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Blockchain-Based Trusted Property Transactions in the Built Environment: Development of an Incubation-Ready Prototype

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Abstract: Blockchain can be introduced to use cases in the built environment where reliability of transaction records is paramount. Blockchain facilitates decentralised, cryptographically secure, trustworthy, and immutable recordkeeping of transactions. However, more research is urgently required to understand the process and complications in implementing blockchain solutions in the built environment. This paper demonstrates a methodology for developing a blockchain system starting from problem analysis, selection of blockchain platform, system modelling, prototype development, and evaluation. The evolutionary prototyping model was selected as the software development methodology for the use case of property transactions. A systematic process protocol involving the multi-criteria decision-making method, Simple Multi Attribute Rating Technique (SMART), was used to select Hyperledger Fabric as the most suitable blockchain platform for the prototype. The system architecture facilitates a simplified, lean property transaction process implemented through chaincode (smart contract) algorithms and graphical user interfaces. System evaluation through test cases allowed iterative improvements, leading to an incubation-ready software prototype. The contribution to knowledge of this paper is in the demonstration of the process to follow to implement a blockchain solution for a specific domain. The findings provide the foundation for developing proofs of concept for other potential applications of blockchain in the built environment.

Keywords: blockchain; built environment; trust; proof of concept; property transactions; Hyperledger Fabric

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1. Introduction

In the built environment, with respect to property transactions, where businesses depend on reliability of transaction records, blockchain has been proposed to enable trust and ensure ownership [1–3]. Blockchain technology is suitable for storing and handling thousands of copies of transaction records to enable transaction authentication [1,4–7]. Whilst traditionally the transaction records for built environment are housed in central servers controlled by a single administration point, in blockchain technology, these transaction records are replicated across the network of computers [2,5,8].

Blockchain is considered to be a disruptive technology that has a significant impact in numerous industries in terms of information and trust [2,9–13]. Blockchain is a distributed ledger technology, where data stored in the network is non-centralised, supports peer-to-peer interactions, and creates a cryptographically secured, immutable chain of records [14–17]. As each peer (node) in the blockchain network maintains a copy of the ledger, and the records cannot be modified without detection, blockchain provides a method of ensuring trust in a trustless environment [18], and produces an audit trail of all transactions in the ledger [19].

Maintaining trusted records on a blockchain would enable benefits such as tracking the history of assets, providing trustworthy proof of ownership, reducing transaction times

and costs, and minimising fraudulent behaviour [19,20]. However, it is noted that only a few papers have discussed the demonstration of blockchain solutions in the property sector, and more so in the built environment [1,12,21]. The Institution of Civil Engineers (ICE) [14], Centre of Digital Built Britain [22], and ARUP reports regarding the future of smart built environment [23,24] have highlighted that trust is a valuable asset for the construction industry, but that the current system is still facing difficulties to ensure trust. It is recommended to introduce a new system that could aid in reliably sharing information amongst stakeholders [25–28]. The blockchain real estate industry report for the year 2021 by the Foundation for International Blockchain and Real Estate Expertise (FIBREE) pointed out that the property sector is still partly digitalised and mostly paper-based, and the use of blockchain as an innovative solution is still at an early trigger stage [29].

This paper demonstrates a methodology for developing a blockchain system starting from problem analysis, selection of blockchain platform, system modelling, prototype development, and evaluation. It presents the development of an incubation-ready software prototype using blockchain for property transactions as a use case to illustrate the potential of blockchain in the built environment. This is achieved by establishing three objectives. Firstly, to understand the potential applications of blockchain in the built environment, and critically review the need for blockchain in enabling trusted transactions. Secondly, to understand the mechanism of Hyperledger Fabric as a blockchain platform in developing the software prototype. Finally, to design, develop, and evaluate a blockchain-based software prototype for a simplified, lean property transaction process implemented through chaincode (smart contracts) and graphical user interfaces. The findings provide the foundation for developing proofs of concept for other potential applications of blockchain in the built environment.

The rest of this paper is structured as follows: Section 2 presents the literature review including the potential applications of blockchain in the built environment. It also presents a critical review of previous studies on blockchain applications for property transactions, and discusses the suitability of Hyperledger Fabric as a blockchain platform. Section 3 describes the research method to develop the blockchain-based software prototype. Section 4 elaborates the proof of concept, including the business scenario, system overview, architecture, implementation, and system evaluation. Section 5 presents the discussion, and the conclusions are presented in Section 6.

2. Literature Review

In the built environment, with respect to property transactions, where businesses depend on reliability of transaction records, blockchain has been introduced to enable trust and ensure ownership [1–3]. Blockchain technology is suitable for storing and handling thousands of copies of transaction records to enable transaction authentication [1,4–7,30]. Whilst traditionally, the transaction records for built environment are housed in central servers controlled by a single administration point, in blockchain technology, these transaction records are replicated across the network of computers [2,5,8]. The structure of the distributed ledger technology effectively means that all participants in a blockchain network have the same transaction records, and the ability to read and write to the ledger [2,5,14]. Figure 1 shows the differences between centralised databases, traditional decentralised databases, and distributed ledger technology for blockchain.

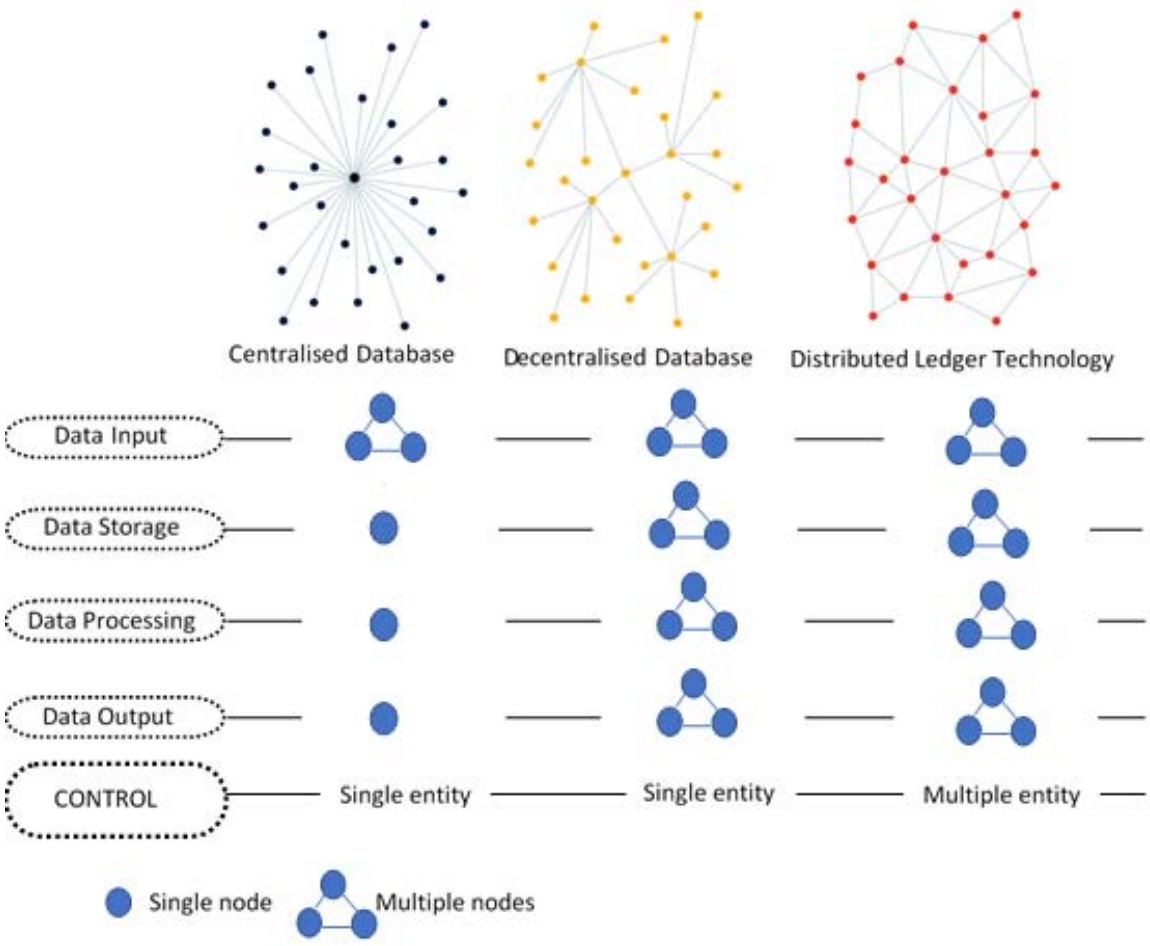

Figure 1. The differences between centralised databases, traditional decentralised databases, and distributed ledger technology (adapted from [2]).

In the built environment and the property sector, still more research is urgently required to exploit the full potential of blockchain as a solution [12,31], such as in title transfer of real estate assets, construction supply chains, and even the integration of Building Information Modelling (BIM) and blockchain.

2.1. The Potential Application of Blockchain in the Built Environment

This section explores some of the main applications of blockchain in the built environment. In theory, one blockchain platform might be implemented to span the entire life cycle of a real estate asset, from materials supply to management of the built asset. It briefly explores real estate title transfer, construction supply chains, and the aspects of BIM and blockchain integration. The applications listed are non-exhaustive but indicate the potential areas involved across the sector.

2.1.1. Title Transfer of Real Estate Assets

Blockchain will ensure the authenticity of land registry title records that could potentially link a real estate asset to the pertinent data relating to a wide range of its stakeholders, thereby streamlining business processes [5]. The data might include information such as digital planning, architecture, certification and verification, specifications, and warranty [3,32] that relate to a given real estate asset. Traditionally, these data have been stored in silos [33,34]. It is still common to have thousands of documents from hundreds of parties [32] where information is disparate, disconnected, and hard to access. Making commitment and collaboration of such information to the blockchain a mechanism for value

transfer [11,35] will ensure the integrity of the data for the real estate asset [31]. Blockchain will enable the adoption of a smart contract to optimise contract formulation and negotiation, while transaction ordering through a consensus service will ensure immutability mechanisms for the transfer or creation of value, and transaction validation through a membership service will create trust in trustless environments to enhance auditability and its accountability while automating the execution of the contract [36–39]. This will be discussed in detail in Section 2.2. Given this, a potential adoption of blockchain-based solutions are being conceptualised with an expectation to help smart city developers adopt blockchain as the embodiment of trust to own, trade, and exchange assets, without central servers controlled by a single administration point, enabling a token economy [40–42].

2.1.2. Construction Supply Chains

Traditionally, construction projects are considered unique, but Construction Supply Chain (CSC) processes are often predictable and repeatable. The CSC has an element of value transfer beyond the monetary value within a low-trust environment, where stakeholders have adversarial relationships and interests and mostly work through an intermediary [2,5,7,8,34,43]. This is where the blockchain's key strength could enable a single source of data integrity, by ensuring the immutability of the record and compliance checking for CSC [2,44]. Another pain point in the CSC that blockchain could overcome is traceability as it provides a full audit pathway for the data by creating an immutable record for the CSC activities [44,45]. Blockchain will pave the way to automate the CSC payments through smart contracts, by ensuring that contracted obligations are satisfied along a supply chain by various stakeholders [5,46,47].

2.1.3. Building Information Modelling (BIM)

BIM has played a key role in the digital transformation of the built environment [23,48]. However, the BIM process for supply chain still bears several shortcomings [49] in the absence of a legal context describing the BIM data ownership and no trusted record of the model changes during construction and operation stages [39]. Ready access to the history of project documentation can be an invaluable information source in all phases of the life cycle of the project [50]. There is a value in an immutable record of the BIM model transactions to agree on using it as a single source of truth (SSoT), by enabling BIM data integrity, reliability, and traceability [5,44]. However, the integration is still in its infancy [12,13].

2.2. Need for Blockchain in Enabling Trusted Property Transactions in the Built Environment

A critical review of previous studies on the application of blockchain technology for land registration was conducted to understand the main research focus, issues in maintaining records for property transactions, proposed software prototypes, type of blockchain platform recommended, and challenges and limitations. The Scopus and Web of Science databases were used to search the application of blockchain technology for land registration. Figure 2 shows the search strategy including keywords, inclusion, and exclusion criteria for shortlisting papers.

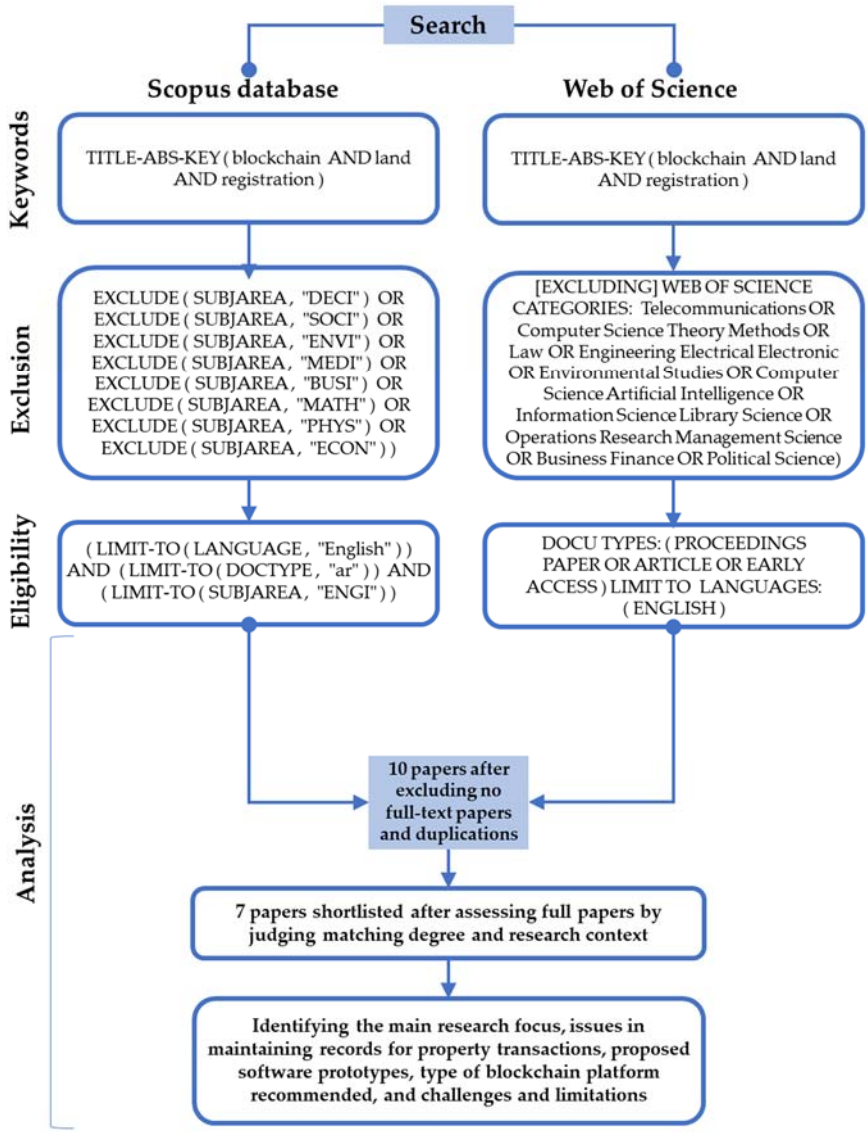

Figure 2. The search strategy.

Most of the previous studies, as illustrated in Table 1, on the application of blockchain for land registration and property transactions are still at a conceptual and/or exploration level, with very few proofs of concept available. This indicates a knowledge gap that needs addressing to examine and validate the usability and challenges in adoption of this technology [1,31,51,52]. However, the previous studies pointed out that the rationale for proposing a blockchain in maintaining records for land registration and property transactions is the capability of this technology to overcome the transparency issue and ensure ownership [1,31,51–55]. In addition, it is argued that adopting blockchain will enable data integrity by assuring the accountability and consistency of data over its entire life cycle, including storing, processing, or retrieving data, while the current system is fragmented with a bureaucratic structure, which leads to ownership conflicts, complexity, and land records documentation issues [31]. There is evidence of corruption in the current system of maintaining records for property transactions in many countries. Adopting blockchain technology will create and maintain a clear audit trail of actions that will help to minimise the possibility of the records being tampered with, by facilitating the litigation proceedings as they arise [1,53,54].

Table 1. A critical review of previous studies on application of blockchain technology for land registration and property transactions.

Main Research Focus	Issues in Maintaining Records for Property Transactions	Proposed Framework/Software Prototype	Type of Blockchain Platform Recommended	Challenges and Limitations	Source
The usage of blockchain for land records management in India. (Conceptual and framework research)	• No data integrity (discrepancies in the records). • Poorly administered. • Lack of transparency. • Current system does not ensure a guarantee of ownership. • Corruption.	• A class diagram and framework of blockchain usage to update land records were proposed. • A software prototype solution was not provided.	Hyperledger Fabric, as it offers a number of Software Development Kits (SDKs) to support various applications.	• Blockchain is still new and very few proofs of concept are available. • Lack of specialised expertise. • Buy-in from participant. • Legal issues (no regulatory standards are available yet). • Instances of security violations. • Cost of implementation.	[1]
To discuss the use of blockchain as a land registration tool in Cyprus. (Horizon scanning research)	• Disputes in land ownership registration and administration. • Lack of transparency. • Lack of accountability.	• Neither a proposed framework nor a software prototype was provided.	Not mentioned.	• Blockchain is still new and more research is urgently required in this area. • Political and legal issues. • Risks of implementation.	[51]
The potential of blockchain application in title registration in Ghana (Exploration and conceptual research)	• Unreliable recordkeeping system. • Land disputes. • Lack of proper boundaries. • Lack of transparency in records verification and transaction.	• Neither a proposed framework nor a software prototype was provided. However, the paper discussed the blockchain-enabled land acquisition and registration model.	Not mentioned.	• Very few proofs of concept are available. • Legal issues (no regulatory standards are available yet).	[52]
An analysis of previous blockchain publications targeted on The Netherlands (Exploration research)	• Lack of transparency. • Lack of accountability. • Fragmented system and no data integrity (data silos).	• Neither a proposed framework nor a software prototype was provided.	Not mentioned.	• Proof of concept study is necessary, limited research has been done into usage of blockchain in the property sector. • Using blockchain to find an innovative configuration for business models for the property sector is not easy.	[31]

Table 1. *Cont.*

Main Research Focus	Issues in Maintaining Records for Property Transactions	Proposed Framework/Software Prototype	Type of Blockchain Platform Recommended	Challenges and Limitations	Source
The potential of blockchain to enable reliable registration of land in real estate (focusing on performance of hash functions in blockchain) (Conceptual and framework research)	• Process in current system is not digitised and leads to records getting tampered with. • Accessing records is time-consuming. • Double registration issue in the establishment of ownership. • Brokerage system (middlemen cost). • Lack of transparency. • Corruption.	• The paper discussed the hashing processing in blockchain and proposed a framework. • A software prototype solution was not provided.	Ethereum as it is the first public blockchain platform supporting smart contracts.	• Not mentioned.	[53]
An analysis of blockchain-based land registration possibilities and challenges (Exploration and conceptual research)	• Complexity of records transfer and registration. • Lack of transparency in records verification and transaction. • Corruption in current system. • No data integrity.	• Neither a proposed framework nor a software prototype was provided. However, the paper discussed some practical applications of blockchain in European countries.	Not mentioned.	• Blockchain in the public type form is not suitable for the specificity of the property sector transfer and land registration. • Defining liability rules is necessary to enable the blockchain in the property sector and land registration. • There is a need to continue the research on optimal legal and technical ways of taking advantage of using blockchain in the property sector.	[54]
The potential of blockchain to enable reliable registration without intermediaries (Horizon scanning research)	• Lack of transparency. • Fragmented system. • Disputes in land ownership registration and administration.	• Neither a proposed framework nor a software prototype was provided.	Ethereum, as it is the first public blockchain platform supporting smart contracts.	• Legal issues (no regulatory standards are available yet). • Buy-in from participant. It is hard to conceive complete protection of consumers in a business-to-consumer relationship in a disintermediated solution such as blockchain.	[55]

Blockchain is still a relatively new technology at an early trigger stage, where the majority of implementations are either in initial or development stage [3,54]. As illustrated in Table 1, most studies use hypothetical cases with a significant gap of a deductive use case, and/or a detailed software prototype to support those hypotheses for land registration and property transactions. Only a few papers have even recommended a specific type of blockchain.

Ethereum was mentioned as the first public blockchain platform supporting smart contracts for mass consumption, such as the financial sector [39,53,55]. However, it is argued that Ethereum is not suitable for the specificity of business, such as the property sector where confidentiality and performance are critical [6,39]. Ethereum as a public (non-permissioned) blockchain platform has a privacy and accountability issue, as it is open to anyone who wishes to participate, and performance and scalability become a challenge as each node has to process each transaction [6,39,54]. Hyperledger Fabric was strongly recommended as a permissioned blockchain platform to satisfy the requirements of privacy, trust, and traceability desirable for a broad range of industry use cases, including property transactions in the built environment [6,39,53]. Hyperledger Fabric offers a number of Software Development Kits (SDKs) based on modular and pluggable components [39] to support various applications, enabling buy-in from participants [53].

Hyperledger Fabric is an open-source blockchain platform hosted by the Linux Foundation that can be used to create permissioned blockchains and develop distributed applications [37]. It is being actively developed by the International Business Machines Corporation (IBM) [56], and has received contributions from Intel and SAP Ariba [37]. The Hyperledger Fabric architecture delivers high degrees of flexibility and confidentiality in its design and implementation, which makes it useful in many of the built environment applications, including property transactions [6,39,56,57]. It helps in achieving privacy, as it requires permission to read and write [6,56]. It also enables auditability by separating transaction processing into three phases; (a) distributed logic processing through Chaincode Services to create a smart contract, which is the business logic code of a transaction in the Hyperledger Fabric platform; (b) transaction ordering through Consensus Services to create blocks of transactions and facilitate trust in the network; and (c) transaction validation through Membership Services to identify the network members and generate a root of trust by satisfying the endorsement policy that defines which peers can run chaincode to execute transaction proposals to be committed to the ledger [36–39]. The use of Hyperledger Fabric as a blockchain platform to enable trusted property transactions is demonstrated in the subsequent sections.

Exploring the use of Hyperledger in the property sector is now increasing: from 6% in 2019 [58] to 14.7% in 2020, according to the FIBREE industry report 2020 for blockchain in the property sector [3]. With only two countries in 2019 using Hyperledger, more than seven countries, including Australia, China, India, the United Kingdom, and the USA, are currently using it. The following section describes the methodology adopted in this paper to provide a use case of blockchain-based trusted property transactions in the built environment.

3. Research Method, Design and Tools

The prototyping model of evolutionary prototyping [59] was selected as the software development methodology for the proposed system. In this method, an initial prototype is constructed, which is then evaluated. Successive prototypes were developed, with additional functionality based on received feedback. The prototyping model was selected due to its advantage of reducing the development time and providing a rapid solution to the identified problem scenario [60]. The steps of the research method followed in this paper are illustrated in Figure 3, and described below.

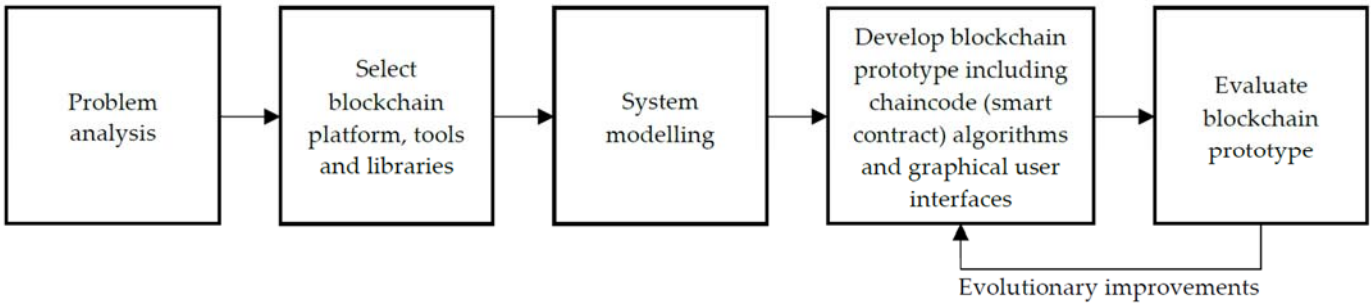

Figure 3. Research method to develop the blockchain-based software prototype.

The scope of the business scenario covers real estate property transactions in New South Wales (NSW), Australia. In a blockchain solution development for an application domain, full modelling of the domain requirements and issues should be undertaken. This may involve data flow modelling, process modelling, and entity-relationship modelling, among others [60]. However, this paper discusses a simplified analysis of the problem domain as presented in Section 4.1, since the focus is on the demonstration of the development of a blockchain system. The system requirements were identified through literature and by reviewing relevant documentation available on NSW government websites. These system requirements are elaborated in Section 4.2.

A systematic process protocol presented in Nanayakkara et al. [61] was followed to identify the most suitable blockchain platform for the prototype. This involved the application of the multi-criteria decision-making method, Simple Multi Attribute Rating Technique (SMART). The SMART method was selected due to the relative simplicity of application to assist accurate decision-making [62]. Blockchain platforms that would suit the system requirements were identified and evaluated based on their salient features. A major initial decision was to choose between permissioned and permissionless blockchain networks. Permissionless networks allow users to freely join the blockchain network and pseudonymously engage in transactions. In contrast, permissioned networks require the participants to be known and authorised to join and transact in the network [6,15]. It was decided that permissioned networks are the most suitable type of blockchain for property transactions, as participants should be known and held accountable for their transactions. Furthermore, permissioned networks will ensure privacy of users' sensitive data. The list of candidate permissioned blockchain platforms included Corda R3, Elements, Hyperledger Fabric, IBM Blockchain, and New Economy Movement (NEM). Subsequent criteria such as cost, level of support, ease of use, performance, and security [61], were considered, and provided weights based on the importance to the system development process. Next, weights for each selection criterion were determined for each of the blockchain platforms based on a two-stage evaluation by the authors, individually and collectively. The finalised platform weights were multiplied by the criterion weights, and finally added together to obtain the total value. Table 2 lists the selection criteria, weights for each criterion, the criteria weights for each platform, calculated values, and total values for the top four blockchain platforms that emerged from the evaluation. The Hyperledger Fabric blockchain platform was selected as the most suitable match for the identified requirements through this method, due to its features and benefits described in Section 2.2.

Next, the tools, libraries and programming languages related to the platform were selected based on the system requirements, following the process protocol of Nanayakkara et al. [61]. The tools, libraries, and programming languages are discussed in Sections 4.3 and 4.4. The system architecture was designed to fulfil the requirements, and is presented in Section 4.3. The blockchain prototype, including chaincode (smart contract) algorithms, was developed, and a graphical user interface was created to facilitate the system operation. Details of the system implementation are provided in Section 4.4. Finally, the functionality of the blockchain prototype was evaluated through test cases. The prototype was iteratively improved based on the evaluation, as discussed in Section 4.5.

Table 2. Top four blockchain platforms suitable for the system requirements based on SMART evaluation (adapted from [61]).

Criteria		A	B	C	D	E	F	G	H	I	Total	Rank
Weight for Criterion		**10**	**8**	**8**	**4**	**10**	**5**	**6**	**7**	**6**		
Hyperledger Fabric	Weight	8	10	8	9	9	9	9	7	9	552	1
	Calculated Value	80	80	64	36	90	45	54	49	54		
Corda	Weight	7	4	7	10	10	6	10	5	10	483	2
	Calculated Value	70	32	56	40	100	30	60	35	60		
NEM	Weight	4	5	9	8	8	3	8	9	7	432	3
	Calculated Value	40	40	72	32	80	15	48	63	42		
IBM Blockchain	Weight	6	3	8	7	8	8	9	6	5	422	4
	Calculated Value	60	24	64	28	80	40	54	42	30		

A—Community availability/learning material/level of support, B—Cost, C—Language and ease of use, D—Performance, E—Permissioned network, F—History and reputation in the industry, G—Security, H—Supports API, I—Updates or release of versions.

4. The Proof of Concept

4.1. The Business Scenario

In NSW, buyers and sellers transfer property ownership digitally by employing the services of real estate agents and registered lawyers or conveyancers [63]. Property titles are stored by the NSW Land Registry Services (NSW LRS) in a centralised land registry. Searches on title and street address, land value, historical data, and so on, are freely available through the NSW LRS online portal. Authorised information brokers provide detailed information related to land and property for a fee [64].

The typical process of property transactions in NSW is detailed as follows, and is illustrated in Figure 4. A person who wishes to sell property ("seller") will contact a real estate agent ("agent"), who will list the property to find prospective buyers [5,65]. The seller will also engage a lawyer to handle the property transaction process. A property buyer will search for properties that match their requirements, and inspect properties on sale. When the buyer identifies a suitable property, the buyer should pay the agent a fee to reserve the property. The buyer will then engage a lawyer to carry out the property transaction. The buyer also has to arrange finances with their bank. The buyer's bank will assign an assessor to verify the market value of the property. A title search will be conducted by the buyer's lawyer through an information broker to ensure that the land being sold is legitimately owned by the seller. Information such as council and water rate adjustments, land type, sewerage line clearance, flood zone, and bushfire prone area, are also queried through the relevant government authorities [64]. Once all the checks have taken place, the buyer pays a deposit to the agent. The seller's lawyer prepares the contract, which is checked by the buyer's lawyer, and the buyer and seller sign the contract. When the mortgage is approved by the buyer's bank, a pre-settlement inspection will be conducted by the buyer or the buyer's lawyer. The final payment is made to the seller's lawyer, who will prepare the documentation to transfer the property title to the buyer, and register the title with the land registry [66,67]. The buyer's lawyer arranges the payment of transfer (stamp) duty to the revenue department, if applicable [68]. The buyer's lawyer will claim all expenses incurred from the buyer. The seller's lawyer will pay the agent, make other deductions, and transfer the payment to the seller.

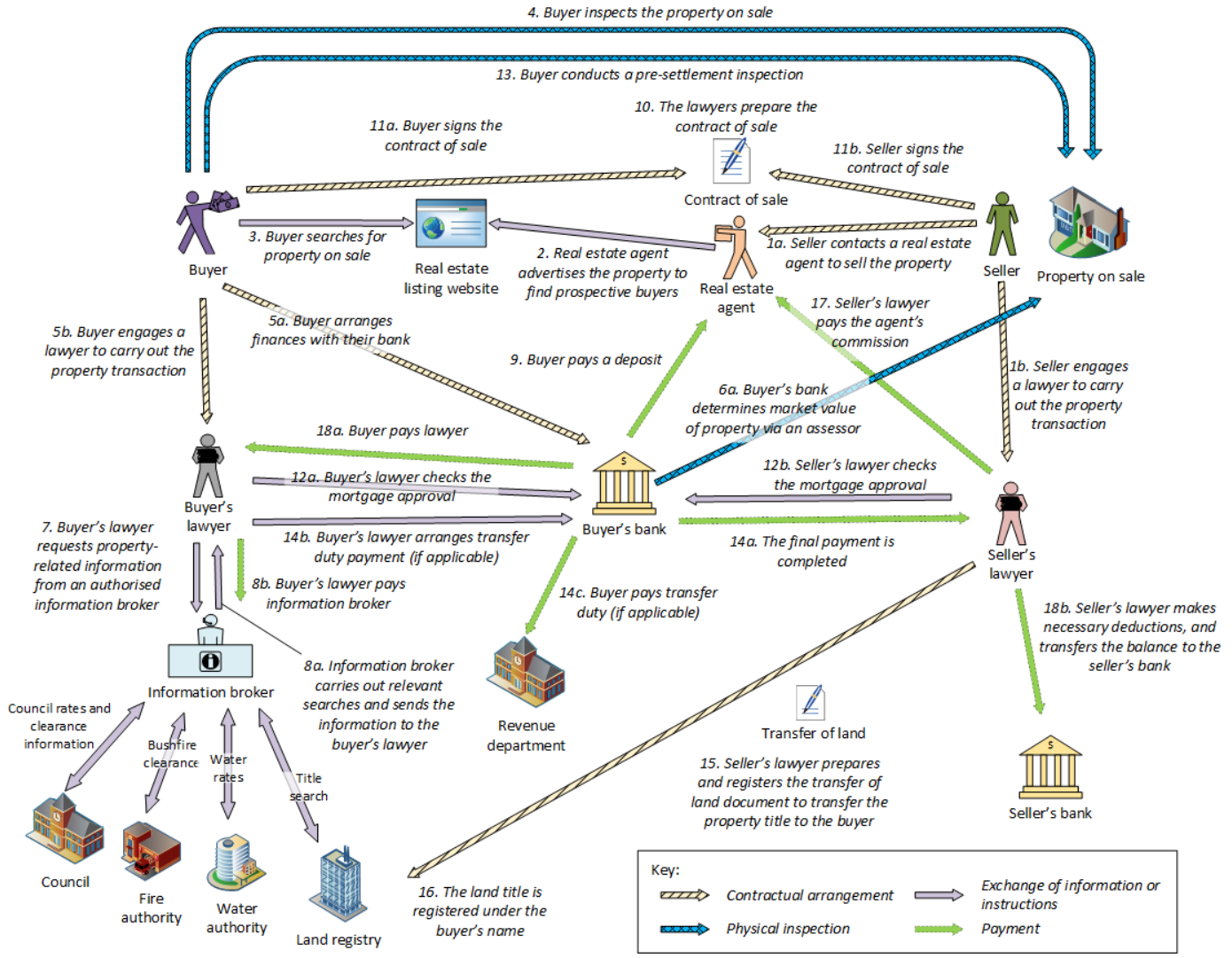

Figure 4. Current process for property transactions.

As seen in Figure 4, this existing process for property transactions is complex, time-consuming, and costly, since many intermediaries are involved. Furthermore, issues such as lack of transparency and data fragmentation are also present. To overcome these issues, a blockchain system architecture that facilitates a simplified, lean property transaction process through Hyperledger Fabric chaincode (smart contracts) and graphical user interfaces is introduced in the following sub-sections.

4.2. System Overview

Registered users of the blockchain system can view details of all properties that they own, advertise their own property to be sold on the land market, search for properties advertised on the market, perform a title search of properties on sale, view the transaction history of their own property or any property on sale, initiate a sale after negotiating with a buyer, and purchase the property once the sale has been initiated by the seller. Clearance information related to the property, such as council and water rates, sewerage line clearance, flood risk and so on, is proposed to be retrieved through chaincode (smart contracts) that will connect to the databases of relevant authorities that provide such information. It is also proposed that property transactions within the system can be performed through exchanging a fiat-collateralised stable cryptocurrency. The detailed operation of the land registry has not been modelled in this prototype, but is indicated here as a requirement

to showcase the possibility of the involvement of multiple agencies and stakeholders. The system features are summarised within the use case diagram in Figure 5. When compared to Figure 4, it is apparent that there are significantly less types of participants in the transaction process. The blockchain system will play the role of intermediaries such as real estate agents, lawyers, and information brokers, and automate the transactions as described in the next section.

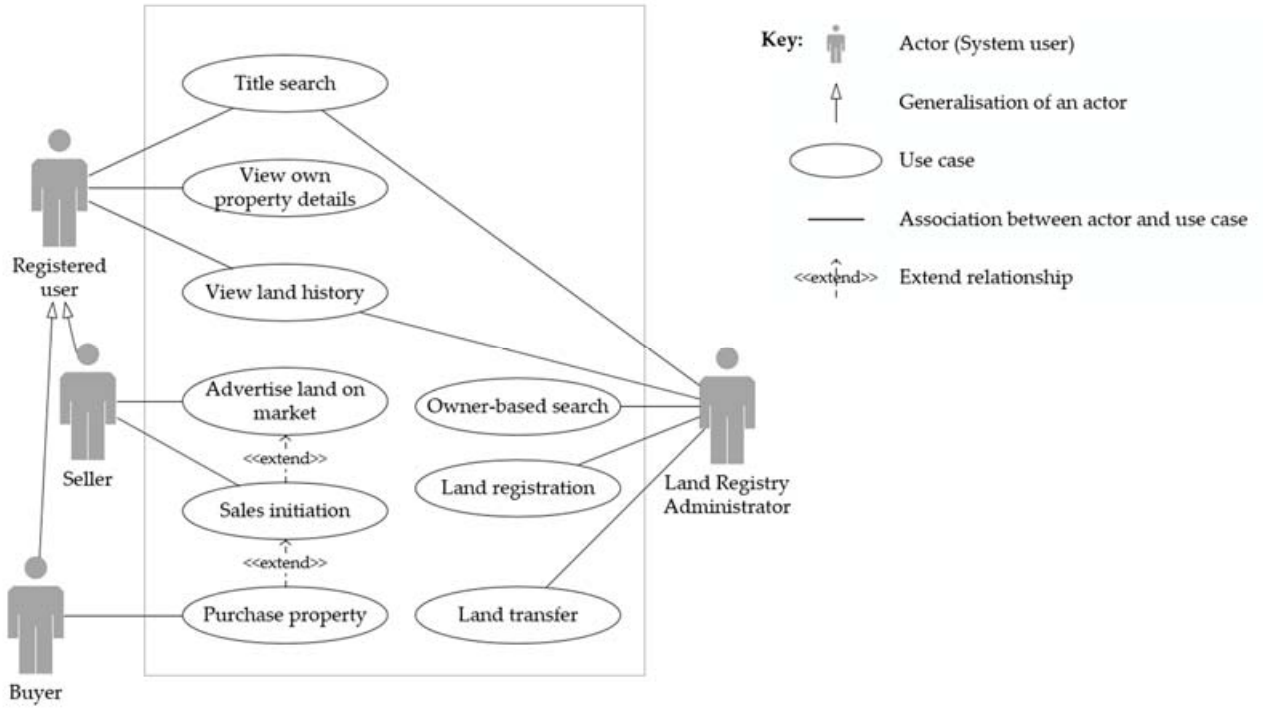

Figure 5. Use case diagram for property transactions.

4.3. System Architecture

This section presents an overview of the system architecture, which is illustrated in Figure 6. The system processes are described using Hyperledger Fabric terminology, and the function of the key terms are summarised in Table 3. The prototype has three main components, namely, the web application for property transactions, the blockchain network, and external chaincodes. The web application (client) provides the graphical user interface for all authorised users to interact with the blockchain network. The blockchain network connects the peers that hold a copy of the ledger and internal chaincode, and the ordering service. The external chaincodes represent processing within external organisations, such as city councils and banks. The client application and the blockchain system are connected through the Hyperledger Fabric Software Development Kit (HLF SDK) Application Programming Interface (API). Authorised users of the system can perform search queries or carry out transactions through the client application, as described in Section 4.2. The client application will connect to the blockchain network and invoke the internal chaincode, which contains the application logic for property transactions, to read or write data from the ledger. The numbers in the following description correspond to the numbering in Figure 6. (1) The command to invoke the chaincode is known as a transaction proposal, which is sent by the client application to the endorsing peers on the blockchain network. (2) The endorsing peers verify the transaction proposal and execute it by invoking the chaincode. (3) This system proposes the use of external chaincodes to obtain relevant data from government authorities, which are called by the internal chaincode when required. (4) The external chaincodes run the application logic and send the responses back to the internal chaincode. (5) The endorsing peers create a proposal response including the

transaction results and peer's signature and send it to the client application. (6) The client application verifies the peer signatures and compares the responses. If the transaction proposal was only a query, the process ends by displaying the result to the user. (7) If a ledger update is required, the client application packages the transaction proposal and endorsed responses into a transaction, and broadcasts it to the ordering service. (8) The ordering service receives transactions from the entire network, orders the transactions, and creates a block of transactions. (9) The ordering service transmits the block to the leading peer, (10) which then distributes the block to all the other peers. (11) The peers validate the transactions within the block and tag the transactions as valid or invalid. If the transaction is valid, then the world state is updated, whereas all valid and invalid transactions are added to the blockchain, which ensures auditability. (12) Finally, the peers emit an event to notify the client about the transaction being valid or invalid, and that it has been added to the blockchain, and the result is displayed to the user [69].

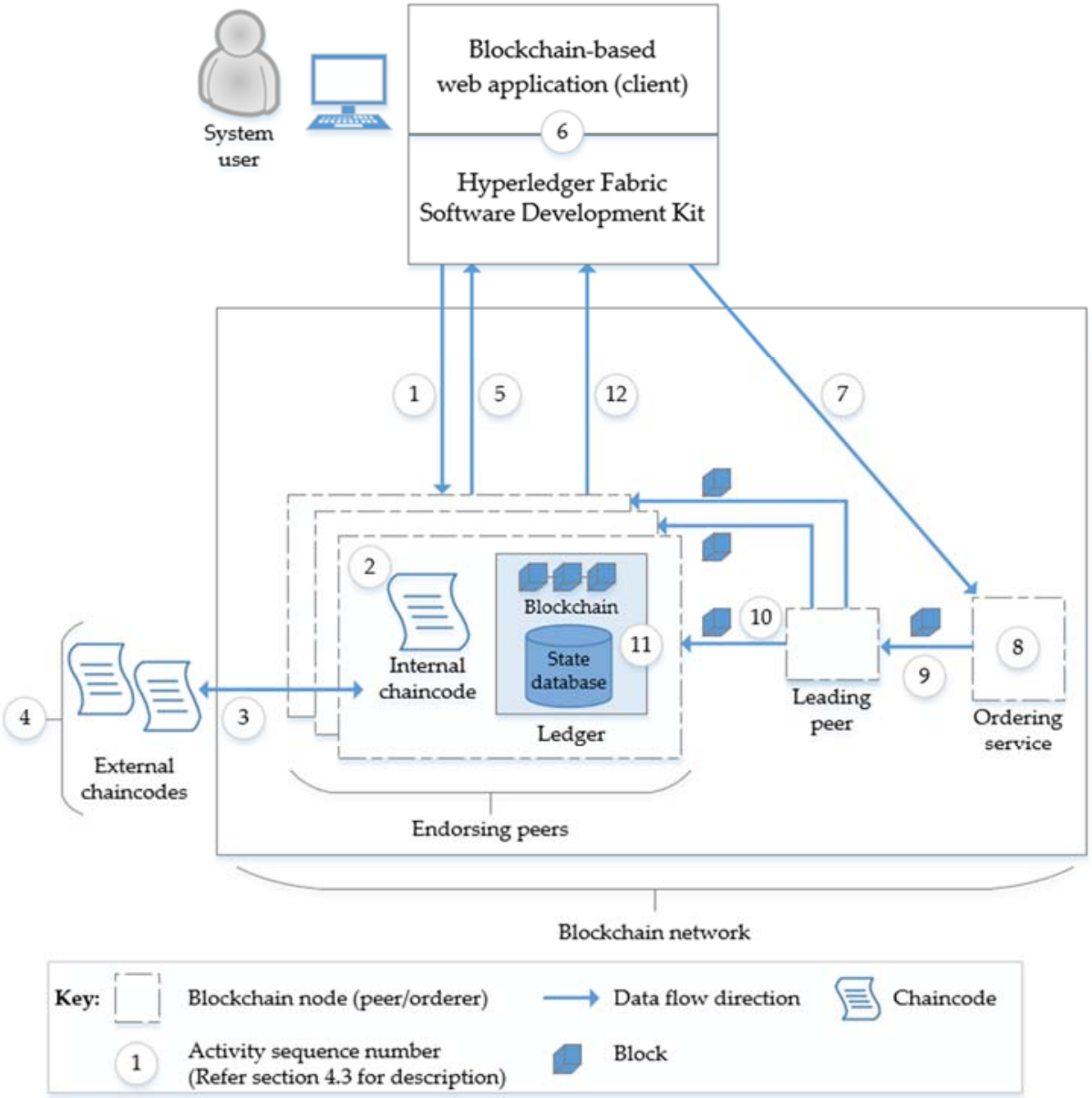

Figure 6. System architecture for the blockchain prototype.

Table 3. The function of Hyperledger Fabric within the prototype.

Term	Description
Ledger	An immutable and sequenced record of all transactions within the prototype. The ledger consists of a blockchain and world state [70].
Blockchain	Consists of blocks, with a sequence of transactions, that are cryptographically linked together [70]. The blockchain will be stored in the file system of each peer connected to the prototype.
World state	Represents the latest values for all keys in the transaction log of the blockchain. A state database is used to store world state data, such as LevelDB and CouchDB. LevelDB is the default state database which stores chaincode data as key-value pairs. Chaincode data is modelled as JSON (JavaScript Object Notation) in CouchDB [70]. This prototype implementation used CouchDB as it allows rich queries of the JSON content.
Chaincode (Smart contract)	Program code installed on peers that implements the application logic, which is invoked by external client applications [70]. The prototype includes internal chaincode for property transactions and external chaincodes to simulate the functionality of connecting to external databases.
Client	An application external to the blockchain network that connects to the network to perform business transactions [70]. All authorised users of the prototype will access the blockchain through the graphical user interfaces in the client application.
Peer	An entity on the blockchain network that maintains the ledger. A subset of peers called *endorsing peers* run chaincode to execute transaction proposals. A *leading peer* communicates with the ordering service and distributes blocks to peers when blocks are received from the ordering service [70]. All peers in the prototype have been defined as endorsing peers.
Ordering service (Orderer)	Performs ordering of transactions into a block and distributes the blocks to connected leading peers. Orderers do not execute or validate transactions [70]. The prototype contains a single ordering service node.

4.4. System Implementation

The process sequence for a successful property transaction within the blockchain prototype, starting from the point a seller advertises a property to the completion of the fund transfer and the consequent update of the blockchain regarding the land title transfer, is illustrated in Figure 7. The interactions between the web application and HLF SDK were omitted from the figure for simplicity; these processes would take place between the internal chaincode and the buyer/seller. Unsuccessful queries and updates are also handled by the prototype, although these processes have not been depicted in the figure for the sake of readability.

The internal chaincode contains all the application logic related to property transactions that were presented in Section 4.2. The external chaincodes would be installed at the government authorities, such as local councils and water authorities, which would be queried through the system to check property title clearance information. Connecting these authorities to the system would reduce the number of intermediaries involved, and decrease the time taken to perform the clearance checks for a given property title, compared to the current process. The study also proposes the use of a fiat-collateralised stable cryptocurrency ("C-AUD") backed by the Reserve Bank of Australia to pay for property transactions. This cryptocurrency will be equal to the Australian Dollar, and there is no price volatility against fiat currency. The bank chaincode contains the logic of checking the cryptocurrency balance of a buyer, and transferring funds from the buyer's account to the seller's account and the transfer duty to the NSW revenue department.

The blockchain prototype uses the Go programming language for the chaincode, Node.js for the web application, and the HLF SDK for Node.js to create the link between the web application and the blockchain network. Go files are written for each chaincode in the system, and contain the instructions to run the blockchain query and update functions.

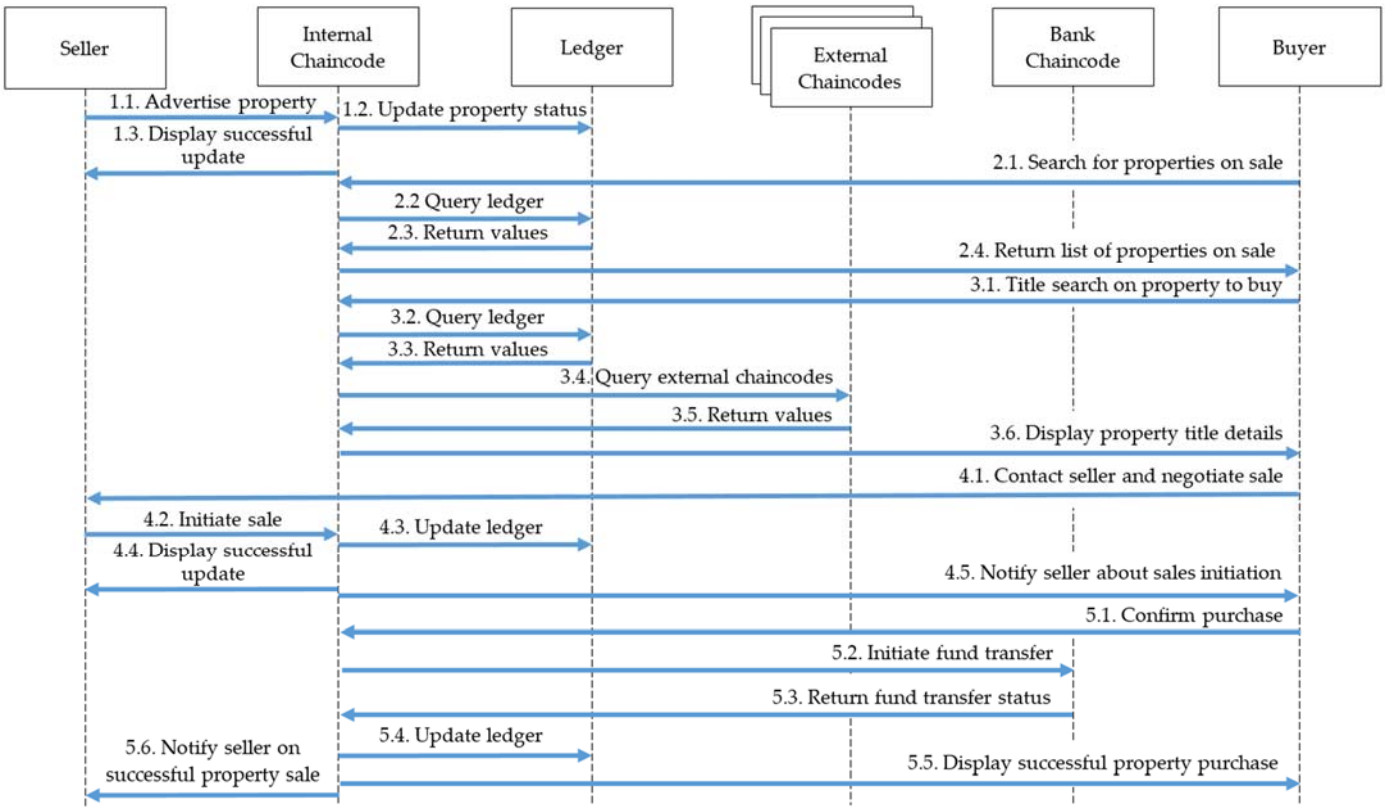

Figure 7. Process sequence for a successful property transaction through the blockchain prototype.

The Hyperledger Explorer tool was configured to be used with the prototype so that the blockchain network administrator can view the blocks, transactions, chaincodes, and other relevant information within the blockchain network. Figure 8 presents a view of the details of a transaction within a particular block using Hyperledger Explorer.

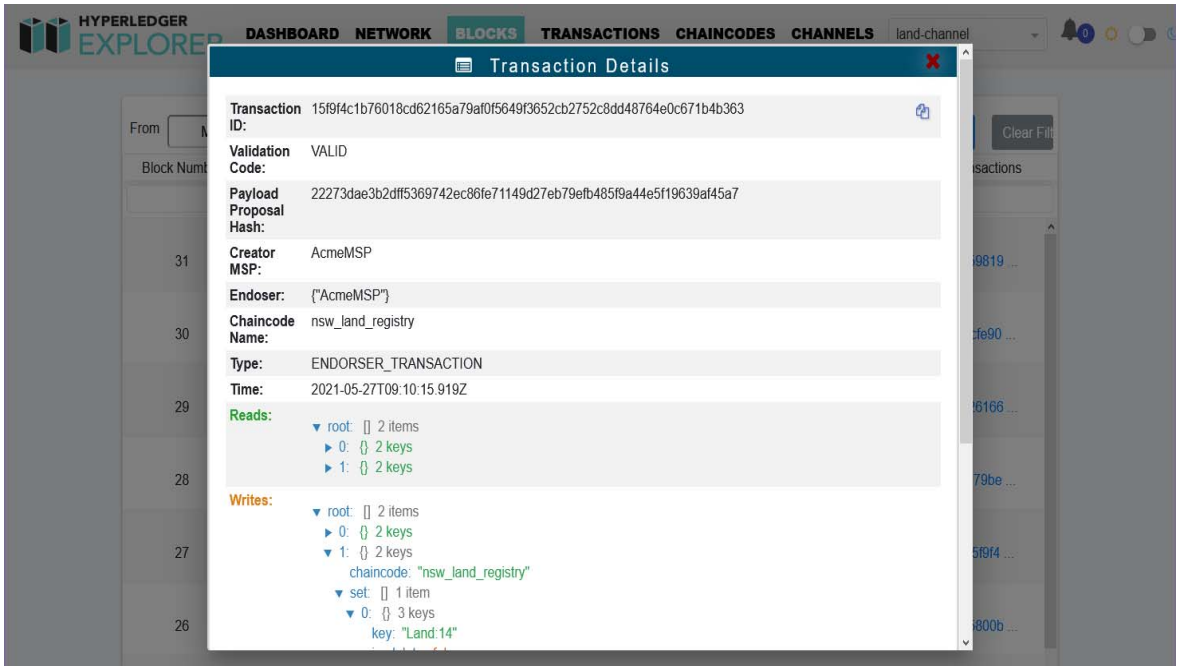

Figure 8. Viewing transaction details in a block through the Hyperledger Explorer tool.

The prototype allows authorised land registry administration to search for land titles, and view land ownership details and transaction history of land titles (Figure 9). Members of the general public will have to register their identity on the blockchain platform using a recognised identification document in order to use the system. Once logged into the system, they can view the details of all properties they own. A prospective seller can advertise their property on the market by listing its selling price, and a prospective buyer can search for properties that are on sale by providing the address, or the name of the street or city, or view all properties on sale (Figure 10). A prospective buyer can perform a title search of the property on sale in order to verify the legitimacy of the sale, and view all clearance information. If satisfied with the land details, the prospective buyer will contact the seller and negotiate the sale of land. When the negotiation is complete, the seller can initiate the sale through the system, and the buyer can purchase the property. The buyers and sellers can view the status of the transactions at any time during the process, which also includes the block details (Figure 11).

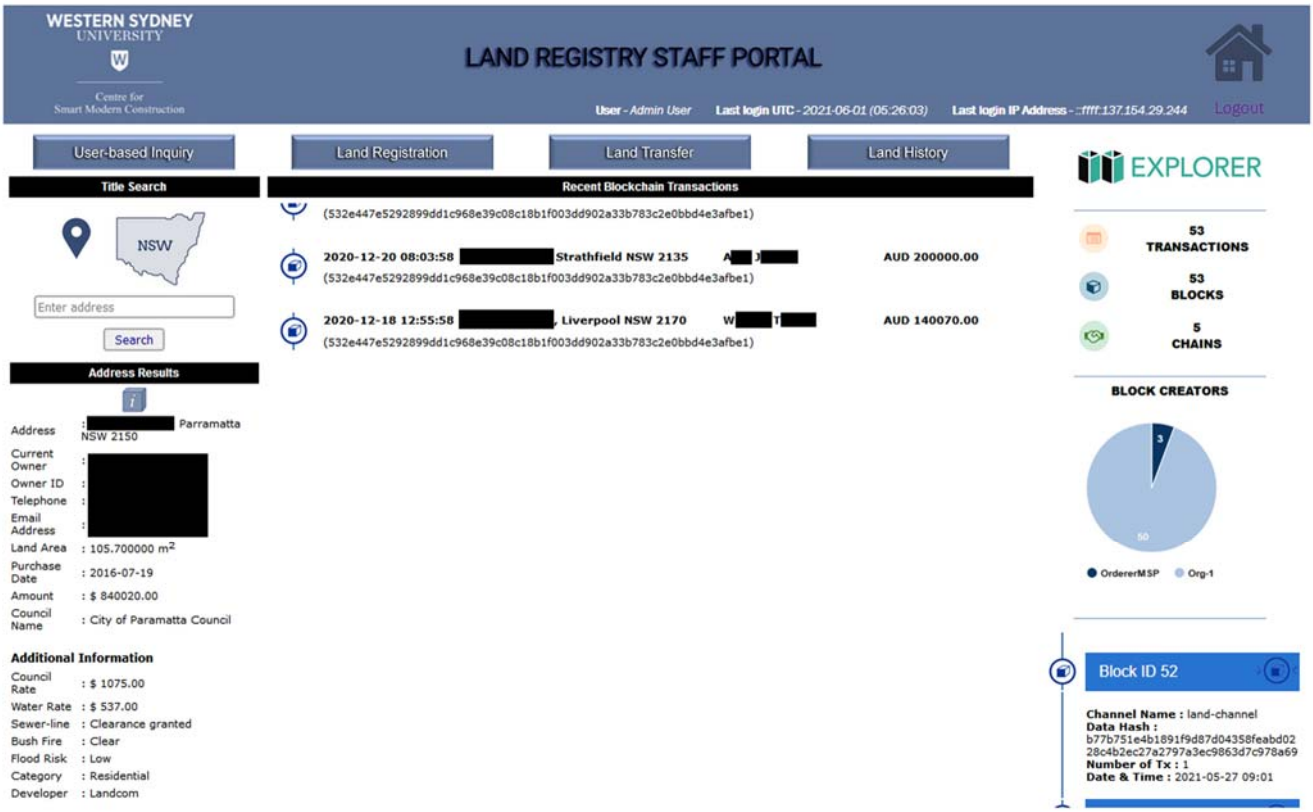

Figure 9. Output of title search blockchain query function available for land registry administration.

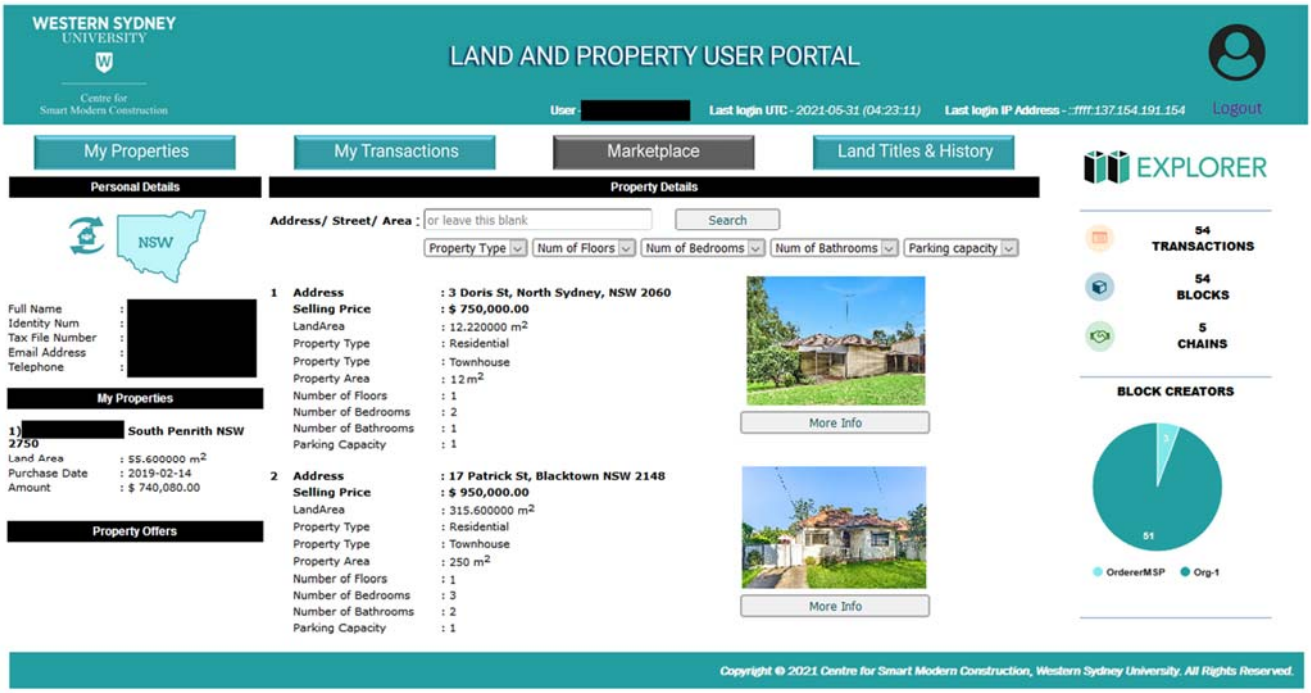

Figure 10. Viewing property on sale in the marketplace.

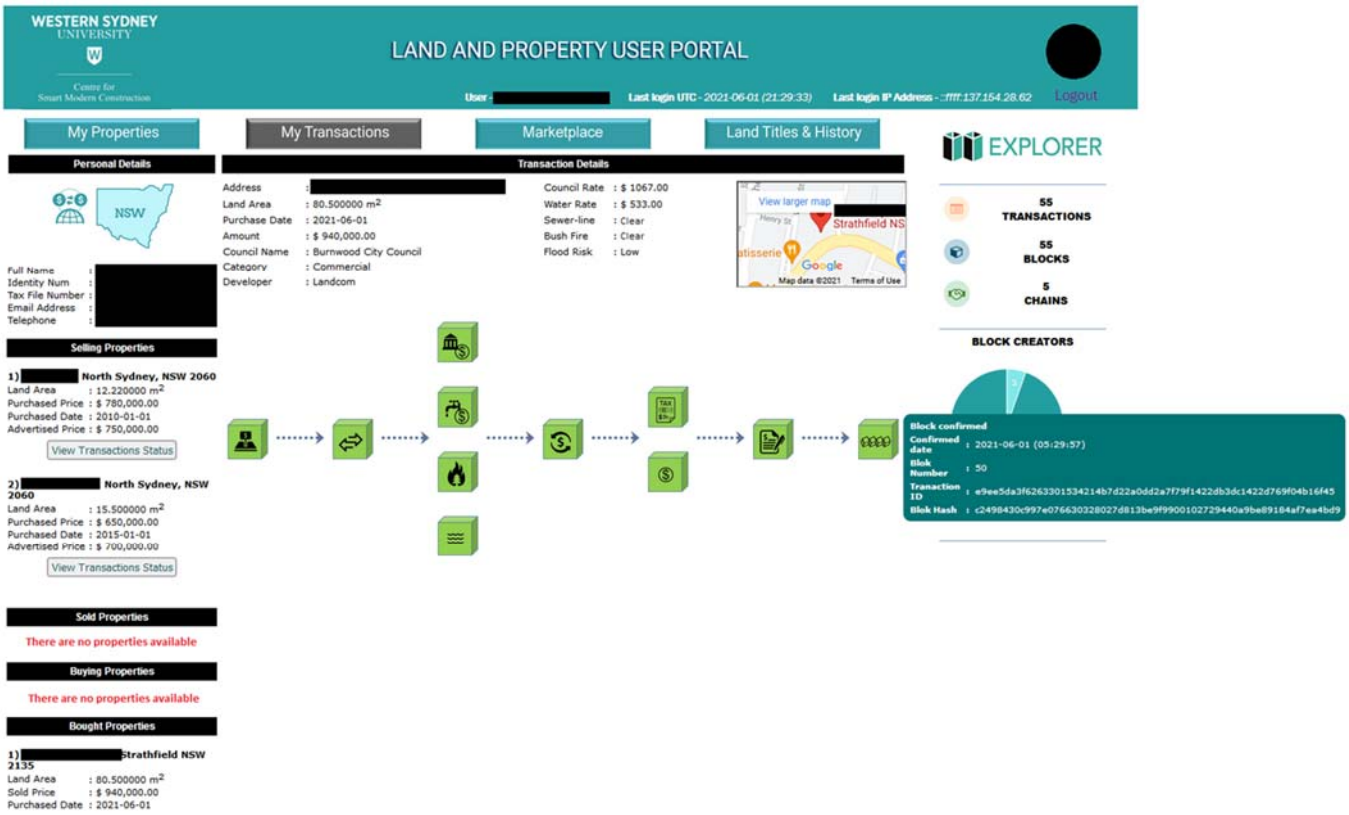

Figure 11. Transaction status view for a property buyer.

4.5. System Evaluation

The blockchain prototype was comprehensively evaluated by the authors to ensure methodological reliability and the accurate execution of smart contracts. The evaluation was conducted using test cases for each of the identified system requirements presented in

Figure 5. A test case scenario for property search in the marketplace using advanced search criteria, such as specifying the property type, number of bedrooms, and so on, is provided in Table 4 as an example. In this scenario, only a blockchain query will be performed, and the blockchain will not be updated. A blockchain update is performed in instances such as confirming the sale of the property. Then, the test cases would also check whether a new block is added, and its details are displayed on the sidebar, and if the number of blocks and transactions are updated on the sidebar. Improvements to the prototype were added iteratively until there were no failures of test cases. The final prototype fulfils all the system requirements, and provides an incubation-ready proof of concept for blockchain-based trusted property transactions. An external validation of the system would be required if the prototype is developed into a minimum viable product that is industry-ready.

Table 4. Example test case scenario.

Test Scenario ID		Property Search–3		**Test Case ID**	Property Search–3A
Test Case Description		User searches for property on sale with advanced search criteria		**Test Priority**	High
Pre-Requisite		Successful login to the user portal		**Post-Requisite**	N/A
Test Execution Steps:					
S. No	**Action**	**Inputs**	**Expected Output**	**Actual Output**	**Test Result**
1	Go to Marketplace page	http://landblocks.online/marketplace	Marketplace page	Marketplace page	Pass
2	Input advanced search criteria and click the Search button	City: Penrith Property Type: Townhouse Number of bedrooms: 2 Parking capacity: 2	Display all properties on sale in Penrith with type Townhouse, 2 bedrooms, and parking capacity of 2.	Display all properties on sale in Penrith with type Townhouse, 2 bedrooms, and parking capacity of 2.	Pass

5. Discussion

Blockchain has been proposed as a solution for many transaction-oriented domains. However, its implementation is novel and challenging. Unlike traditional software solutions, it requires a solution based on a full ecosystem. Therefore, development of blockchain solutions for application domains are complicated, and require further research. This research attempted to demonstrate the process of development of a blockchain prototype, taking property transactions as the use case. Maintaining property transaction records on a blockchain will potentially accelerate a shift in the work environment to a transparent and cooperative chain of transactions by assuring the accountability and consistency of data over the entire life cycle, including storing, processing, and retrieving data, leading to data integrity [31,39,71]. The Ethereum platform is still being considered in most use cases in the property sector [3]. However, Hyperledger Fabric was strongly recommended, as it will address the privacy issue of Ethereum, ensure accountability of network participants, and support various applications, as it has modular and pluggable components to satisfy a broad range of industry use cases [6,39,53].

The developed prototype provides a tangible proof of concept for the application of blockchain for property transactions, providing the benefits of blockchain including increased data integrity, transparency of transactions, and increased trust related to property transactions. The proposed connecting of relevant government authorities to the blockchain system through external chaincodes is expected to reduce the number of intermediaries involved, and the time taken for clearance checking. This prototype also differs from other existing and proof of concept property transaction systems through the proposed integration of a fiat-collateralised stable cryptocurrency. This is expected to help ensure trust in the system in its initial stages, rather than by enabling transactions through volatile cryptocurrencies. Future iterations of the system may provide the capability of transacting through alternative payment media mutually agreed upon by buyers and sellers. Currently,

these two features require further development due to the limitations discussed below. Furthermore, connecting these external organisations would require integrating disparate systems and ensuring proper data transfer among the systems.

The operation of the blockchain was tested by entering test data for multiple test cases through the graphical user interface. The graphical user interface was created to shield the complexity of the blockchain from a general user of the system; all the blockchain operations occur in the backend of the system, and are not visible to a typical user. However, the Hyperledger Explorer tool within the prototype enables a system administrator to graphically view the operation of the blockchain, and verify blocks, data, and transactions within the blockchain.

The intention of this software prototype is to showcase the potential of a blockchain solution for property transactions in the built environment. Therefore, the prototype has a few limitations, as follows. If users wish to use the blockchain system, they will have to register their identity on the blockchain platform and be provided with login credentials. The user registration process is not covered within the current scope of this prototype. Linking users' bank details to the system would also be part of the user registration process, and is not handled currently. Therefore, user details are represented within the prototype by manually inserting sample data. The prototype demonstrates the capability of connecting the system to external government organisations in order to query required information, by calling external chaincodes through the main chaincode. However, developing the actual data processing code for these external organisations is not within the scope of the prototype, and is only simulated through sample functions within the external chaincode. Furthermore, the property title details would need to be integrated with existing governmental systems in order to ensure proper regulation. The subsequent property transactions could be facilitated by developing the system as an enterprise blockchain system with an appropriate financial model for it to be commercially viable. The proposed system has eliminated most of the intermediaries involved in the property transaction process. However, it is acknowledged that the involvement of lawyers may be required to maintain the legality of transactions.

Apart from the limitations of the proposed software prototype in this research, adoption of blockchain is going beyond just a new technology solution to a digital transformation of the current business model [31], and that will require involvement of all relevant stakeholders as part of this solution, such as legal professionals [52,55], to set a new regulatory standard and define new liability rules, which are not easy to establish. It would also entail transferring the vast amount of existing property title data to the new system, which would involve high costs in terms of time and effort. Given this, the challenges also include buy-in from the participants, as it is hard to conceive complete protection of consumers in a business-to-consumer relationship that bypasses intermediaries [55,72], a lack of specialised expertise required for this adoption [1], and the cost of this adoption [1,51].

6. Conclusions

This paper illustrates the potential of blockchain in the built environment. It uses property transactions as a use case in demonstrating the development of a blockchain system in a step-by-step, systematic approach. Adopting blockchain technology will create and maintain a clear audit trail of actions that will help to minimise the possibility of the records being tampered with by facilitating the litigation proceedings as they arise. Trustworthy and immutable records are essential for establishing ownership of property titles in the built environment. Blockchain will enable the adoption of a smart contract to optimise contract formulation and negotiation, while transaction ordering through a consensus service will ensure immutability mechanisms for the transfer or creation of value, and transaction validation through a membership service will create trust in trustless environments to enhance auditability and its accountability, while automating the execution of the contract.

The prototyping model of evolutionary prototyping was selected as the software development methodology for the proposed system. The SMART method was used due to the relative simplicity of application to assist accurate decision-making to identify the most suitable blockchain platform for the prototype. Hyperledger Fabric, through the development of a prototype, was strongly recommended as a permissioned blockchain platform to satisfy the requirements of privacy of sensitive data, trust, and traceability, which can be desirable for a broad range of industry use cases, including property transactions in the built environment. This study has achieved its aim by understanding the mechanism of the Hyperledger Fabric blockchain platform, and developing a prototype proof of concept that enables trusted property transactions. The blockchain prototype was comprehensively evaluated by the authors to ensure methodological reliability and the accurate execution of smart contracts. The prototype includes functionality for land registry administrators and users of the general public who wish to buy and sell properties. It facilitates execution of smart contracts for property transactions through chaincodes. It also enhances trust in the network by identifying authorised users, and ensuring transactions are validated and propagated through the blockchain network. The proposed system will eliminate the need for many intermediary service providers by connecting users directly with relevant information sources, thereby reducing the time taken for property transactions. This system has been included as a use case for land and property management in the official Hyperledger wiki [73]. Future research development requires a comprehensive analysis of the problem domain that involves the whole property transaction ecosystem. Modelling of the relevant domain is an essential precursor to the development of any blockchain system. The authors envision that the business case for the adoption must remain the focus while technology overcomes the temporary barriers of reliability, traceability, and interoperability. Finally, the findings provide the foundation for developing proofs of concept for other potential applications of blockchain in the built environment.

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References

1. Thakur, V.; Doja, M.; Dwivedi, Y.K.; Ahmad, T.; Khadanga, G. Land records on blockchain for implementation of land titling in India. *Int. J. Inf. Manag.* **2020**, *52*, 101940. [CrossRef]
2. Vadgama, N. *Distributed Ledger Technology in the Supply Chain*; UCL Centre for Blockchain Technologies: London, UK, 2019.
3. FIBREE. *Global Industry Report "Blockchain Real Estate"*; FIBREE: Vienna, Austria, 2020.
4. Niranjanamurthy, M.; Nithya, B.; Jagannatha, S. Analysis of blockchain technology: Pros, cons and SWOT. *Clust. Comput.* **2019**, *22*, 14743–14757. [CrossRef]
5. Davies, E.; Kirby, N.; Bond, J.; Grogan, T.; Moore, A.; Roche, N.; Rose, A.; Tasca, P.; Vadgama, N. *Towards a Distributed Ledger of Residential Title Deeds in the UK*; University College London: London, UK, 2020.
6. Perera, S.; Nanayakkara, S.; Rodrigo, M.; Senaratne, S.; Weinand, R. Blockchain technology: Is it hype or real in the construction industry? *J. Ind. Inf. Integr.* **2020**, *17*, 100125. [CrossRef]
7. Hewavitharana, T.; Nanayakkara, S.; Perera, S. Blockchain as a project management platform. In Proceedings of the 8th World Construction Symposium: Towards a Smart, Sustainable and Resilient Built Environment, Colombo, Sri Lanka, 8–10 November 2019; pp. 137–146.
8. Rodrigo, M.N.N.; Perera, S.; Senaratne, S.; Jin, X. Potential application of blockchain technology for embodied carbon estimating in construction supply chains. *Buildings* **2020**, *10*, 140. [CrossRef]

9. Paulavičius, R.; Grigaitis, S.; Igumenov, A.; Filatovas, E. A decade of blockchain: Review of the current status, challenges, and future directions. *Informatica* **2019**, *30*, 729–748. [CrossRef]
10. Yli-Huumo, J.; Ko, D.; Choi, S.; Park, S.; Smolander, K. Where is current research on blockchain technology?—A systematic review. *PLoS ONE* **2016**, *11*, e0163477.
11. Hijazi, A.A.; Perera, S.; Alashwal, A.; Calheiros, R.N. Blockchain adoption in construction supply chain: A review of studies across multiple sectors. In Proceedings of the International Council for Research and Innovation in Building and Construction (CIB) World Building Congress—Constructing Smart Cities, Hong Kong, China, 17–21 June 2019.
12. Li, J.; Greenwood, D.; Kassem, M. Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Autom. Constr.* **2019**, *102*, 288–307. [CrossRef]
13. Hijazi, A.A.; Perera, S.; Calheiros, R.N.; Alashwal, A. Rationale for the integration of BIM and blockchain for the construction supply chain data delivery: A systematic literature review and validation through focus group. *J. Constr. Eng. Manag.* **2021**, *147*, 03121005. [CrossRef]
14. Institution of Civil Engineers. *Blockchain Technology in the Construction Industry: Digital Transformation for High Productivity*; Institution of Civil Engineers: London, UK, 2018.
15. Belotti, M.; Božić, N.; Pujolle, G.; Secci, S. A vademecum on blockchain technologies: When, which, and how. *IEEE Commun. Surv. Tutor.* **2019**, *21*, 3796–3838. [CrossRef]
16. Singh, S.K.; Sharma, P.K.; Pan, Y.; Park, J.H. BIIoVT: Blockchain-based secure storage architecture for intelligent internet of vehicular things. *IEEE Consum. Electron. Mag.* **2021**. [CrossRef]
17. Bordel, B.; Alcarria, R.; Martin, D.; Sanchez-Picot, A. Trust provision in the internet of things using transversal blockchain networks. *Intell. Autom. Soft Comput.* **2019**, *25*, 155–170. [CrossRef]
18. Ølnes, S.; Ubacht, J.; Janssen, M. Blockchain in government: Benefits and implications of distributed ledger technology for information sharing. *Gov. Inf. Q.* **2017**, *34*, 355–364. [CrossRef]
19. Lemieux, V.L. Evaluating the use of blockchain in land transactions: An archival science perspective. *Eur. Prop. Law J.* **2017**, *6*, 392–440. [CrossRef]
20. Graglia, J.M.; Mellon, C. Blockchain and property in 2018: At the end of the beginning. *Innov. Technol. Gov. Glob.* **2018**, *12*, 90–116. [CrossRef]
21. Lemieux, V.L. A typology of blockchain recordkeeping solutions and some reflections on their implications for the future of archival preservation. In Proceedings of the 2017 IEEE International Conference on Big Data, Boston, MA, USA, 11–14 December 2017; pp. 2271–2278.
22. Centre of Digital Built Britain. *Year One Report: Towards a Digital Built Britain*; Centre of Digital Built Britain: Cambridge, UK, 2018.
23. ARUP. *Blockchain and the Built Environment*; ARUP: London, UK, 2019.
24. Kinnaird, C.; Geipel, M. *Blockchain Technology: How the Inventions Behind Bitcoin are Enabling a Network of Trust for the Built Environment*; ARUP: London, UK, 2017.
25. Love, P.E.; Edwards, D.J. Forensic project management: The underlying causes of rework in construction projects. *Civ. Eng. Environ. Syst.* **2004**, *21*, 207–228. [CrossRef]
26. Bankvall, L.; Bygballe, L.E.; Dubois, A.; Jahre, M. Interdependence in supply chains and projects in construction. *Supply Chain Manag. Int. J.* **2010**, *15*, 385–393. [CrossRef]
27. Thunberg, M. Developing a Framework for Supply Chain Planning in Construction. Ph.D. Thesis, Linköping University, Linköping, Sweden, 2016.
28. Cha, J.; Singh, S.K.; Pan, Y.; Park, J.H. Blockchain-based cyber threat intelligence system architecture for sustainable computing. *Sustainability* **2020**, *12*, 6401. [CrossRef]
29. FIBREE. *Global Industry Report "Blockchain Real Estate"*; FIBREE: Berlin, Germany, 2021.
30. Deng, Z.; Ren, Y.; Liu, Y.; Yin, X.; Shen, Z.; Kim, H.-J. Blockchain-based trusted electronic records preservation in cloud storage. *Comput. Mater. Contin.* **2019**, *58*, 135–151. [CrossRef]
31. Veuger, J. Dutch blockchain, real estate and land registration. *J. Prop. Plan. Environ. Law* **2020**, *12*, 93–108. [CrossRef]
32. McNamara, A.J.; Sepasgozar, S.M. Developing a theoretical framework for intelligent contract acceptance. *Constr. Innov.* **2020**, *20*, 421–445. [CrossRef]
33. Mason, J.; Escott, H. Smart contracts in construction: Views and perceptions of stakeholders. In Proceedings of the FIG Conference, Istanbul, Turkey, 6–11 May 2018.
34. Nanayakkara, S.; Perera, S.; Bandara, H.D.; Weerasuriya, G.T.; Ayoub, J. Blockchain technology and its potential for the construction industry. In Proceedings of the 43rd Australasian Universities Building Education Association (AUBEA) Conference: Built to Thrive: Creating Buildings and Cities that Support Individual Well-Being and Community Prosperity, Noosa, QLD, Australia, 6–8 November 2019; pp. 662–672.
35. Drescher, D. *Blockchain Basics: A Non-Technical Introduction in 25 Steps*, 1st ed.; Apress: Frankfurt am Main, Germany, 2017.
36. Androulaki, E.; Barger, A.; Bortnikov, V.; Cachin, C.; Christidis, K.; De Caro, A.; Enyeart, D.; Ferris, C.; Laventman, G.; Manevich, Y. Hyperledger fabric: A distributed operating system for permissioned blockchains. In Proceedings of the 13th EuroSys Conference, Porto, Portugal, 23–26 April 2018; pp. 1–15.
37. Hyperledger. Hyperledger Fabric. Available online: https://hyperledger-fabric.readthedocs.io/en/release-2.0/whatis.html (accessed on 26 June 2020).

38. Cocco, S.; Singh, G. Top 6 Technical Advantages of Hyperledger Fabric for Blockchain Networks. Available online: https://developer.ibm.com/technologies/blockchain/articles/top-technical-advantages-of-hyperledger-fabric-for-blockchain-networks/ (accessed on 28 July 2020).
39. Nawari, N.O. Blockchain technologies: Hyperledger fabric in BIM work processes. In Proceedings of the International Conference on Computing in Civil and Building Engineering, Melbourne, VIC, Australia, 3–4 February 2020; pp. 813–823.
40. Kundu, D. Blockchain and trust in a smart city. *Environ. Urban. ASIA* **2019**, *10*, 31–43. [CrossRef]
41. Catalini, C.; Gans, J.S. *Initial Coin Offerings and the Value of Crypto Tokens*; National Bureau of Economic Research: Cambridge, MA, USA, 2018.
42. Lemieux, V.L. Blockchain and distributed ledgers as trusted recordkeeping systems. In Proceedings of the Future Technologies Conference (FTC), Vancouver, BC, Canada, 29–30 November 2017.
43. Rodrigo, M.; Perera, S.; Senaratne, S.; Jin, X. Blockchain for construction supply chains: A literature synthesis. In Proceedings of the ICEC-PAQS Conference, Sydney, NSW, Australia, 18–20 November 2018.
44. Hijazi, A.A.; Perera, S.; Alashwal, A.; Calheiros, R.N. Enabling a single source of truth through BIM and blockchain integration. In Proceedings of the International Conference on Innovation, Technology, Enterprise and Entrepreneurship (ICITEE), Manama, Bahrain, 24–25 November 2019; pp. 385–393.
45. Nanayakkara, S.; Perera, S.; Senaratne, S. Stakeholders' perspective on blockchain and smart contracts solutions for construction supply chains. In Proceedings of the CIB World Building Congress, Hong Kong, China, 17–21 June 2019.
46. Nanayakkara, S.; Perera, S.; Senaratne, S.; Weerasuriya, G.T.; Bandara, H.M.N.D. Blockchain and smart contracts: A solution for payment issues in construction supply chains. *Informatics* **2021**, *8*, 36. [CrossRef]
47. Sigalov, K.; Ye, X.; König, M.; Hagedorn, P.; Blum, F.; Severin, B.; Hettmer, M.; Hückinghaus, P.; Wölkerling, J.; Groß, D. Automated Payment and Contract Management in the Construction Industry by Integrating Building Information Modeling and Blockchain-Based Smart Contracts. *Appl. Sci.* **2021**, *11*, 7653. [CrossRef]
48. Lamb, K. *Blockchain and Smart Contracts: What the AEC Sector Needs to Know*; Centre for Digital Built Britain: Cambridge, UK, 2018.
49. Mason, J. The BIM fork—Are smart contracts in construction more likely to prosper with or without BIM? *J. Leg. Aff. Disput. Resolut. Eng. Constr.* **2019**, *11*, 02519002. [CrossRef]
50. Shergold, P.; Weir, B. *Building Confidence: Improving the Effectiveness of Compliance and Enforcement Systems for the Building and Construction Industry across Australia*; Australian Institute of Building Surveyors: Gordon, NSW, Australia, 2018.
51. Yapicioglu, B.; Leshinsky, R. Blockchain as a tool for land rights: Ownership of land in Cyprus. *J. Prop. Plan. Environ. Law* **2020**, *12*, 171–182. [CrossRef]
52. Mintah, K.; Baako, K.T.; Kavaarpuo, G.; Otchere, G.K. Skin lands in Ghana and application of blockchain technology for acquisition and title registration. *J. Prop. Plan. Environ. Law* **2020**, *12*, 147–169. [CrossRef]
53. Ranjith, V.; Sathyajith, R.; Naveen Kumar, U.; Pushpalatha, M. A performance comparison of different security hashing in a blockchain based system that enables a more reliable and SWIFT registration of land. *Int. J. Adv. Sci. Technol.* **2020**, *29*, 1-06.
54. Kaczorowska, M. Blockchain-based land registration: Possibilities and challenges. *Masaryk Univ. J. Law Technol.* **2019**, *13*, 339–360. [CrossRef]
55. Nasarre-Aznar, S. Collaborative housing and blockchain. *Administration* **2018**, *66*, 59–82. [CrossRef]
56. Sajana, P.; Sindhu, M.; Sethumadhavan, M. On blockchain applications: Hyperledger fabric and Ethereum. *Int. J. Pure Appl. Math.* **2018**, *118*, 2965–2970.
57. Cachin, C. Architecture of the hyperledger blockchain fabric. In Proceedings of the Workshop on Distributed Cryptocurrencies and Consensus Ledgers, Chicago, IL, USA, 25 July 2016.
58. FIBREE. *Global Industry Report "Blockchain Real Estate"*; FIBREE: Paris, France, 2019.
59. Sherrell, L. Evolutionary prototyping. In *Encyclopedia of Sciences and Religions*; Runehov, A.L.C., Oviedo, L., Eds.; Springer: Dordrecht, The Netherlands, 2013; p. 803.
60. Rodrigo, M.N.N.; Perera, S.; Senaratne, S.; Jin, X. Systematic development of a data model for the blockchain-based embodied carbon (BEC) estimator for construction. *Eng. Constr. Archit. Manag.* **2021**. [CrossRef]
61. Nanayakkara, S.; Rodrigo, M.N.N.; Perera, S.; Weerasuriya, G.T.; Hijazi, A.A. A methodology for selection of a blockchain platform to develop an enterprise system. *J. Ind. Inf. Integr.* **2021**, *23*, 100215. [CrossRef]
62. Moges Kasie, F. Combining simple multiple attribute rating technique and analytical hierarchy process for designing multi-criteria performance measurement framework. *Glob. J. Res. Eng.* **2013**, *13*, 15–29.
63. NSW LRS. eConveyancing in NSW. Available online: https://www.nswlrs.com.au/eConveyancing (accessed on 24 June 2020).
64. NSW LRS. Find Records. Available online: https://www.nswlrs.com.au/Find-Records (accessed on 24 June 2020).
65. Australia and New Zealand Banking Group Limited (ANZ). Real Estate Agents and Property Advertising. Available online: https://www.anz.com.au/personal/home-loans/tips-and-guides/agents-and-advertising/ (accessed on 24 June 2020).
66. Shuaib, M.; Daud, S.M.; Alam, S.; Khan, W.Z. Blockchain-based framework for secure and reliable land registry system. *Telkomnika* **2020**, *18*, 2560–2571. [CrossRef]
67. Australia and New Zealand Banking Group Limited (ANZ). Property Settlement: What Is It and How Does It Work? Available online: https://www.anz.com.au/personal/home-loans/tips-and-guides/property-settlement-what-is-it-how-does-it-work/ (accessed on 24 June 2020).

68. NSW Government. Exchanging Contracts and Settlement. Available online: https://www.nsw.gov.au/life-events/living-nsw/buying-residential-property-nsw (accessed on 24 June 2020).
69. Hyperledger. Transaction Flow. Available online: https://hyperledger-fabric.readthedocs.io/en/release-2.1/txflow.html (accessed on 15 July 2020).
70. Hyperledger. Glossary. Available online: https://hyperledger-fabric.readthedocs.io/en/release-2.2/glossary.html (accessed on 15 July 2020).
71. Lemieux, V.L. Blockchain recordkeeping: A SWOT analysis. *Inf. Manag.* **2017**, *51*, 20–27.
72. Cheng, M.; Liu, G.; Xu, Y.; Chi, M. When blockchain meets the AEC industry: Present status, benefits, challenges, and future research opportunities. *Buildings* **2021**, *11*, 340. [CrossRef]
73. Hyperledger Wiki. Land and Property Management. Available online: https://wiki.hyperledger.org/display/LMDWG/Land+and+Property+Management (accessed on 20 May 2021).