiple copies being distributed among unknown parties [37]. Also, although some of these contracts usually do not require to be in the land registry (e.g., short-time lease agreement), they should be communicated to the legal authorities for taxation purposes [12]. Another issue relates to the transaction history that is not usually stored properly, which could decrease the trust of tenants and buyers [88] [91]. Then, through the implementation of smart contracts powered by blockchain, the transfer of ownership rights can be completed quicker, with clearer and more secure transactions that avoid physical archives of registers [72], as the blockchain technology allows contracts to be automatically executed under predetermined conditions [32]. Also, real estate agents and agencies can integrate these smart contracts into their systems to replace traditional contracts and empower citizens to make more informed decisions through more transparent contracts [96]. Then, smart contracts not only define the rules and penalties around a contract like a traditional contract does, but also automatically enforces those obligations,

which means that there is no need for any authority to manage the flow with the consensus between the parties [9].

Furthermore, in recent years, the leasing or selling/buying property processes have been highly impacted by the rapid development of information technology, allowing citizens to browse properties in different locations and compare conditions, including in some cases to perform an agreement online [99]. However, there are still several issues in the processes, as citizens cannot completely rely on online services to complete the transactions (e.g., sharing lock key online) and usually, the available online services include extra charges for landlords (Kang et al., 2020), that pay large agency fees to a real estate agency, who may not be highly trusted [94]. Also, when leasing or purchasing and sale land, plenty of time is spent on due diligence activities, in order to assess rental or supply and demand rated, and implies manual verification processes, which increase the time, needed costs, and the possibility of errors [35]; consequently, this results in a time-consuming and document-intensive process [95] [97].

Therefore, some authors propose the use of an integrated blockchain-based solution with smart contracts, to expedite some of the activities by simply verifying the physical identity related to the digital one, which can contain all the information such as vacancy, tenant profile, financial and legal status [35]. Then, blockchain can aid in process automation by streamlining the multiparty processes, which will help reduce complexity and the time needed to fulfil the service to the stakeholders [37]. This can promote the improvement of efficiency and security of transparent transactions between several parties, by transforming the traditional agreements workflow into smart contracts permanently stored on the blockchain. Also, the smart contracts workflow ensures synchronization among participants involved in the transaction and can partially disintermediate some traditional parties.

Additionally, based on the previous areas mapped, every paper consisting of a particular blockchain-based practical implementation is categorized in **Table 13** to organize the collected data and to assess a comparative analysis of the practical works proposed in the literature. The comparison is based on functional aspects, like the real estate area identified and corresponding blockchain technology functionality provided, and technical aspects, like the status of the implementation, the technical blockchain architecture, and the governance architecture. The findings show (**Figure 13**) that there is more proof of concepts in the transaction of property agreements area (62%). In technical terms (**Figure 12**), most works follow a private permissioned governance model (50%) and Ethereum (41%) is the technology most used for technical architecture followed by Hyperledger (29%). Based on the status of the proposed

solutions, it can be concluded that blockchain-based land administration systems are not fully functional yet, and it is therefore not easy to evaluate their full impact [30], which is intensified by the majority of the works (59%) being on the conceptual status (**Figure 13**). Also, despite the works presented on implementation status (41%), these are still on an early implementation stage with deployed with only control data involved and not real scenarios. Only some evidence points to solutions already as pilot projects, apart from the propositions mentioned in peer-review papers, including countries like Brazil, Dubai, Georgia, India, Kenya, Ghana, Ukraine, Sweden, Honduras/Factom, and others [24] [102]. These are not analysed in detail because the context of this research is restricted to academia peer-reviewed works, then commercial proposals are considered out of scope.

Table 13. Comparison of practical works proposed in literature based on functional and technical aspects.

Blockchain Functionality	Real Estate Area	Governance Architecture	Technical Architecture	Implementation Status	References
Transaction automation – smart contracts	Transaction of Property Agreements: transfer of properties rights – buy, sell, or lease	-*	-*	Conceptual	[122] [123]
		-*	Custom	Implementation	[95]
		Private Permissioned	Multichain	Implementation	[86]
			Hyperledger	Conceptual	[9] [37] [94] [81] [116]
				Implementation	[124] [125]
			Ethereum	Conceptual	[96]
				Implementation	[126] [127]
Synchronization of shared information		Public Permissionless	Bitcoin	Conceptual	[35]
			Ethereum	Conceptual	[11] [35] [128] [96] [76]
				Implementation	[113] [97] [58] [129]
		Public Permissioned	Ethereum	Implementation	[130] [74]
Provenance/ notarization/ recording of data	Registration of Property Details: record and verification of property details – structure, ownership, mortgaging	Private Permissioned	Multichain	Implementation	[87] [131]
			Hyperledger	Conceptual	[80] [116] [132] [88]
				Implementation	[22] [124] [110]
			Ethereum	Implementation	[24] [58][127]
		Public Permissioned	Ethereum	Conceptual	[102] [82]
				Implementation	[130] [74] [133] [78]
		-*	-*	Conceptual	[89]

* The article does not identify the approach used.

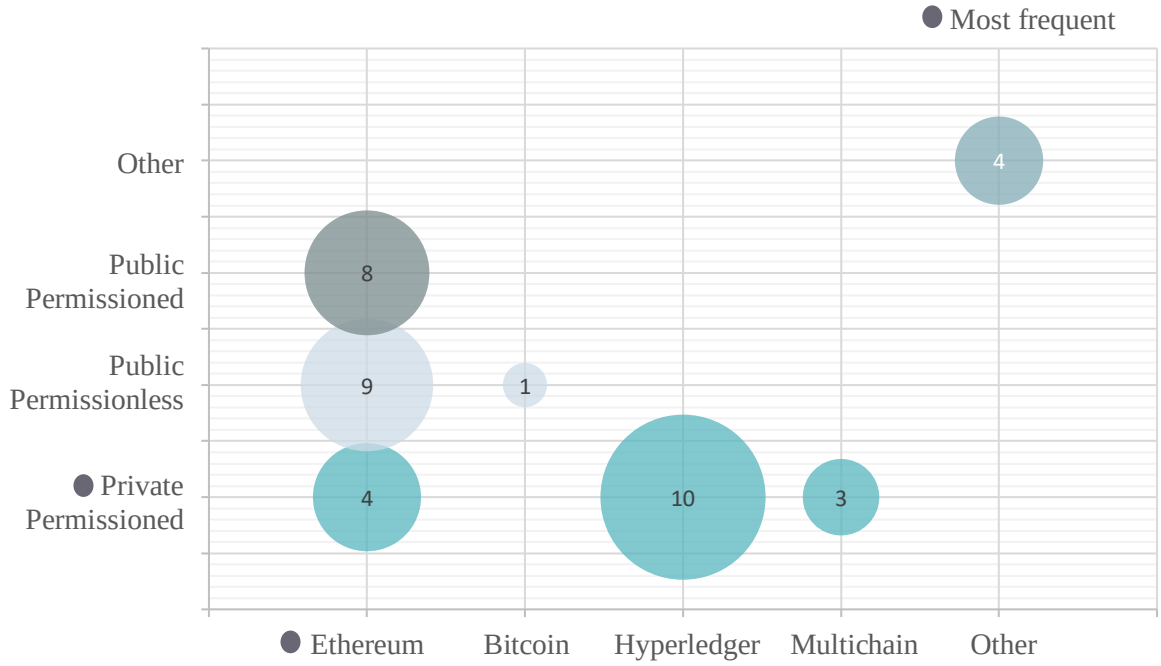

Figure 12. Distribution of the blockchain-based solutions by governance model and technical architecture.

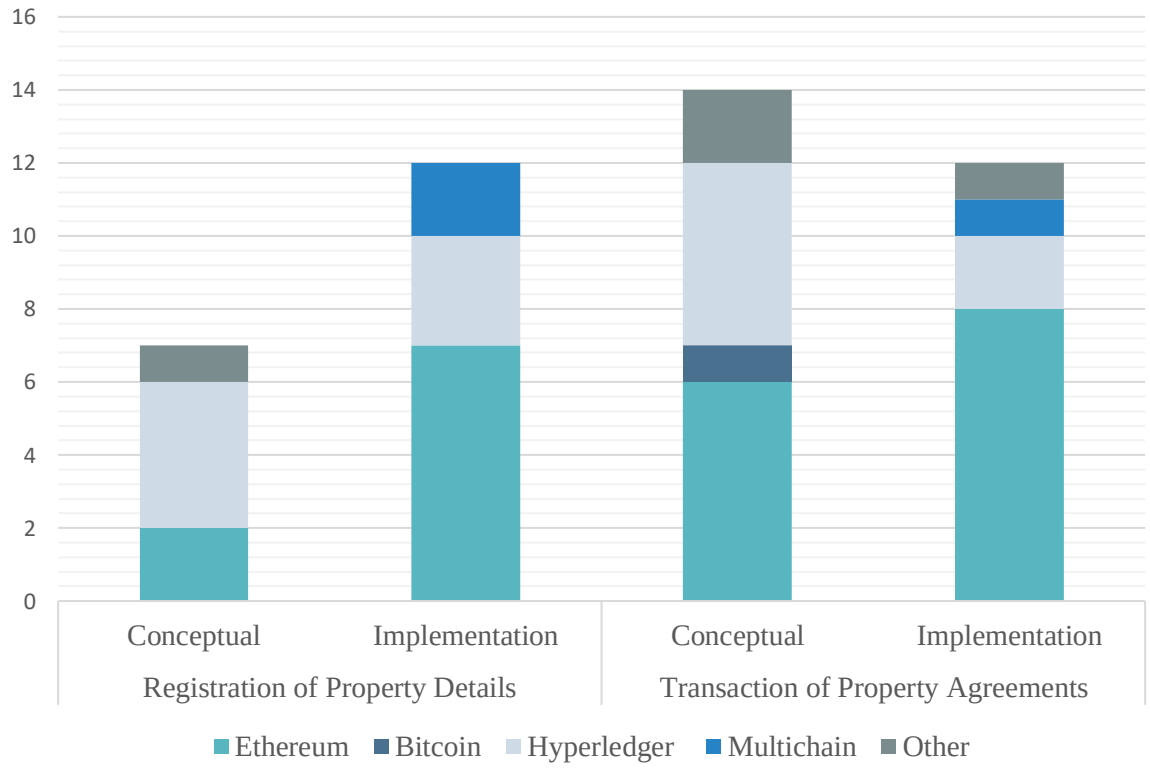

Figure 13. Distribution of the stage of development of blockchain-based solutions by real estate area of application and technical architecture.

RQ3. *What are the current barriers to blockchain technology adoption in real estate?*

Despite the usage of blockchain technology in real estate may enhance stakeholders' experience in several procedures, as discussed before, by bringing process efficiency and reliability of record-keeping, practical implementation is distant to be regarded as widely acceptable [100] and the remaining question is whether blockchain technology is currently sufficiently developed to sustain core functions, ensuring secure real estate transactions [12]. As expected, regardless of the benefits and efforts to implement blockchain technology in recent years, conducting real estate transactions using any novel technology presents its issues. According to **Table *12***, the following section identifies, categorizes, and discusses these barriers in the context of blockchain technology adoption, in particular for the real estate sector, which are classified through technological and societal drivers.

Legal Regulation Barrier. The regulation barrier relates to the lack of a comprehensive legal standard framework for blockchain-based transactions validation (e.g., the definition of how transactions should be written, what the minimum set of attributes on the transactions) [75] [103] [104] and for the undeveloped public key infrastructure (PKI) to deal with the low level of understanding of digital signature laws [101], in opposition to the highly regulated real estate sector that is known as resistant to change [31]. Also, despite the delays in searching real estate information (e.g., about land parcels and properties ownership) and the effort to information digitalization in several countries, the current legal regulations of laws and institutional arrangements tend to require paper-based registrations, then, there could be a high resistance and much slower involvement due to the reluctance to significant changes [20].

On the other hand, in a blockchain ecosystem, the lack of standards of legal and regulatory frameworks for smart contracts has also been of concern [101] [134]. Smart contracts are based on code, while regular contracts are still interlinked and protected by the existing laws, even though they have some autonomy [100] [56] [102]. In addition, it might be difficult to program certain rules and rights into the code of a smart contract [30], for example, while the civil law co-ownership by shared parties is relatively easy to represent with two keys and wallets to confirm a transaction, there are several more complex situations to be incorporated into a blockchain that might require external information to make decisions, like a usufruct, the right to build, right to use, and others [12], which increase its dependability on the actors outside the blockchain systems, also known as oracles. However, as oracles operate in external

environments, there are also challenges to ensuring reliable communication between the oracles and the smart contracts [47].

Essentially, blockchain as a novel technology will evolve and change in a fast way, but regulation usually takes a long and slow pathway to adapt [35], which is expected to constrain the diffusion of blockchain, especially in terms of international adoption [27], as law varies from country to country.

Social Barrier. The social barrier arises because applying blockchain technology not only impacts the procedures but also the stakeholders involved in the processes, who will need a period of exploration to understand the technology and support it [94]; especially because most of the population is not familiar with blockchain technology, therefore a large work on digital education is highly demanded [56]. Besides that, in general, the increase in using technology instead of people might result in a perception of less flexibility and restructuring of some jobs (or even job losses) [31] [27]. Otherwise, even if we increasingly rely on the digital world today, human input will still be essential, as such, the willingness of real estate stakeholders to engage with the technology should be investigated [26]; in particular, because the stages before the land records are moved to blockchain are prone to fraud [101]. Therefore, a proper collaboration among participants such as blockchain innovators and industry incumbents is also necessary to maximize the benefits [101].

Usability Barrier. The usability barrier is given to the current immaturity and complexity of the technology [105], as blockchain is still in its early stages and there is a lack of mature tools [102]. This results in limited expertise in using blockchain platforms and developing smart contracts to implement, understand, teach, and operate solutions [31] [104] [80], which is also increased by a lack of technology literacy [101] to understand the clarity on concepts such as nodes, keys, networks, smart contracts, and others [17]. Then, despite improving literacy rates, a large proportion of the population lacks the literacy and digital skills required to benefit from a blockchain-based system, so there is a risk of excluding parties that are not sufficiently digitally literate [134] [17] [101]. In addition, being a new technology there are very fewer examples of successful blockchain real estate applications and proof of concepts available [26] [103]. Thus, an increase in awareness of this technology and the development of user-friendly solutions are essential to consider the adoption, and even though the advantages of blockchain technology look bright, the maturity level is still low, as expected, because of the history of the technology is not very long [81].

Immutability Barrier. The immutability barrier links directly to one of the essential advantages of using blockchain technology, because, despite this characteristic can bring trust

and support to anticorruption of real estate data, being unable to delete or modify data is a problem if we consider bugs or wrong and outdated information that may mislead stakeholders [20] [102] or if we consider that the immutable nature creates fear in the minds of people, which incentivizes they to continue with the existing systems rather than adopting the new technology [103] [104]. However, even with the principle of information unchangeable, some authors argue that a proper architecture can address this issue [100] because blockchain is based on timestamping, then, with all transactions chronologically recorded, information can be updated by publishing corrected data and assuming that the more recent data is the accurate one. At the same time, blockchain's immutability is only useful if measures are taken to ensure that land-related data entered into the ledger are accurate [101] [134] .

Scalability Barrier. The scalability of transactions barrier relates to the decentralization nature of blockchain technology network that enables thrustless verification, which provides security of data, but may suffer from latency issues to interact with the several entities associated with the transactions when dealing with large amounts of data of records on the ledger [103]. This may largely limit the scalability of the solutions [83] and result in relatively low transaction propagation efficiency compared with centralized systems. Then, the real estate procedures may result in a large value of transactions and consequently slow down the blockchain performance. As a result, a careful consideration of the technical architecture is essential for ensuring the ledger performs reasonably, while remaining lightweight, to support blockchain viability in real estate. Additionally, blockchain is not useful for storing large amounts of data and should not be used as primary storage but as some sort of index or transaction validation layer [102].

Anonymity/Pseudonymity Barrier. The anonymity barrier is an issue present in several kinds of transactions conducted through the internet, including with blockchain technology, that by itself does not check the identifications of the parties [27]. For example, some of the major blockchains, like Bitcoin and Ethereum, do not require any type of personal information when creating a new account/wallet, which can lead to illegal activities (e.g., money laundering, financing terrorism, or other unlawful activity) [12]. In particular, to implement blockchain technology for the execution of real estate transactions, the identification of the parties is essential (e.g., the need to know who owns a particular property). Then, without an overlaid solution for digital identities and trust services, it is almost impossible to create any viable governance model [100], where a digital link is made to a real identity [102]. Using blockchain technology, currently the authorization and authentication for a transaction are provided through the private and public keys, where the public key is used to generate the address of the

transaction and it is the only public record that identifies the user. However, despite those addresses could be deanonymized (e.g., IPs, behaviour patterns), some authors argue [100] [12] blockchain protocol is not suitable for keeping records on property and securities from the perspective of governments and users themselves.

Privacy Barrier. The privacy barrier also results from the immutable nature of blockchain, especially for blockchains that are designed to be publicly visible, where any published data is exposed. This led to the conclusion that ledgers are not suitable for storing personal information because of data privacy preservation concerns, as an individual should have the right to remove their data from registers (e.g., Art. 17 of General Data Protection Regulation (GDPR), Right to erasure – 'the right to be forgotten'[15]) [27], which strongly apply to real estate records. Regardless, this limitation may have more impact on the private entities than on public sector services, like property services, as these may be justified by the needs of complying with a legal obligation under the law, or for the performance of a task distributed within the public interest or within the exercise of official authority, and therefore the request to remove data may be rejected. Even if personal data could be encrypted and stored on-chain, this storage approach creates inefficiencies to deal with large data over the network. A possible solution is to only record a cryptographic hash as immutable anonymised evidence in the blockchain, that provides a one-way link to the personal data, but the data itself is stored off-chain on the user's device or a closed third party's server [100]. However, publishing hashes does not provide for a safe store of the initial data itself, because once the data is removed or suffer any changes in the off-chain database, the anonymised reference stored in the blockchain would no longer lead to anything, which undermine the veracity of the data stored in the blockchain [134]. Then, the record must be protected from modifications, wherever it is stored off-chain on a storage system, so that hashes of the original and stored data in the blockchain always sync [134]. To address this issue, the solution development must require more transparency and a reliable design of the hashing method that strictly links the on-chain hash to the actual off-chain record. However, the main concern about this method is that it does not provide any basis for tokenization on the blockchain, the property records are still exclusively stored on the off-chain storage system, and so these are prone to be deleted and modified [100].

[15] According with the Art. 17 GDPR Right to Erasure – *'the right to be forgotten', the controller may, in certain situations, be required to, and the data subject shall have the right to, demand from the controller the deletion of any personal data pertaining to him or her without unreasonable delay*. Full article available at: gdpr-info.eu/art-17-gdpr/

Political Barrier. The political barrier relates to the constraint to implement a solution unless the government has the will to promote it [134], as real estate strongly relates to public services. Despite some projects trying to disrupt the old-fashion centralized and bureaucratized real estate transaction systems, in general, the problem with the architecture of such solutions is that records have legal force when they are stored in the closed governmental database. All P2P transactions on a blockchain between parties make no legal sense, as far the last word is on the side of the one who controls the central registry, which reinforces the need for legislative changes. Hence, without shifting from a centralized to a distributed architecture, any attempts of disruption turn into mimicking the existing system, by digitizing bureaucracy and middlemen [100].

Also, the experiences of government blockchain projects have shown that the migration and integration of legacy and database management systems into a blockchain-based system would be a difficult task. The integration of diverse data and systems into blockchain platforms could be costly and time-consuming [101]. Therefore, the commitment on the part of the government, political consensus to promote the technology, and broad public support are some of the key factors that lead to the large-scale adoption of blockchain in property rights enforcement [101].

Lack of Standardization Barrier. The lack of standardization barrier arises because stakeholders use different taxonomy [17], which makes it difficult for the standardization and automation of processes to implement blockchain-based solutions [27] [26], besides promoting inefficiencies. This is also increased by the lack of collaboration and coordination of parties, that usually work separately, which is a critical constraint for enhancing the real estate network. Potential causes for this conduct include acquiring individual interests and a lack of desire to collaborate with rivals. Semantic interoperability [135] and standardization are critical requirements for enhancing real estate blockchain communication among stakeholders. Therefore, it is essential to bring standardization and semantic interoperability through cooperation between parties before considering the adoption of a blockchain-based solution.

Security Barrier. The security barrier relates to technological constraints of the implementation of blockchain solutions based on the overestimation of the technology [17], especially because real estate transactions deal with large sensitive data that are exchanged among several parties, thus, the security requirements are high to ensure that new systems are resilient against cyber-attacks [29] [94]. Several security risks can be specified and, despite the increased data security and transparency, the validation and verifying of data uploaded through the processes are required to ensure that the connection between digital records and physical

entities is properly established, as well as the information uploaded on the blockchain, and associated storage system is secure and accurate, avoiding the propagation of erroneous data across the network [134]. Moreover, there are several security-specific breaches associated with the technical properties, such as the leakage or loss of private keys, and the exploitation of smart contracts and consensus mechanisms vulnerabilities [27]; regarding these, blockchain technology by itself does not enforce any legitimate judicial decision or any rightful action by authorities, then the architecture will require the involvement of a trusted third party [100].

Overall, the new technological approaches also opened new opportunities for fraud, for this reason, most land administration systems have tended to take a conservative stance and have been later technology adopters [52].

In conclusion, knowing that real estate has shown slow to adopt process and technology innovation, it is evident that much still needs to be discussed and encouraged among researchers and professionals to adopt blockchain, accordingly, a shift is required, in addition to government and industry investment [136]. Particularly, due to the technological and societal constraints pointed out above, a complete, automated, standalone, and decentralized solution with the disintermediation and elimination of the third parties is currently not visible, according to Morena and colleagues [35], as non-blockchain interventions off-chain are still necessary, but such a possibility may exist in the future if the technology achieves a sufficient level of maturity, an appropriate regulatory framework is built, and wider user acceptance is promoted [102]. In particular, the application of blockchain technology requires a proper architecture of the overlaid technologies to support changes for outdated and mistaken data, address issues of digital identity, underdeveloped privacy and security practices, promote social involvement with the technology, legal compliance, enforceability of smart contracts, and the scalability of the distributed ledgers. In the real estate ecosystem, the major barrier to adopting the potential of blockchain technology is the incompatibility between blockchain-based solutions and existing legal and organizational frameworks. Therefore, the innovation can only be successful if the underlying data and infrastructure are prepared for the change and if all parties involved are cooperating, including with ways to counteract resistance from vested interests [84], thus, reducing incompatibility requires not only the adaptation of technology to legacy systems, but also a transformation of existing processes, organisations, and structures. This reinforces the importance of institutional changes and transformations in order to apply the technology because blockchain is a ‘social technology’ designed to govern people’s behaviours [101] that not only requires the coordination of different stakeholders but also requires institutional

agreements on social, legal, and political changes of existing standards and processes [73]. Also, instead of attempting to force fit existing land registration systems into blockchain technology era, the effort might be in unlocking the full potential of the data stored on a digitalised land registry first [28].

These issues still require research attention with regards to scaled implementation, as the continuation of the development trajectory will depend on re-examining concepts of institutional trust, legal, and policy issuer, sustainable business models, stakeholders' awareness, partnership building, data decentralisation, and security [52].

CHARTER 7

Conclusion

This chapter highlights the main conclusions of this research, identifies the study's limitations, and proposes paths for future work.

In this dissertation, we aimed to provide a clear understanding and summary of the knowledge state of the existing literature related to the suitability of DLT, in particular blockchain, in the real estate field. This goal was achieved through the presentation of an SLR of the extant scientific studies, including the analysis of 129 papers, to comprehensively assess the current research that approaches this emerging topic. The research process was based on six well-regarded databases, following specifically designed protocols to identify as many relevant articles as possible. Additionally, the study was guided by the main research question focused on identifying the potential role of blockchain technology in solving real estate issues, identifying the existing thematic areas of application of blockchain technology according to the real estate processes (mainly related to land and properties administration), and identifying the current barriers of blockchain technology adoption in the real estate industry. Therefore, the finding results of existing knowledge on blockchain's application in the specific sector of real estate were used to comprehensively answer the proposed research question, which is summarized in the main conclusions. Future avenues of research are presented through the extant limitations, recommendations, and emergent gaps in current literature, identified during this review. These final insights are presented in the following sub-sections.

7.1 Main Conclusions

Starting in 2008, blockchain technology has been demonstrating its usefulness through widespread use and an increasing number of solutions enabling principally greater transparency and security in transactions, reduction of intermediation costs, and efficiency improvements in record keeping, traceability and auditability. By recording transactions on a distributed ledger, reliability is increased and, as the ledger connects current entries with previous transactions in an append-only manner, this results in a fully auditable history. Also, as the ledger is distributed in the network, every node has the same shared copy in real-time, which makes it resistant to failure or malicious behaviour through the synchronization of information. Nevertheless, blockchain technology is still in its infancy, particularly in the real estate industry, where most

of its applications are in the early stages of experimentation, which makes it challenging to present a solid orientation for institutions and governments, even though blockchain is built on underlying widely implemented principles and technologies. Regardless, the utilisation of blockchain technology has the potential to drive significant benefits realised in some real estate areas, like registration of property details or transaction of property agreements. However, this novel technology will certainly not be a solution to all the issues in the existing real estate processes, as well as will not completely automate and disintermediate transactions, as some trusted intermediaries and manual stages would still be necessary to check technical and legal requirements. Then, at least for now, several centralized technologies like central registries are still needed to support it, besides some parties may not be interested in limiting their power by encouraging consensus mechanisms established directly between citizens. As a result, the adoption of blockchain technology in this sector should be seen as an additional layer of certainty to stakeholders' trust, in practice, one of several components in the technical design of the services provided. Moreover, the findings showed multiple technical and legal barriers concerning the wider implementation of blockchain; examples of these open issues include security, privacy, scalability, usability, integration with other systems, and regulatory and acceptance matters. Lastly, the adoption of blockchain, like any other novel technology should be carefully investigated and applied only if it is the appropriate approach, not just because it is new or trending. Overall, due to the continuous technological evolution, as with most new technology, blockchain must come as a way to improve people [137], processes, and business.

7.2 Research Limitations

Despite following a rigorous methodology, the findings of the current study should be considered given its limitations, which are presented below in terms of selection bias, publication bias, inaccuracy of data extraction, and misclassification. First, the review only considers scientific articles appearing in peer-reviewed journals, conferences, and book series, available in the selected scholarly databases, or available as a result of the backward snowballing technique based on the articles' references. Thus, other forms of publications (also known as grey literature), such as news or reports, were excluded. Second, the review considered several keywords as similar interchangeable terms, like blockchain, smart contracts, and distributed ledger technology, however it is possible that other terms are missing, particularly for the real estate field where terms are broader. Third, the manual screening process of filtering articles based on the defined criteria can lead to the exclusion of relevant

papers. Fourth, the subsequent interpretation of hundreds of the selected papers inevitably introduces subjectivity based on the authors' interpretation, particularly because this research involved only one reviewer in the data extraction process, which can lead to possible biased conclusions; yet, to the extent possible, we tried our best to select the sufficiently comprehensive and relevant content of the papers to support our analysis.

Therefore, these limitations may be addressed in future review research by considering additional keywords and sources of information to expand the scope of the assimilated information, as well as collaborating with more researchers in the reviewing process to avoid inaccuracy or bias in the data analysis.

7.3 Future Work

We hoped that this research will encourage research on blockchain applications for real estate among academics, industry professionals, and government entities. There are several directions this work can be taken further in order to grow effectiveness and easier adoption of the blockchain technology potential, through the increase of distributed ledger maturity. In particular, since privacy and security play a key role in real estate, future research could focus on supporting the development of international governance standards compliant with blockchain architectures, as a way to safeguard the information stored in the blockchain-based systems, as well as managing the public and private cryptographic keys for the network nodes. Also, despite the practical works and some of the pilot projects, there is still a need to advance from the conceptual knowledge of blockchain applications for specific issues, such as managing land and property records or executing direct transactions about property rights. In other words, there is a need to develop a complete, as well as legally and ethically compliant, real estate ecosystem with robust data management and authentication protocols; and even if each country has its institutions that have their roles in the registration and verification of the real estate transactions, these roles would need to be harmonised and replicated to scale easier. For that, there is also a need to define reference conditions and shared infrastructures most suitable for the specific use cases. Moreover, the incompatibility between blockchain-based solutions and existing regulatory frameworks has been shown as the major barrier to unlocking the transformative potential of blockchain, hence, future research should focus on increasing the technological maturity of distributed ledgers, as well as must promote policy actions that should aim to, not only adapt the technology to existing ecosystems, but also transform and redesign the existing procedures, organizations, and structures of real estate services.

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Appendices

Appendix A

Table A1. Selected studies included for the systematic literature review.

	Title	Authors	Year	Country	Source Type	Source	Rank	Citations	Keywords
001	A Blockchain Based Land Registration and Ownership Management System for Bangladesh	Shithy, Mohammad, Ruhullah, Oni & Al-Amin	2021	China	Conference	4th International Conference on Blockchain Technology and Applications (ICBTA)	-	0	Blockchain; Chaincode; Hyperledger Fabric; Land registration; Land registry office (LRO); Land Management; Smart Contract
002	A Blockchain Based Land Registration System Proposal for Turkey	Mendi, Sakakl & Cabuk	2020	Turkey	Conference	4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)	-	7	Blockchain; Land Registration; Geographical Information Systems
003	A Blockchain Framework for Proptech: Success Model Through Disintermediation and Self-regulation	Arya, Naganathahalli & Shukla	2019	India	Conference & Book Series	International Conference on Intelligent Computing, Information and Control Systems (ICICS) & Part of the Advances in Intelligent Systems and Computing book series	Q3	4	Blockchain; PropTech; Disintermediation; Self-regulation; Governance
004	A Blockchain Solution for Securing Real Property Transactions: A Case Study for Serbia	Sladic, Milosavljevic, Nikolic, Sladic & Radulovic	2021	Serbia	Journal	International Journal of Geo-Information	Q1	17	Blockchain; Land Administration; Smart Contract; Real Property Transactions; Transaction Transparency; Ledger
005	A Blockchain-based Housing Rental System	Qi-Long, Rong-hua, Fei-long	2019	China	Conference	International Conference on Advances in Computer Technology, Information Science and Communications (CTISC)	-	3	Blockchain, Smart Contract, IPFS, Ethereum, Rental System
006	A Blockchain-based Land Title Management System for Bangladesh	Alam, Rahman, Tasnim & Akther	2022	Bangladesh	Journal	Journal of King Saud University – Computer and Information Sciences	Q1*	16	Bangladesh; Land Title Management; Transparent Governance; Hybrid Blockchain; Smart Contract; Ethereum
007	A Buyer and Seller's Protocol via Utilization of Smart Contracts Using Blockchain Technology	Kumar, Dhanush, Srivatsa, Nithin & Sahisnu	2019	India	Conference & Book Series	International Conference on Advanced Informatics for Computing Research & Part of the Communications in Computer and Information Science book series	Q3	9	Smart Contract; Land Registry; Blockchain Technology; Ethereum; Ether
008	A conceptual framework for blockchain smart contract	Ullah & Turjman	2021	Australia Turkey	Journal	Neural Computing and Applications	Q1	41	Blockchain; Smart Contracts; Smart Real Estate Management;

	adoption to manage real estate deals in smart cities								Smart Cities; Smart Contract Implementation; Smart Contract Design
009	A Decentralized Land Sale and Ownership Tracking System using Blockchain technology	Mohaghegh & Panikkar	2020	New Zealand	Conference	5th International Conference on Innovative Technologies in Intelligent Systems and Industrial Applications (CITISIA)	-	0	-
010	A New Approach to Land Registry System in Turkey: Blockchain-Based System Proposal	Mendi, Demir, Sakakli, Çabuk	2020	Turkey	Journal	Photogrammetric Engineering & Remote Sensing	Q3	1	-
011	A Novel Framework for Implementation of Land Registration and Ownership Management via Blockchain in Bangladesh	Islam, Iqbal & Islam	2020	Bangladesh	Conference	IEEE Region 10 Symposium (TENSYMP)	-	9	Blockchain; Land Registration; Ethereum; Smart Contract; Cryptocurrency; Decentralized Architecture
012	A secure blockchain-based housing rental platform	Yu, Wang,, Zhang, Guan	2021	China	Conference	IEEE 4th Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC)	-	0	Housing Rental, Blockchain, Smart Contract, Zero-Knowledge Proof
013	A secured land registration framework on Blockchain	Nandi, Bhattacharjee, Jha, Barbhuiya	2020	India	Conference	3rd Conference on Security and Privacy (ISEA-ISAP)	-	14	Blockchain; Land Registration; Liquid Asset Storage, Asset as Token
014	A Transparent and Trusted Property Registration System on Permissioned Blockchain	Ali, Nadeem, Alzahrani & Jan	2020	Arabia	Conference	International Conference on Advances in the Emerging Computing Technologies (AECT)	-	8	Blockchain; Real Estate; Hyperledger Fabric, Decentralize Networks, property Registration
015	Accommodation Finder: An Augmented Reality Based Mobile Application Integrated with Smart Contracts	Parameswarab, Perera, Aluthgedara, Amanda, Ishara, Ganegoda	2021	Sri Lanka	Conference	3rd International Conference on Advancements in Computing (ICAC)	-	0	NLP, ASR, Augmented Reality, Blockchain, KNN
016	An Enhanced Real Estate Transaction Process Based on Blockchain Technology	Mashatan & Roberts	2017	Canada	Conference	23rd Americas Conference on Information Systems	A/B1	21	Blockchain; Real Estate, Shared Ledger, Transaction Process, Bidding Process, Fraud
017	An Implementation of House Rental Platform with Blockchain Technology	Kang, Chang, Chan, Tsai & Liu	2020	Taiwan	Conference & Book Series	International Conference on Frontier Computing & Part of the Lecture Notes in Electrical Engineering book series	Q4	2	Blockchain; Smart Contract; Ethereum; Rental platform
018	Assessing the usability of blockchain for sustainability: Extending key themes to the construction industry	Figueiredo, Hammad, Haddad & Tam	2022	Brazil & Australia	Journal	Journal of Cleaner Production	Q1*	0	Blockchain; Distributed Ledger Technology; Sustainable Construction; Real Estate; Building Information Modelling

									(BIM); Life Cycle Sustainability Assessment
019	Asymmetric Information in High-Value Low-Frequency Transactions: Mitigation in Real Estate Using Blockchain	Hoksbergen, Chan, Peko & Sundaram	2019	New Zealand	Conference & Book Series	International Conference on Future Network Systems and Security & Part of the Communications in Computer and Information Science book series	Q3	5	Transaction; Information Asymmetry; Blockchain; New Zealand real Estate; Information Value Chain
020	Autochain platform: expert automatic algorithm Blockchain technology for house rental dApp image application model	Kim & Huh	2020	Korea	Journal	EURASIP Journal on Image and Video Processing	Q3 (Q2)	8	Blockchain, IoT, Artificial Intelligence, Security, Big Data, dApp, Autochain
021	Blockchain and land administration: Possible applications and limitations	Stefanovic, Przulj, Ristic & Stefanovic	2018	Serbia	Conference	5th International Scientific Conference on Contemporary Issues in Economics, Business and Management (EBM)	-	12	Blockchain, Land Administration Systems, Real Estate Transactions
022	Blockchain and real estate: Dopo di Noi project	Morena, Truppi, Pavesi, Cia, Giannelli & Tavoni	2020	Italy	Journal	Property Management	Q3	12	Blockchain; Real Estate, Dopo di Noi, After us, Valorization, Trust instrument
023	Blockchain and Regional Workforce Development: Identifying Opportunities and Training Needs	Prager, Martinez & Cagle	2021	USA	Book Series	Blockchain and the Public Sector Part of the Public Administration and Information Technology book series	-	2	Blockchain, Workforce development, Regional economic development, New technology
024	Blockchain as a tool for land rights: ownership of land in Cyprus	Yapicioglu & Leshinsky	2020	Cyprus Australia	Journal	Journal of Property, Planning and Environmental Law	Q3	15	Cyprus; peace; Land Registration; Blockchain; Disputed Titles Sidechains
025	Blockchain as a tool to facilitate property rights protection in the Global South: lessons from India's Andhra Pradesh state	Kshetri	2021	USA	Journal	Third World Quarterly	Q1	0	Andhra Pradesh; Blockchain; Global South; Land-Titling Reform Projects; Proverty; Proverty Rights Protection
026	Blockchain as an Instrument for Land Ownership and Authorization of Services	Manocha, Som & Manocha	2021	India	Conference	9th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)	-	0	E-Governance; Cloud Computing; Blockchain; Eco-System; Flexible; Scalable
027	Blockchain Based Efficient and Accurate Property Title Retrieval and Secured Storage System	Joshi, Umale, Rajeswari	2019	India	Conference & Book Series	International Conference on Computer Networks and Inventive Communication Technologies & Part of the Lecture Notes on Data Engineering and Communications Technologies book series	-	0	Blockchain; Ethereum; Smart Contracts; Solidity
028	Blockchain based Land Registry System	Ghanpathi, Srivastava, Bhosikar, Chattar & Shitole	2022	India	Conference	3rd International Conference on Advances in Engineering,	-	0	Blockchain, Immutable Transactions, Ledger

						Technology & Business Management (ICAETBM)			
029	Blockchain based land registry systems using Ethereum Blockchain	Khan, Ansari, Jain & Sachdeva	2020	India	Journal	Journal of Xi'an University of Architecture & Technology	Q4	11	Ethereum; Blockchain; Cryptography, Ledger, Distributed Transaction, Land Registration
030	Blockchain based Land Registry with Delegated Proof of Stake (DPoS) Consensus in Bangladesh	Majumdar, Monim & Shahriyer	2020	Bangladesh	Conference	IEEE Region 10 Symposium (TENSYMP)	-	5	Blockchain; Mining; Consensus; Delegated Proof of Stake; Land Registry; Bangladesh; Security; Protocol Cryptography; Proof of Work; Bitcoin; Hash Function; SHA256
031	Blockchain enabled Digitization of Land Registration	Suganthe, Shanthi, Latha, Gowtham, Deepakkumar & Elango	2021	India	Conference	International Conference on Computer Communication and Informatics (ICCCI)	-	1	Government; Distributed databases; Blockchain; Data structures; Delays; Reliability; Informatics (IEEE keywords)
032	Blockchain for Real Estate: A Systematic Literature Review	Santana, Mira da Silva, Galvão da Cunha	2021	Portugal	Conference	29th International Conference on Information Systems Development (ISD)	A/B4	0	Blockchain; Land Registry, Advantages, Challenges, Pilots
033	Blockchain land transfers: Technology, promises, and perils	Ooi, Peng & Soh	2022	Singapore	Journal	Computer Law & Security Review	Q1*	1	Blockchain; Land Registration; E-Conveyancing
034	Blockchain Technology and Land Registry	Themistocleous	2018	Cyprus	Journal	Cyprus Review	Q4	28	Blockchain Technology; Land Registry; Cyprus
035	Blockchain Technology and Real Estate – a cluster analysis of applications in global markets in the year 2021	Schmidt & Elferich	2021	Germany	Conference	Web of Conferences Globalization and its Socio-Economic Consequences	-	0	Blockchain Technology; Real Estate; Applications
036	Blockchain Technology for rural Property Registration	Tarazona, Rivero & Gallego	2021	Spain	Conference & Book Series	International Conference on Disruptive Technologies, Tech Ethics and Artificial Intelligence & Part of the Advances in Intelligent Systems and Computing book series	Q4	0	Blockchain; Registry; Real Estate National Registration Number; Smart Contract; Rural Property
037	Blockchain technology in commercial real estate transactions	Wouda & Opdenakker	2019	The Netherlands	Journal	Journal of Property Investment & Finance	Q2	51	Innovation; Commercial real estate; Blockchain technology; Transaction process; Information system; Design science research
038	BlockChain to Prevent Fraudulent Activities: Buying and Selling Property Using BlockChain	Bhanushali, Koul, Sharma, Shaikh	2020	India	Conference	5th International Conference on Inventive Computation Technologies (ICICT)	-	7	Blockchain; Real Estate; Buying; Selling; Security

039	Blockchain-based adoption framework for authentic land registry system in Malaysia	Aborujilah, Yatim & Al-Othmani	2021	Malaysia United Kingdom	Journal	TELKOMNIKA Telecommunication, Computing, Electronics and Control	Q3	2	Blockchain; Land records; Land registry; Open sources; Prototype; Smart Contracts
040	Blockchain-based Digital Record-keeping in Land Administration System	Pereira, Tasnim, Rizon & Islam	2021	Bangladesh	Conference & Book Series	International joint Conference on Advances in Computational Intelligence & Part of the Algorithms for Intelligent Systems book series	-	1	Blockchain; Land Administration System; Mutation; Smart Contract
041	Blockchain-based digitization of land record through trust value-based consensus algorithm	Yadav & Kushwaha	2021	India	Journal	Peer-to-Peer Networking and Applications	Q2	8	Peer-to-peer . Blockchain . InterPlanetary file system (IPFS) . Consensus algorithm . Trust value . Property transaction . Distributed ledger technology
042	Blockchain-based framework for secure and reliable land registry system	Shuaib, Daud, Alam & Khan	2020	Malaysia/ Arabia	Journal	TELKOMNIKA Telecommunication, Computing, Electronics and Control	Q3	39	Blockchain; Land Registry; Security; Smart Contract
043	Blockchain-based Land Record Management in Pakistan	Aquib, Dhomeja, Dahri & Malkani	2020	Pakistan	Conference	3rd Conference on Computing, Mathematics and Engineering Technologies (iCoMET)	-	4	Blockchain; Hyperledger Fabric; Hyperledger Composer, Smart Contract, CURL, Dependencies
044	Blockchain-Based Land Registration System: A Conceptual Framework	Khalid, Iqbal, Alturki, Hussain, Alabrah & Ullah	2022	Pakistan Saudi Arabia Brunei Darussalam Norway	Journal	Applied Bionics and Biomechanics	Q3*	2	-
045	Blockchain-based Land Registration: Possibilities and Challenges	Kaczorowska	2019	Poland	Journal	Masaryk University Journal of Law and Technology	Q4	31	Blockchain Technology; Informatization; Land Registration; Real Estate; Transactions
046	Blockchain-Based Systems in Land Registry, a Survey of Their Use and Economic Implications	Mezquita, Parra, Perez, Prieto & Corchado	2021	Spain	Conference & Book Series	13th International Conference on Computational Intelligence in Security for Information Systems (CISIS) & Part of the Advances in Intelligent Systems and Computing book series	Q4	0	Blockchain; Land Registry; E-government; Review; Survey
047	Blockchain-Powered Real Estate System	Jain, Chitroda, Dixit & Dalvi	2020	India	Book Series	Advanced Computing Technologies and Applications	-	1	Blockchain; Real Estate; Smart Contracts; Tokenizing
048	Business Process Models of Blockchain and South African Real Estate Transactions	Tilbury, Rey, Schyff	2019	South Africa	Conference	International Conference on Advances in Big Data, Computing and Data Communication Systems (icABCD)	-	12	Blockchain, distributed ledger, smart contract, conveyancing, real estate, South Africa
049	Can digital technologies speed up real estate transactions?	Saull, Baum & Braesemann	2020	UK	Journal	Journal of Property Investment & Finance	Q2	20	Commercial real estate, real estate transactions, PropTech, Property

									Passport, Blockchain, Automated Valuation Models
050	Can digital technologies speed up real estate transactions?	Saull, Baum & Braesemann	2020	UK	Journal	Journal of Property Investment & Finance	Q2	20	Commercial real estate, real estate transactions, PropTech, Property Passport, Blockchain, Automated Valuation Models
051	Can Fintech Progress the Real Estate Sector? The Disruptive Role of Crowdfunding & Blockchain: A Systematic Literature Review	Creta & Mazaj	2021	Italy	Journal	European Journal of Islamic Finance (EJIF)	-	0	FinTech; Crowdfunding, Blockchcain, Real Estate, Systematic Literature Review
052	Chain of Ownership – A Solution to Reduce Land Forgery through a Transparent Land Ownership Portal	Hariharan & Kirupananda	2021	Sri Lanka	Conference	International Conference on Intelligent Technologies (CONIT)	-	0	Blockchain; Land Information System; Land Parcel; Landowner; Land Registration; Rental Contract; Transparent
053	Challenges and Opportunities using MultiChain for Real Estate	Avantaggiato & Gallo	2019	Italy	Conference	IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom)	-	13	Blockchain, Metadata, Smart Contracts, Bitcoin, Conferences, Stakeholders
054	Collaborative housing and blockchain	Nasarre-Aznar	2018	Spain	Journal	Administration	Q3	39	Collaborative housing, access to housing, disintermediation, blockchain, collaborative economy
055	Comparative Analysis of the Legal Concept of Title Rights in Real Estate and the Technology of Tokens: How Can Titles Become Tokens?	Konashevych	2018	Ukraine	Conference & Book Series	International Conference on Financial Cryptography and Data Security & Part of the Lecture Notes in Computer Science book series	Q2	6	Blockchain; Smart Contracts; Titles; Real Estate; Tokens; E-Governance; E-Voting; E-Democracy
056	Constraints and benefits of the blockchain use for real estate and property rights	Konashevych	2020	Italy	Journal	Journal of Property Planning Environmental Law	Q3 (Q4)	34	Real Estate, Blockchain, Property Rights, Smart Contracts, Distributed Ledger Technology, Land Registry
057	Design of Land Administration and Title Registration Model Based on Blockchain Technology	Kombe, Manyilizy & Mvuma	2017	Tanzania	Journal	Journal of Information Engineering and Applications	-	20	Blockchain, Bitcoin Blockchain, Factom Blockchain, Land Management System, Model Design
058	Design of the Blockchain Smart Contract: A use Case for Real Estate	Karamitsos, Papadaki, Al Barghuthi	2018	United Arab Emirates	Journal	Journal of Information Security	-	209	Blockchain, Ethereum, Smart Contract, Smart City, Real Estate
059	Digital Land Registry System using Blockchain	Sharma, Galphat, Kithani, Tanwani, Mangnani, Achhra	2021	Mumbai	Conference	4th International Conference on Advances in Science & Technology (ICAST)	-	1	Blockchain; Ethereum; Smart Contracts; Cryptography; Land Registry
060	Digitalization of Land Records using Blockchain Technology	Mishra, Sahoo, Anand	2021	India	Conference	International Conference on Advance Computing and Innovative	-	2	Decentralized, Immutable, Auditable, Traceable, Transparent

						Technologies in Engineering (ICACITE)			
061	Digitalization of Land Records: From Paper to Blockchain	Benbunan-Fich & Castellanos	2018	USA	Conference	39th International Conference on Information Systems (ICIS)	A/A2	45	Blockchain; Digitalization; Land Records; Public Private Partnership; IS Readiness
062	Digitalizing land administration: The geographies and temporalities of infrastructural promise	Rodima-Tayloy	2021	USA	Journal	Geoforum	Q1	6	Land Registry; Digitalization; Infrastructure; Blockchain; Conveynancing; Proptech
063	Digitization of Land Record Through Blockchain-based Consensus Algorithm	Yadav & Kushwaha	2021	India	Journal	IETE Technical Review	Q2	4	Blockchain; Consensus mechanism; Distributed Ledger Technology (DLT); InterPlanetary File System; Peer-to-peer network; Property transaction
064	Digitizing Physical Assets on Blockchain 2.0: A Smart Contract Approach to Land Transfer and Registry	Coffie & Saint	2021	Rwanda	Conference & Book Series	International Conference on e-Infrastructure and e-Services for Developing Countries & Part of the Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering book series	Q4	0	Blockchain; Smart Contract; Ethereum; Digital Assets; E-Infrastructure; E-Government; Land Title; Land Registry
065	Distributed Ledger Technology-based land transaction system with trusted nodes consensus mechanism	Yadav, Agrawal & Kushwaha	2021	India	Journal	Journal of King Saud University – Computer and Information Sciences	Q1	13	Blockchain; Peer-To-Peer Computing; InterPlanetary File Technology; Distributed Ledger Technology; Property transaction system; Consensus Mechanism
066	Dutch blockchain, real estate and land registration	Veuger	2020	The Netherlands	Journal	Journal of Property, Planning and Environmental Law	Q3	10	Land registration; Blockchain; Exploration; Influence; Technology
067	Entangled Blockchains in Land Registry Management	Sekhari, Chatterjee, Dwivedi, Negi & Shukla	2019	India	Conference	3rd Workshop on Blockchains and its Applications	-	7	Blockchain, Hyperledger, Land records, Records of Rights
068	Exploring Blockchain and Smart Contract Technology for Reliable and Secure Land Registration and Record Management	Soner, Litoriya & Pandey	2021	India	Journal	Wireless Personal Communications	Q3	4	Blockchain; Stamp; Registry; Authentication; Smart Contract
069	Exploring the potentials of blockchain application in construction industry: a systematic review	Kiu, Chia & Wong	2020	Malaysia	Journal	International Journal of Construction Management	Q2	26	Blockchain, Smart Contract; building information modeling, real estate management, contract management, funding

									management, electronic document management
070	Georgia's Blockchain-powered Property Registration: Never blocked, Always Secured – Ownership Data Kept Best!	Goderdzishvili, Gordadze & Gagnidze	2018	Georgia	Conference	11th International Conference on Theory and Practice of Electronic Governance (ICEGOV)	-	15	Blockchain; Property Registry; Privacy Security; Smart Contracts
071	Hybrid Approaches for Smart Contracts in Land Administration: Lessons from Three Blockchain Proofs-of-Concept	Bennett, Miller, Pickering & Kara	2021	Australia; The Netherlands; Sweden; Canada	Journal	MDPI land	Q2	12	Blockchain; Smart Contract; Land Administration; Land Registration; Cadastre; Technology Readiness Levels; Land Conveyance; Mortgage Discharge
072	Identity Model for Blockchain-Based Land registry System: A Comparison	Shuaib, Hassan, Usman, Alam, Bhatia, Koundal, Mashat & Belay	2022	Arabia, India, Malaysia Ethiopia	Journal	Wireless Communications and Mobile Computing	Q2*	11	-
073	Implementation of real estate contract system using zero knowledge proof algorithm based blockchain	Jeong & Ahn	2021	Korea	Journal	The Journal of Supercomputing	Q2	4	Blockchain, Zero Knowledge, Ethereum, Smart Contract, Real Estate
074	Implications of Block Chain in Real Estate Industry	Mehendale, Masurekar & Patil	2019	India	Journal	International Journal of Recent Technology and Engineering	Q4	6	Block; Blockchain; Cryptography; Intermediaries; Real Estate
075	Improvement Of Land Administration System in Nigeria: A Blockchain Technology Review	Ibrahim, Daud, Azmi, Noor & Yusoff	2021	Nigeria	Journal	International Journal of Scientific & Technology Research	Q2	0	Blockchain; Land; Land Administration System; Nigeria; Land Tenure; Land Ownership; Registration; Land Title
076	Improving the Authenticity of Real Estate Land Transaction Data Using Blockchain-Based Security Scheme	Shuaib, Alam & Daud	2020	Malaysia & Yemen	Conference & Book Series	International Conference on Advances in Cyber Security & Part of the Communications in Computer and Information Science book series	Q4	17	Authentication; Security; Land Registry, Real-Estate; Blockchain
077	Influence of Blockchain in the Real Estate Sector	Nijland & Veuget	2019	Netherlands	Journal	International Journal of Applied Science	-	18	Blockchain, Commercial real Estate, Added Value, Stakeholders
078	Land Record Management using Hyperledger Fabric and IPFS	Mukne, Pai & Ambawade	2019	India	Conference	10th International Conference on Computing, Communication and Networking Technologies (ICCCNT)	-	18	Blockchain, Hyperledger Fabric; IPFS, Passport, P2P, decentralized, land record management
079	Land records on Blockchain for implementation of Land Titling in India	Thakur, Doja, Dwivedi & Ahmad	2020	India/UK	Journal	International Journal of Information Management	Q1	130	Blockchain; Land records; Land registry; Smart contracts; Land acquisition; Mutation; Land Titling

080	Land Records System Using Hybrid Blockchain	Kadam, Vidhani, Bane, Valecha & Giri	2020	India	Conference	IEEE International Conference on Convergence to Digital World – Quo Vadis (ICCDW)	-	0	Hybrid Blockchain; Security; Land Records; Smart Contract; Ethereum
081	Land Registration System Using Blockchain	Gollapalli, Krishnamoorthy, Jagtap & Shaikh	2020	India	Conference	International Conference on Smart Innovation in Design, Environment, Management, Planning and Computing (ICSIDEMPC)	-	1	Blockchain; Land; Hyperledger, Land Registration; Secure
082	Land Registry Management using Blockchain	Thosar, Sarode, Harne & Kaur	2020	India	Conference	International Conference on Smart Innovations in Design, Environment, Management, Planning and Computing (ICSIDEMPC)	-	0	Blockchain; Ethereum; Smart Contracts; Ganache; Metamask; Truffle
083	Land Registry Using Blockchain – A Survey of existing systems and proposing a feasible solution	Shinde, Padekar, Raut, Wasay & Sambhare	2019	India	Conference	5th International Conference on Computing, Communication, Control and Automation (ICCUBEA)	-	10	Blockchain; IPFS; Smart contract, Land Registry
084	LandChain: A Blockchain Based Secured Land Registration System	Biswas, Faysal & Ahmed	2021	Bangladesh	Conference	International Conference on Science & Contemporary Technologies (ICSCT)	-	6	Blockchain; Land Registration, Security, Hashing Algorithm, NextGec Proof of Work (PoW), 4th Industry Revolution
085	Landcoin: A Practical Protocol for Transfer-of-Asset	Patil & Shyamasundar	2021	India	Conference & Book Series	International Conference on Information Systems Security (ICISS) & Part of the Lecture Notes in Computer Science book	Q2 B B3	0	Blockchain; Land Management; Privacy; Access Control
086	LandLedger: Blockchain-powered Land Property Administration System	Cupta, Das, Nandi	2019	India	Conference	IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)	-	6	
087	Legal challenges and opportunities of blockchain technology in the real estate sector	Garcia-Teruel	2020	Spain	Journal	Journal of Property Planning Environmental Law	Q3 (Q4)	42	Real estate, Land registry, Blockchain, Sharing economy, Rental contracts, Tokenization
088	Minimization of fraudulent activities in land authentication through Blockchain-based system	Jayabodhi, Rajapakse & Senanayake	2020	Sri Lanka	Conference	International Research Conference on Smart Computing Systems Engineering	-	1	Blockchain Mining; Land Authentication; Smart Contract
089	New technology interventions including blockchain technology in land record and registry management in India	Kaushik	2020	India	Conference	13th International Conference on Theory and Practice of Electronic Governance		0	Land Record; Blockchain; E-Governance; India
090	Novel blockchain reference model for government services: Dubai government case study	Alketbi, Nasir & Talib	2020	United Arab Emirates	Journal	International Journal of System Assurance Engineering and Management	Q3	23	Blockchain; Government Services; Hyperledger Fabric; Blockchain use cases; Blockchain; Case study

091	Opportunities and Barriers of Using Blockchain in Public Administration: The Case of Real Estate Registration in Kazakhstan	Akhmetbek & Spacek	2021	Kazakhstan Czech Republic	Journal	NISPAcee Journal of Public Administration and Policy	Q3	1	Blockchain; Public Administration; real Estate Registration; Kazakhstan
092	Permissioned Distributed Ledgers for Land Transactions; A Case Study	Fernando & Ranasinghe	2019	Sri Lanka	Conference & Book Series	International Conference on Business Process Management & Part of the Lecture Notes in Business Information Processing book series	A/A2 & Q3	7	Permissioned distributed land ledger; land transaction density, fault tolerance, transaction, throughput; latency
093	Possible Applications of Smart Contracts in Land Administration	Stefanovic, Stefanovic, Boijkic & Przulj	2018	Serbia	Conference	26th Telecommunications Forum (TELFOR)	-	9	Blockchain; Land Administration, Smart Contract
094	Proof-Of-Concept (PoC) of Land Mortgaging Process in Blockchain-based Land Registration System of Thailand	Pongnumkul, Khonnasee, Lertpattanasak & Polprasert	2020	Thailand	Conference	2nd International Conference on Blockchain Technology	-	4	Blockchain; Ethereum; land Registration; Smart Contracts
095	Real Estate Management System based on Blockchain	Mittal, Sharma & Ranjan	2020	India	Conference	International Conference on Electrical, Electronics and Computer Engineering	-	1	Blockchain; Distributed Storage; Real Estate Management
096	Real Estate Management via a Decentralized Blockchain Platform	Ahmad, Alqarni, Almazroi & Alam	2020	Arabia/ Pakistan	Journal	Computers, Materials & Continua	Q2 (Q1)	6	Blockchain, Real Estate; Smart Contracts
097	Reducing Forgery on Land Registry System Using Blockchain Technology	Ramya, Sindhuja, Atsaya, Dharani & Golla	2018	India	Conference & Book Series	International Conference on Advanced Informatics for Computing Research & Part of the Communications in Computer and Information Science book series	Q3	16	Multichain; Distributed ledger; Streams; Hash value; Consensus protocol; Digilocker
098	Registration of Land and Building Certificate Ownership using Blockchain Technology	Syawaludin & Munir	2021	Indonesia	Conference	International Conference on ICT for Smart Society (ICISS)	-	0	System; Blockchain; Certificate; Technology; Data
099	Research on Real Estate Transaction Platform Based on Blockchain Technology	Yang & Wang	2019	China	Journal	Journal of Physics: Conference Series	Q4** 2020	1	-
100	Reshaping the Real Estate Industry Using Blockchain	Krupa & Akhil	2019	India	Book Series	Emerging Research in Electronics, Computer Science and Technology. Lecture Notes in Electrical Engineering (Part of the Lecture Notes in Electrical Engineering book series)	Q3	15	Blockchain Technology; Real Estate Industry; Transactions; Distributed Ledger; Smart Contract

101	Role of Blockchain Technology in Digitization of Land Records on Indian Scenario	Singh	2020	India	Conference	IOP Conference Series: Earth and Environmental Science	-	8	-
102	Secure Digitization of Land Record using Blockchain Technology in India	Samal, Mohanta, Sharma & Jena	2021	India	Conference	12th International Conference on Computing Communication and Networking Technologies (ICCCNT)	-	0	Land record digitization; Blockchain; Secure Storage; Ethereum; Security
103	Secured Data Storage Framework for Land Registration using Blockchain Technology	Humdullah, Othman, Razali & Mammi	2021	Malaysia	Conference	3rd International Cyber Resilience Conference (CRC)	-	1	Land Registration, Blockchain, Land Fraud
104	Secured Land Title Transfer System in Australia using VPN based Blockchain Network	Sheikh, Khattak. Khan & Hussain	2022	Australia	Conference	International Conference on Advanced Communication Technology (ICACT)	-	0	Blockchain; Land Records, VPN, Routing Attacks, Hyperledger Fabric
105	Secure-reliable smart contract applications based blockchain technology in smart cities environment	Varfolomeev, Alfarhani & Oleiwi	2021	Russia	Journal	Procedia Computer Science	-	3	Smart City; Blockchain; Smart Contract
106	Securing Land Registration using Blockchain	Krishnapriya & Sarath	2020	India	Conference	3rd International Conference on Computing and Network Communications	-	24	Blockchain; PoW; Hash; merkle Tree
107	Sharing of Encrypted Lock Keys in the Blockchain-Based Renting House System from Time- and Identity-Based Proxy Reencryption	Wang, Qian, Chen & Sun	2021	China	Journal	China Communications	Q1	0	Identity-based proxy reencryption; time stamp, renting houses system; blockchain
108	Smart Contract Application for Managing Land Administration System Transaction	Stefanovic, Przulj, Ristic, Stefanovic & Nikolic	2022	Serbia	Journal	IEEE Access	Q1	1	Blockchain, Ethereum, Land Administration, Real Estate, Smart Contract
109	Smart Contract Definition for Land Registry in Blockchain	Sahai & Pandey	2020	India	Conference	9th IEEE International Conference on Communication Systems and Network Technologies (CSNT)	-	7	Blockchain; Smart Contract; Solidity; DApp; Land Registry
110	Smart Contract for Real Estate Using Blockchain	Kothari, Bharambe, Motwani & Rathi	2020	Mumbai	Conference	3rd International Conference on Advances in Science & Technology (ICAST)	-	4	Real Estate; Smart Contract; Ethereum; Blockchain
111	Study of factors influencing the decision to adopt the blockchain technology in real estate transactions in Kosovo	Hoxha & Sadiku	2019	Albania	Journal	Property Management	Q3	29	Security, Transparency, Kosovo, Blockchain technology, Transactions costs, Real estate transactions system
112	The Application of Blockchain as a Distributed Ledger and Smart Contract for Property Registration	Goragandhi, Shah, Doshi & Nanade	2021	India	Conference	International Conference on Disruptive Technologies for Multi-Disciplinary Research and Applications (CENTCON)	-	0	Blockchain; Property Registration; Smart Contracts; Decentralization; Distributed Ledgers

113	The blockchain technology in real estate sector: Experience and prospects	Pankratov, Grigoryev & Pankratov	2020	Russia	Conference	IOP Conference Series: Materials Science and Engineering	-	7	-
114	The digital tokenization of property rights. A comparative perspective	Garcia-Teruel & Simón-Moreno	2021	Spain	Journal	Computer Law & Security Review	Q1	19	Asset-backed tokens; Blockchain; Ownership; Tokenization; Smart contracts
115	The Possibilities of the Blockchain Technology in the Provision of the Real Estate Rights' Registration Services	Sadkov, Vekhov, Kotelnikov & Sadkov	2020	Russia	Conference & Book Series	Institute of Scientific Communications Conference (ISC) "Smart Technologies" for Society, State and Economy & Part of the Lecture Notes in Networks and Systems book series	Q4	0	Blockchain; Public Services; State Services; Real Estate
116	The Potential of Blockchain in Building Construction	Dakhli, Lafhaj, and Mossman	2019	France	Journal	MDPI buildings	Q2	65	Blockchain; Construction; BIM; Transactional Costs; Lean Construction
117	The Real Estate Transaction Trace System Model Based on Ethereum Blockchain Platform	Vo & Nguyen	2022	Vietnam	Conference	14th International Conference on Computer and Automation Engineering	-	0	Blockchain Technology; Smart City; Real Estate; Service and Public Sector Systems
118	The rise of PropTech: emerging industrial technologies and their impact on real estate	Starr, Saginor & Worzala	2020	USA	Journal	Journal of Property Investment & Finance	Q2	23	Real estate 4.0; Industry 4.0; PropTech; Fintech; Real estate technology; COVID-19 pandemic; Technology disruption; Internet of Things (Io), Internet of everything, Real estate profession, Built environment, property
119	The Role of Blockchain in Documenting Land User' Rights: The Canonical Case of Farmers in the Vernacular Land Market	Daniel & Speranza	2020	Switzerland	Journal	Frontiers in Blockchain	-	24	Blockchain; Informal Land Market; Land Tenure, Agriculture; Vernacular Land Market
120	Tokenization of Real Estate Using Blockchain Technology	Gupta, Rathod, Patel, Bothra, Shanbhag & Bhalerai	2020	India UK	Conference & Book Series	International Conference on Applied Cryptography and Network Security & Part of the Lecture Notes in Computer Science book series	B/B1 Q3	12	Blockchain; Real Estate; Ethereum; Tokenization; Security token; Special purpose vehicle
121	Tokenomics: A new opportunity in the Real Estate business? A qualitative approach to crowdfunding and blockchain interaction	Creta & Tenca	2021	Italy	Journal	First Monday	Q1	0	real estate crowdfunding; blockchain; tokenomics; tokenization

122	Transformation of the real estate market on the basis of use the blockchain technologies: opportunities and problems	Kalyuzhnova	2018	Russia	Conference	International Scientific Conference "Investment, Construction, Real Estate: New Technologies and Special-Purpose Development Priorities" (ICRE)	-	19	-
123	Transparency of Land Administration and the Role of Blockchain Technology, a Four-Dimensional Framework Analysis from the Ghanaian Land Perspective	Ameyaw & Vries	2020	Germany	Journal	MDPI land	Q2	20	Land Administration; Blockchain Technology; Land Tenure; Land Valuation; Land Use Planning; Land Development Ghana
124	Trust in a viable real estate economy with disruption and blockchain	Veuger	2018	The Netherlands	Journal	Facilities	Q2	118	Values, Strategic management, Real Estate, Artificial intelligence, Property portfolio management, Value management
125	Usage of Blockchain-based Provenance Enabled Technology to Process and Track Land Transactions	Sravani & Murali	2019	India	Journal & Conference	International Journal of Research in Advent Technology & International Conference on Technological Emerging Challenges (ICTEC)	-	3	Security; Blockchain; Privacy; Provenance; Permissioned Blockchain; Data Integrity; Immutability
126	Use of Blockchain Technology in Automation of Ad-Hoc Leasing Agreements	Gatt & Inguanez	2021	Malta	Conference	IEEE 11th International Conference on Consumer Electronics	-	0	Blockchain; Smart Contract; Notarization; Real Estate
127	Using blockchain technology to facilitate property transactions	Amadi-Echendu	2021	South Africa	Journal	South African Journal of Information Management	-	0	Blockchain Technology; Cryptocurrency; Distributed Ledger; Land Administration Systems; Property Transactions
128	Usurping Double-Ending Fraud in Real Estate Transactions via Blockchain Technology	Mashatan, Leumieux, Lee & Szufel, Roberts	2021	Canada Poland	Journal	Journal of Database Management (JDM)	Q2	3	Blockchain technology; Real Estate; Double-ending Fraud; Transparent Transactions; Agent-Based Modelling; Hyperledger Fabric
129	Verification Plan Using Neural Algorithm Blockchain Smart Contract for Secure P2P Real Estate Transactions	Huh & Kim	2020	Korea	Journal	MDPI Electronics (Switzerland)	Q2	12	Real Estate; Real Estate Blockchain; Real Estate Transactions; Blockchain; Blockchain Consensus Algorithm; Smart Contract; Ethereum

* Journal classification for 2022 has not yet been released, therefore, the classification of the previous year is used.

Appendix B

Table B1. Selected studies excluded from the systematic literature review.

#	Title	Authors	Year	Country	Source Type	Source	Reason of Exclusion
001	Review of Existing Solutions in the Field of Real Estate and Cadastral Accounting Based on Blockchain Technology	Averin, Rukhlov & Musaev	2021	Russia	Conference	International Conference on Quality Management, Transport and Information Security, Information Technologies (IT&QM&IS)	The article reviews some of the existing real estate solutions based on blockchain technology, however, as a short paper, the article only explored the main purposes of each solution mainly from a commercial perspective
002	Blockchain Real Estate Relational Value Survey	Seigneur, Pusterla & Clerc	2020	France	Conference	35th Annual ACM Symposium on Applied Computing	The article is mainly focus on how the types of relations who have contributed to a product impact price premium and what real estate agencies think about real estate relational value, especially on a web marketplace implemented, and blockchain technology is only used for products certifications transparency