land

Article

Hybrid Approaches for Smart Contracts in Land Administration: Lessons from Three Blockchain Proofs-of-Concept

Rohan Bennett [1,2,*], Todd Miller [3], Mark Pickering [1] and Al-Karim Kara [4]

[1] Swinburne Business School, Swinburne University of Technology, Hawthorn, VIC 3122, Australia; mpickering@swin.edu.au
[2] Kadaster International, Netherlands' Cadastre, Land Registry and Mapping Agency, 7311 KZ Apeldoorn, The Netherlands
[3] ChromaWay, S-111 64 Stockholm, Sweden; todd.miller@chromaway.com
[4] Land Title and Survey Authority of British Columbia, Victoria, BC V8W 9J3, Canada; Al-Karim.Kara@ltsa.ca
* Correspondence: rohanbennett@swin.edu.au

Abstract: The emergence of "blockchain" technology as an alternative data management technique has spawned a myriad of conceptual and logical design work across multiple industries and sectors. It is also argued to enable operationalisation of the earlier "smart contract" concept. The domain of land administration has actively investigated these opportunities, albeit also largely at the conceptual level, and usually with a whole-of-sector or "big bang" industry transformation perspective. Less reporting of applied case applications is evident, particularly those undertaken in collaboration with practicing land sector actors. That said, pilots and test cases continue to act as a basis for understanding the relative merits, drawbacks, and implementation challenges of the smart contract concept in land administration. In this vein, this paper extends upon and further refines the existing discourse on smart contracts within the land sector, by giving an updated, if not more nuanced, view of example applications, opportunities, and barriers. In contrast to the earlier works, a hybrid solution that mixes smart contract use with existing technology infrastructure—enabling preservation of the role of a land registry agency as the ultimate arbiter of valid claims—is proposed. This is hypothesised to minimise disruptions, whilst maximising the benefits. Examination of proof-of-concept work on smart contract and blockchain applications in Sweden, Australia (State of New South Wales), and Canada (Province of British Columbia) is undertaken. Comparative analysis is undertaken using several frameworks including: (i) business requirements adherence, (ii) technology readiness and maturity assessment, and (iii) strategic grid analysis. Results show that the hybrid approach enables adherence to land dealing business requirements and that the proofs-of-concept are a necessary step in the development trajectory. Furthering the uptake will likely depend on again taking a whole-of-sector perspective, and attending to remaining issues around business models, stakeholder acceptance, partnerships and trust building, and legal issues linked to data decentralisation and security.

Keywords: blockchain; smart contracts; land administration; land registration; cadastre; technology readiness levels; land conveyance; mortgage discharge

Citation: Bennett, R.; Miller, T.; Pickering, M.; Kara, A.-K. Hybrid Approaches for Smart Contracts in Land Administration: Lessons from Three Blockchain Proofs-of-Concept. *Land* **2021**, *10*, 220. https://doi.org/10.3390/land10020220

Academic Editor: Volker Beckmann
Received: 29 January 2021
Accepted: 17 February 2021
Published: 22 February 2021

1. Introduction

Subsequent to the initial and overly simplified hype around the potential application of blockchain technology to the domain of land administration, a more circumspect discourse on the relative merits and immediacy of its implementation is emerging [1–3]. This is not to suggest that critical assessments were not forthcoming [4], or that the overstatements have abated fully: works continue to espouse conceptual blockchain land registry designs and the imminent benefits [5–7]. That said, such conceptual works appear to be fewer in number, and the level of attention apportioned them is more aligned to the depth of technical inquiry underlying them.

Meanwhile, one of the key discernments from the more balanced discourse is that the notion of placing an entire title or deed registry, and all related transactions and processes, on the blockchain is fanciful, at least in the short term [1]: any full tokenisation of property in a given jurisdiction is still likely to be many years away. Anecdotal evidence from practice suggests full uptake is something that governments, the conventional custodians of these records, will only consider in the context of a more matured technology offering; one that can be shown to fully satisfy cyber-security considerations, and that has had the commensurate policy, legislative, and regulatory development attention of government.

This does not necessarily preclude the utilisation of blockchain technology in the land sector in the short term. A more nuanced appraisal suggests that more targeted and smaller-scale applications of the technology to specific land dealings might be more realistic, not to say more useful, in the land administration domain.

Examples of specific land dealings, or subset use cases of land administration, could include land conveyance, mortgage creation and discharge, or off-plan development approvals. These transactions could utilise blockchain technology by integration with existing land administration technology infrastructures. That is, rather than seeking to fully re-engineer and shift all land administration processes, data and document storage onto the blockchain, the focus in the short term could be on capitalising on the immediate benefits of the technology to make more efficient specific land administration processes.

Land dealings, such as land transfer or mortgage discharge, are those processes that enable the transferring of rights over a spatial unit of land, from one party to another [8]. In all cases, they generally require at least two transacting parties, that is a buyer and seller, and depending on the local legal and financial systems, numerous third-party actors to support the transaction. A contract, or deed, signed by both transacting parties, accompanied by a statutory legal instrument, is usually an essential component.

These specific land dealing blockchain use cases are enabled by the customisable programming logic stored in blockchains. This enables the operationalisation of "smart contracts", a conceptual idea predating blockchain technology by more than a decade [9,10]. Whilst this convergence of theoretical concept (smart contracts), emerging technology (blockchain), and potential application (land dealings) in the land sector is not entirely novel [11,12], these specific but important transaction subsets of land administration are all too often bundled up, if not lost, in the more radical sector-wide digital transformational visions, foreseen to be underpinned by blockchain, but that have, to date, lacked the combination of political will, public finance, and land agency impetus to implement.

For the smaller use cases of specific land dealings, this need not be the case: smart contracts supporting land conveyance, for example, can be implemented on the blockchain, and could be enacted as a somewhat independent technology layer, enabling interaction between transacting parties, the land registry, financial institutions, attorneys, and other parties, whilst not requiring the wholesale disruption of embedded existing technology arrangements.

The hypothesis is that this "hybrid" approach would simply provide a more efficient layer or interface for making and enforcing land-related agreements between actors; ones that could provide shorter-term solutions for the provision of a more secure, auditable, and distributable solution for supporting property record changes amongst buyers and sellers. Unlike earlier larger-scale sector-wide digital transformation visions, the relatively simple smart contract concept could be implemented without the need for significant land agency disruption, complete IT infrastructure rebuilds, or full database redesign.

To this end, this paper explores the potential for the application of smart contracts, implemented using blockchain technology, for the specific land dealings inherent to land administration. The overarching aim is to contribute to the more nuanced understandings of the potential role, benefits and drawbacks, of blockchain technology in the land sector—by beginning from a more incremental or targeted mindset with regards to implementation.

To achieve this aim, a comparative analysis is undertaken of findings from three proof-of-concept studies undertaken in Sweden, the Australian State of New South Wales, and the Canadian Province of British Columbia. For each study, smart contracts were applied, and proofs-of-concept developed for specific land dealings within those jurisdictions. Several theories are used to guide the case analyses, thereby enabling case comparison and subsequent results triangulation. These frameworks included the core business requirements of land dealings, technology readiness and maturity level analysis, and strategic grid analysis.

The remainder of the paper is structured as follows. A contemporary update is provided on the principles of, and relationships between, land dealings, land administration, smart contracts, blockchain technology, technology readiness/maturity, and hybrid solutions. This leads to an outline of the comparative study methodology, and subsequent presentation of the results. Each case is first presented separately before the discussion section delivers the synthesis. This section, along with the conclusion, makes predictions on the likely future development and research trajectories of blockchain and smart contracts applied to the land administration domain.

2. Background

2.1. Land Dealings and Conveyance

Before examining the potential role of smart contracts for specific land dealings, it is necessary to provide a brief overview of evolution of land dealings theory and practice. This informs, justifies, and provides criteria upon which to assess the relative benefits and drawbacks of any subsequent smart contract-based land dealing proof-of-concept.

Procedures for enabling the transfer of immovable property developed over millennia. Notwithstanding vastly different social and environmental contexts, and the land transfer mechanisms they espoused [13], suggests that for any situation, a means of transaction and evidence piece can be identified. Using these constructs, he suggests four major developments can be observed—particularly if a Western standpoint is taken.

Initially, transfer processes were linked to localised social customs, involving symbolic gestures to validate transfers, and witnesses as the key form of evidence. Paper-based systems followed, with private conveyancing between two consenting parties being supported by the creation of a deed (or legal document), again witnessed by a third party with the appropriate social, religious or juridical status. These documents formed an evidence base to not only support land transfer, but could also enable use of land as collateral, to support claims in cases of dispute, and for supporting inheritance.

As nation states further developed after the medieval period, beyond the European Renaissance, and into the Enlightenment, more organised systems or repositories for the registration of deeds were developed. That is, the trusted third party (i.e., state or religious institution), not only witnessed deeds, but also made and stored copies of the deeds at a central location [14]. The input or responsibility of the third party, in terms of verification of the legal validity of the transaction, and the associated liability assigned the third party in the case of fraudulent activity instigated by the transacting parties, may have been rather limited.

In cases where third party involvement developed to include the writing of a government-backed title or certificate, terminology evolved to contrast "**deeds registration**" from "**title registration**" [15]—the "Torrens" system being one variation. The key differentiating feature of title registration is the certificate transfer. Unlike a signed and witnessed deed, that merely acted as one piece of evidence that a transaction had occurred, the certificate of title provided a legal point of "truth", to the point that, if later it was discovered that a certified transaction was actually a fraudulent one, with the fraud committed by a seller without the authority to transfer, an unwittingly defrauded land holder would receive compensation from the State, rather than receiving their land rights back, under certain conditions.

The period of European colonisation resulted in those deeds and title registration systems being transferred globally [15,16]. Consequently, the statutory, if not formal, land transfer processes, in most nation states find antecedence in either deeds registration, title registration, or a combination of the two (e.g., Trinidad and Tobago, where land parcels in the same jurisdiction might be recorded and administered in separate systems) [17]. Whereas deeds registration systems record legal fact, title registration systems record legal consequence.

The required higher levels of government involvement oversight in title systems sees them sometimes referred to as "**positive systems"**, in contrast to "**negative**" deeds systems[1]. As pointed out by [18], "improved" deeds registration systems now appear very similar in practice and process to title registration systems. Indeed, modern theorists tend to argue that types of registration system can be considered on a continuum, rather than fitting clearly into one of the two historical and theoretical categories [19].

Regardless of the statutory system in use, transacting parties are required to compile a set of legal documents (or instruments) to get the transaction onto the register [18]. Specifications for these documents, and perhaps complexity in requirements, typically increased over time—dependent on the drivers and problem cases (e.g., fraud) experienced within a jurisdiction. In many cases, it will require the completion of a prescribed transfer form, a contract of sale, and a mortgage creation instrument.

Modern deeds and title registration systems were responses to identified weaknesses in earlier transfer methods. The strength of both lies in their simplicity with regards to four principles [15,18]. First, the **registration principle** (sometimes called "curtain" in Torrens literature) demands that, in order for a transaction to be considered "legal fact", it needs to be recorded in the authoritative "book" (or database in modern systems) [14]. This means that person-to-person, without government oversight, transactions are not recognised legally. The major reasoning[2] here is to stop a land unit (or parcel) being transferred multiple times by a single party: the authoritative book would reveal that the land has already been transferred.

Second, the **principle of publicity** demands that the book and transactions within, must be available and accessible for the public to view. The principle helps to remove information asymmetries and ensure transparency in conduct, for both transacting parties, and the government alike. In practice, books are not fully open, and may be considered semi-open: privacy and security controls are placed on the ways and means for accessing transacting data [18].

Third, the **consent principle** articulates that for any changes to be recorded in the book, relating to a person or parcel, the impacted parties must give consent. This principle builds on the previous two, with anti-fraud being a major motivation.

Finally, the **principle of speciality** declares that both parties and land units must be unambiguously defined. This is increasingly the focus of international standardisation efforts [20], and usually achieved through person and parcel identification (ID) systems, and the use of cadastral maps and field sketches. The IDs make transaction processes simpler, and seek to minimise identity fraud. It should be noted that literature on Torrens and

[1] It should be noted that it is usually Anglophone literature that makes these distinctions, with preference for title registration perhaps being transferred to the subsequent terminology.

[2] The registration principle also supports value capture via land taxation by government agencies.

other titling systems expand the four principles to also include: curtain, mirror, and insurance[3]. Each of these generally seeks to increase the power of the body doing the registration and fast track dispute resolution.

Despite the successes of both systems, they carry limitations—or at least perceived weaknesses. First, regarding **time**, in many systems, transfer processes generally take weeks, if not months, to complete [21]. This lag between transaction instigation and completion has been argued as inefficient by the property sector and related actors [22], and ultimately supports weak governance, if not corruption and informality in the sector.

Second, **cost** to transfer, particularly in developing contexts, is argued as prohibitive [21]. A transfer usually involves a range of professionals and several parallel processes, each attracting fees or duties. In theory, modern IT should reduce costs of storage, processing, and transparency provision [23]—yet, have these gains been passed on, or is a level of rent seeking persistent to some systems? Arguments and examples can be presented from both sides. What is clearer, is that if cost to register is too high, informal non-statutory transactions will occur, "outside of the books"—undermining the utility and value of the register, and the first principle above mentioned [24].

Third, like all administrative developments, **complexity** seeps into processes over time—in terms of parties, processes, and systems involved [8,21]. Regulatory reform is often a response [25], yet regulatory reform has often proved difficult to deliver in the land sectors in many jurisdictions.

Fourth, the **duplication** of effort is also evident in many systems [20,23]. This may include repeating data entry, superfluous checking of documents, and so on. Duplication could be considered a subset of the cost issue.

Finally, and perhaps most importantly, despite the best efforts of both deeds and registration systems, **fraud** is still possible and certainly occurs [26]. This can be actioned by buyers, sellers, other actors, or even the registry officials: the systems and controls are still penetrable with loopholes relating to instruments, documents and processes available for exploitation.

Like most sectors, over the last five decades (approximately), technology in the form of digital systems, databases, internet, and web services has greatly impacted upon registration systems—in terms of function and service delivery [27]. These have served to reduce existing limitations in both systems in terms of time, cost, complexity and duplication: many cases of cost reduction and process simplification (or access) can be observed. However, the new technological approaches also opened up new opportunities for fraud—and for this reason, amongst others[4], most land administration systems have tended to take a conservative stance and have been later technology adopters. Contemporary systems tend to still use a mix of digital and paper-based processes and documents. Whilst the developments are yet to fundamentally challenge or alter the underlying theoretical principles inherent to both deeds and registration systems, emerging concepts and tools relating to blockchain, including smart contracts, create interesting questions, if not opportunities [1].

2.2. Smart Contracts

It is also necessary to provide a contemporary overview on smart contracts in terms of theory and application, and to distinguish it from those of blockchain, recalling that the latter refers to one mechanism of how and where data in a smart contract is stored, validated, and viewed. This background supports understanding the smart contract proof-of-concepts developed in Sweden, Australia, and Canada, and subsequent assessment.

[3] Torrens and other titling systems add to the four above mentioned principles, including the insurance principle, whereby the authority responsible for the book (i.e., often government) will provide compensation to parties judged to have been defrauded of property, due to inadequate checks by the registry, at the time of registration.

[4] Rent seeking, enabled by manual processes, for example, is recognised as another reason for land sector inertia.

"Contracts" are agreements that can be enforced by law [28]. They are generally legally binding documents (although, can be merely verbal), agreed upon by at least two parties, prescribing the rights and duties of the parties involved [29]. Groupings of the elements can vary; however, contracts are generally considered to require offer; acceptance; intention to create legal relations; consideration (or value); legal capacity; and consent [28].

Translating from Hemmo, "Contracts enable organized collaborative activity and are used to carry out economic activity" [10,30,31]. This view allows the contracting mechanism to be positive and actionable, versus the common perspective that contracts are primarily designed to manage risk and exposure, thus resulting in the limiting of business activity.

Envisioning the impact and consequences of information technologies on contracts, business, and legal practice, the "smart contract" concept emerged in the 1990s. Whilst agreement on the scope of the "smart contract" concept has become more difficult on account of significantly increased attention across domains, Szabo's definition [9] of the concept, constituting a "set of promises, specified in digital form, including protocols within which the parties perform on these promises" remains prominent, and essentially foresaw the conversion of traditional paper-based contracts, elements, and associated manual processes, into digital self-executing ones.

That is, the smart contract concept saw the "if, then, else" statements of conventionally legal contracts, fitting comfortably with the constructs used in computer programming: legal agreements could be translated and executed as computer code. This could include all the binding elements and specific clauses of a contract. This digitisation then opens the opportunity for the digitalisation of workflows, and completion of contractual actions by computers that previously required human action or involvement. It would make transactions between geographically and even socially disparate (i.e., non-trusted) parties far easier.

Taking this broad definition, smart contracts were already in play in the 1990s. Szabo, for example, referenced vending machines as operating on an implicit contract: a dollar is exchanged for a can of soda. Moving forward, parties now routinely sign digital agreements with online service providers such as Netflix, Apple and Google, approving debiting of accounts, in return for use of an asset. If the party fails to live up to the terms of contract (e.g., failure to pay subscription), the party's online account, and access to the asset, may automatically be suspended. It should be noted that these examples are not "trustless" transactions. They require the users to inherently trust that online service providers will deliver the services, as all require payments in advance. That is, consumers have to trust service providers like Netflix to provide the movie when they pay in advance. This means it is an asymmetrical trust relationship. Netflix say they have "Ben Hur", and the consumer "hopes" that it will be provided after payment. Netflix validates the consumer through a credit provider (e.g., Mastercard), but the consumer has no way of validating Netflix. Continuing the analogy, a true "trustless" transaction would be where the consumer can actually see on an independent blockchain that Netflix "owns" the rights to "Ben Hur", and an exchange is recorded on the blockchain, which gives me access to the movie.

At any rate, whilst the "smart contract" concept and even its application can be considered decades old, for some applications, technology limitations (amongst those of a more institutional nature) stymied scaled and decentralised implementation: creating verifiable public and decentralised agreements, on the order in which a series of digital transactions had occurred, was an unsolved technical challenge.

Enter Satoshi Nakamoto's 2008 bitcoin currency [32], underpinned by blockchain technology. It resolved the order of transaction issue [33], and thus paved the way for recorded and completed decentralised and verifiable online public agreements. Blockchain technologies enabled non-trusting parties to record and execute agreements, on a distributed peer-to-peer network, without the need for a trusted intermediary [34]. In this way, "smart contracts" can be distinguished from "blockchain": the former, initially conceived in 1997, predates the latter by 11 years [32]. Put simply, the combination of blockchain technology and smart contract concepts enabled a new form of transparent "trustless" transactions.

Mainstream blockchain development platforms emerged, including Ethereum and Hyperledger, and consequently, the smart contract concept experienced a revival in development attention [35], albeit still with more limited scaled application [10]. Essentially, smart contracts take the form of code, residing on the blockchain, and these codes can be used to automatically verify and enforce contracts, digitally, without central authorisation [35].

Putting the above into practice, Table 1 reveals the current state-of-play with regards to actual implementation of smart contracts, as compared to more conventional contracts. Several features are worthy of mention. Firstly, on specification, in the smart contract situation, the contract, including the terms of agreement, has been converted to computer code. This is the key characteristic that subsequently enables the downstream execution of many of the contract terms and tasks can be achieved through automated processes. These processes can include the transfer of property title, automated payment of duties or fees, or payment credits to cover escrow accounts.

Table 1. Comparison of traditional contracts against smart contracts.

Criteria	Conventional Contracts	Smart Contracts
Specification	Natural language and legal prose	Code
Identity and Consent	"wet" signatures	Digital Signatures
Dispute Resolution	Judges, adjudicators, arbitrators	Consensus via blockchain
Nullification	Parties via legal enforcement Process of breached terms	Parties via Agreed Upon Digital Nullification workflow and block consensus
Payment	Independent third-party Process	Automatic, based on executed terms (Built into Contract)
Escrow	Independent third-party Process	Automatic, based on executed terms (Built into Contract), or not even required

Second, in terms of identity and consent, digital signatures, using asymmetric cryptography dating back to the 1970s, are fundamental to smart contracts. Every transaction connected to a smart contract must be signed. The integrity of the system rises and falls on the level of confidence that the network has about each party to the contract. In essence, this is the very reasoning for the principle of speciality in conventional registration systems.

Every person required to execute their part of the contract must have a digital key. The challenges for architects of a smart contract network are to balance the relative simplicity of a central authority that issues credentials versus challenges of self-sovereign identity and key management. Key management is certainly a non-trivial issue, but multi-signature frameworks and custody models have emerged to address both security and consumer adoption concerns.

Third, in terms of dispute resolution, nullification, payments, and escrow, it can be seen that these tasks are largely automated, programmed as workflows, and thus remove the need for trusted third party decision making and action in the smart contract solution.

2.3. Technology Readiness Levels

Having defined smart contracts, differentiating them from both conventional contracts and blockchain, an introduction is now given to analysing and understanding the relative readiness and maturity of the technology, in the context of its potential utilisation in land administration, and specific land dealings.

The concept of "**Technology Readiness Levels**" (TRL) is an approach to classifying technology from basic principles and conceptualisation through to implementation in an operating environment. The TRL framework was developed by NASA for the development of technology in the Space Program in the 1970s [36]. The framework has been adapted and utilised for information technology systems development [37] and new product development [38]. The nine phases in the original NASA framework as adapted to commercial development are (adapted from [38]): TRL 1: Principal research into key properties of a technology; TRL 2: Conceptualisation of a new potential application for the technology; TRL 3: Develop analytical "proof of concept" of core functionality; TRL 4: Component and/or breadboard validation in a laboratory environment; The focus of technology development is on achieving project objectives; TRL 5: Validation of basic technological capabilities in a relevant environment; TRL 6: "High-fidelity alpha prototype demonstrated in a relevant environment"; TRL 7: Beta prototype demonstrated in an operational environment; TRL 8: System completed and qualified to relevant project requirements/ industry standards through test and demonstration; and TRL 9: System proven to achieve all project requirements in operational environment. Preliminary appraisal of blockchain applications in land administration, as uncovered in [1], suggests that existing developments lie between TRL 2 and TRL 3: most reported developments are conceptual or limited proofs of concept.

While useful to explore the technology readiness of blockchain and smart contracts to perform land registry functions, TRL has some limitations. TRL ignores organisational considerations of the organisation developing or implementing the technology and the environment in which the organisation operates [36] and fails to consider integration of the new technology/system with existing systems [37]. The TRL framework finishes with the successful operation of systems in the target environment and does not progress to commercialisation and diffusion throughout an industry or market.

A parallel can be drawn between the limitations of TRL and previous studies on the maturity of blockchain: most studies on blockchain focus on the technology and ignore the organisational considerations of adopting new technology [39]. While an argument for the adoption of blockchain is the elimination of intermediaries [40], there is still the need for the governance of organisations within a blockchain network [41].

Therefore, to support TRL analyses and evaluations of blockchain and smart contracts in the land dealings, it seems pertinent to also include **technology adoption theories**. The technology, organisational, and environmental (TOE) framework examines antecedents to technology adoption [42]. This model has recently been used in a systematic review of the literature exploring blockchain adoption considerations [43]. The major technological considerations identified were complexity, perceived benefits, security, compatibility, maturity, relative advantage and smart contract coding. Most referenced organisational capabilities were organisational readiness, including value chain readiness, appropriate knowledge and financial resources; top management support; organisational size, business model readiness and innovativeness. Major environmental considerations included market dynamics encompassing competitive pressure and market standards, the regulatory environment, government and stakeholder support, business use cases and industry pressure.

In a similar approach to TOE, [39] identified that institutional and market factors need to be considered as well as the technological factors. From an institutional perspective, cultural resistance by industry incumbents needs to be overcome; knowledge and understanding need to be developed amongst businesses, customers and government around the potential use and implications of use of blockchain; and how the technology can be integrated into existing strategies and processes [39]. Market factors include the changing role of intermediaries and associated potential disruption; the need to embed smart contracts in software; and impact on business processes [39].

Another supportive theoretical framework for blockchain application evaluation is those linked to **capability maturity models**. Typical engineering capability maturity models [44,45] have been adapted to develop a maturity model for the engineering of distributed ledgers as shown in Table 2 [46]. These can also be useful for assessing maturity with respect to smart contract approaches to facilitating land dealings.

In summary, analyses of the progress of the use of blockchain and smart contract technologies in land dealings could benefit from identifying the TRL phase of the selected projects, exploring the degree to which TOE factors have been considered, and the blockchain maturity phase that the project represents.

Table 2. A maturity model for blockchain and smart contract application in land dealings.

Maturity Phase	Intention	Artifact	Scope
1. Initial	Discovery of the potential benefits and how the replacement of intermediaries may impact process and governance structures	Development of Minimum Viable Product (MVP) blockchain prototypes	Selection of blockchain platforms is not systematic and the roles of the blockchain and existing database technology are indistinct
2. Structured	Use a structured technology-selection process to identify appropriate platform	An appropriate platform selected and the design of a partner network and governance frameworks	Specific criteria have been used to select blockchain use cases and to distinguish the solution from existing database technology
3. Automation	Moves toward process automation based on smart contracts	Smart Contracts—use the platform to go beyond distributed transaction management	The scope of smart contracts is limited to "single dependencies between data or business processes"
4. Business Collaboration	Distributed autonomous organisation	Complex relationships and automated processes across	A network of visible partners is expressed by inter-linked smart contracts.
5. Verification	Formally proven automation	Correctness of smart contracts and DAOs checked	Verification by known model checkers

[1] Adapted from [46].

2.4. Towards Hybrid Solutions

Putting all the above together, despite the perceived benefits of smart contracts applicable in many sectors, beyond crypto currencies such as Bitcoin, scaled implementation of the smart contract concept via blockchain within mature industries, such as those with heavy government oversight or regulatory control, still remains limited.

This applies equally to the land sector: despite much hype and conceptual design work, evidence of fully operationalised blockchain-driven solutions in the land sector remains scarce [1]. Land dealings are complex transactions encumbered with the body of sometimes very old legislative and regulatory controls and processes. Existing legal systems and accompanying administrative procedures need adaptation to incorporate the smart contract concept, at least if the transaction is to be considered "legal" under any form of deeds or title registration system). Moreover, there persists the notion that smart contracts might operate beyond human control and bind the parties to agreements or expose them to unintended liabilities through malicious behaviours.

That said, more circumspect conceptual thinking on "hybrid" approaches is emerging. In [47] the term "hybrid" refers to designs that tend towards semi-private and more permissioned write access, aligning them with conventional land administration processes. Only identified and authenticated actors would be permitted to write. Going further, in this work, the term is adapted to include the combined use of conventional database technologies, integrated with blockchain technology. Additionally, the idea is to veer away from earlier whole-of-sector digital transformations designs, and focus in on specific dealings, activities, and actors. The aim is for minimal disruption to existing institutions and infrastructures, or even to demonstrate integration with those systems. These hybrid approaches seek to deliver the benefits of smart contracts to land dealings, whilst minimising risk and resistance—however, they also require rigorous scrutiny.

Consequently, there appears to exist a sound argument to evaluate these smaller-scale or incremental developments in the context of adherence to business requirements, technology readiness/maturity, and impact—with a view to evaluating whether a trajectory of uptake is evident, or not, and where this alternate implementation approach may be leading.

3. Materials and Methods

Building from the findings in the previous section that—i) institutional constraints mean whole-of-sector blockchain transformations of the land administration sector will not be realised in the short term; ii) the technical readiness level (TRL) of smart contracts, underpinned by blockchain, is considered to be at best, at the level of proof-of-concept (2-3); and iii) that specific land dealings appear highly suited to smart contract application with respect to maximising the benefits, whilst mitigating the current limitations of blockchain technology—a methodology was developed to support the examination of the possibility and benefits of hybrid land dealings solutions, combining land registry processes with smart-contract/blockchain technology.

The developed methodology was fundamentally built from the pragmatist research paradigm and can be considered "design research", or at least design evaluation: the methodology sought to assess a solution "that works" in a given context and application area, rather than seeking any absolute truth [48]. Justification for this design approach can be found in other land administration research and development work, recently including [49–54]. Building from these works, the methodology can be said to be inspired by, although not a direct application, of the living labs approach [55], reflexivity and action research [56]; these specific methods already finding justification and application in land administration studies. On this, it should be noted that some of the co-authors were involved in the proofs-of-concept work in the jurisdictions, however, these were considered separate undertakings to the analyses informing this work.

In this vein, the methodology primarily utilised publicly available data and findings from rapid prototyping development work completed by ChromaWay, between 2016 and 2020 in three jurisdictions. This data includes reports, presentations, published code, technology descriptions, amongst other artefacts. ChromaWay is a software and blockchain solutions provider operating globally, but is primarily based in Sweden. ChromaWay has developed a generic suite of blockchain tools, customising them for multiple jurisdictions, across multiple sectors, including the land administration sector. A brief overview of the ChromaWay design and development process, and the resultant key components of the solution, are explained in Section 4.1. The publicly available ChromaWay data was supplemented by the pre-existing expert knowledge and contextual awareness of the authors.

The results of three specific proof-of-concept studies are drawn upon for this specific work, namely undertakings in Sweden (2016–2018), Australia (State of New South Wales) (2018), and Canada (Province of British Columbia) (2018), and further follow-up activities in 2019–2020. For each case, smart contracts were applied, and proofs-of-concept developed for a land dealing, namely a portion of the land conveyance process, in those jurisdictions. Subsequent to those studies, a framework was developed to enable assessment of each; first individually, and then comparatively. The framework assessed the specific use case of smart contracts for land conveyance within the jurisdiction, in terms of lead sponsors, required partners, smart contract technology components and features (i.e., the hybrid approach), the specific land conveyance use case, process participants, pre-existing problems with the process, challenges with the specific study, and key benefits. The results of these analyses are presented in Section 4.2, 4.3, and 4.4. Additionally, the cases were comparatively assessed against theories, including the core business requirements of land dealings, technology readiness and maturity levels, and strategic grid analysis. These results are presented in Section 5.

The findings were then synthesised to make generalised determinations of the contemporary potential for more nuanced and incremental application of smart contracts, implemented using blockchain technology, for the land administration sector.

4. Results

4.1. The Hybrid Approach

First, an overview of the developed generalised hybrid approach is provided in terms of the developed business, application, information, and technology architecture.

In terms of the **business architecture**, the philosophy behind the hybrid proof of concepts was to move beyond the concept of "big bang" sector-wide blockchain transformation for land administration, which would necessarily involve comprehensive and substantial re-engineering of all the business processes, in terms of land dealings, actors, and tasks. Instead, the focus was placed on specific land administration tasks or transactions that would most immediately utilise and benefit from smart contract application, envisioning connection to the existing land registration technology infrastructure, with minimal disruption. This is referred to as the "hybrid solution". It should be noted that the proof-of-concept did not connect to the production-level technology infrastructure.

For smart contracts to take hold in land registration processes—at least those transactions taking place in formal, legal, and/or statutory systems—a level of reform to existing legislative, regulatory, and administrative processes would be required: transactions involving immovable property are subject to specific laws in each jurisdiction (i.e., beyond regular contract law). That said, it is possible to explore the potential role of smart contracts in the land registration and transfer process.

In terms of the **application architecture,** in each of the proofs-of-concept, the existing processes were mapped in terms of actors and tasks. From this, alternative conceptual workflows were developed that incorporated smart contract technology. The actual smart contracts were designed using code which drove automated tasking and workflows where the rules defined what "messages" were acceptable at every state of the contract. For example, the property purchase process code defined a "buyer" who must sign-off on a contract. Digital signatures were used to establish message authenticity, in order to prevent "attackers" impersonating one of the parties, posting invalid or malicious information, and to indicate that the signing party was responsible for message contents, similar to a signature on a paper document or contract.

Here, it is also necessary to introduce the concept of "boundary connectors", the opposite of barriers to entry. Boundary connectors—technology, data, and collaborative business arrangements—enable business processes to cross organisational and jurisdictional lines. A simple example is the strategy of introducing regional "smart pass" transponders to allow vehicles to quickly and securely cross local highway jurisdictions (a "smart pass" is simply a smart contract device; a fee is deducted in exchange for the right to pass through a toll gate). The processing of land registration and associated mortgage lending processes can be thought of in a similar fashion (see Figure 1). The distributed ledger serves to connect buyers, sellers, settlement agents, lenders, and land registries into a single network (i.e., the road network) and the smart contract acts as a sort of "transponder", guiding the property transfer (or other transaction) to move across the ledger network.

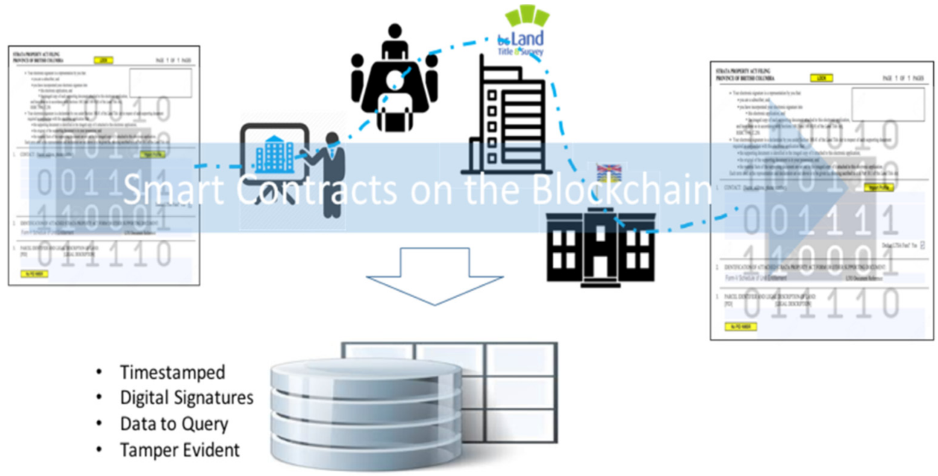

Figure 1. Simplified workflow schematic of a land dealing process enabled via smart contracts on the blockchain.

Information Architecture: Figure 2 illustrates the components of the hybrid conveyance solution proposed in this paper. There are three high level architectural components: (1) client-distributed applications (Dapps); (2) source of on/off chain data; and (3) the blockchain Backend. In the blockchain backend, smart contracts are written either with Esplix or using Postchain (explained below). The Conveyance Dapp is written like any other business application, except data is written to the blockchain nodes (BC Nodes) instead of a central database. Data in the Dapp is appended to/presented from the blockchain. The behaviour of the Dapp is driven by the codified smart contract (for each conveyance type) and the workflow which orchestrates the interaction of property ecosystem participants.

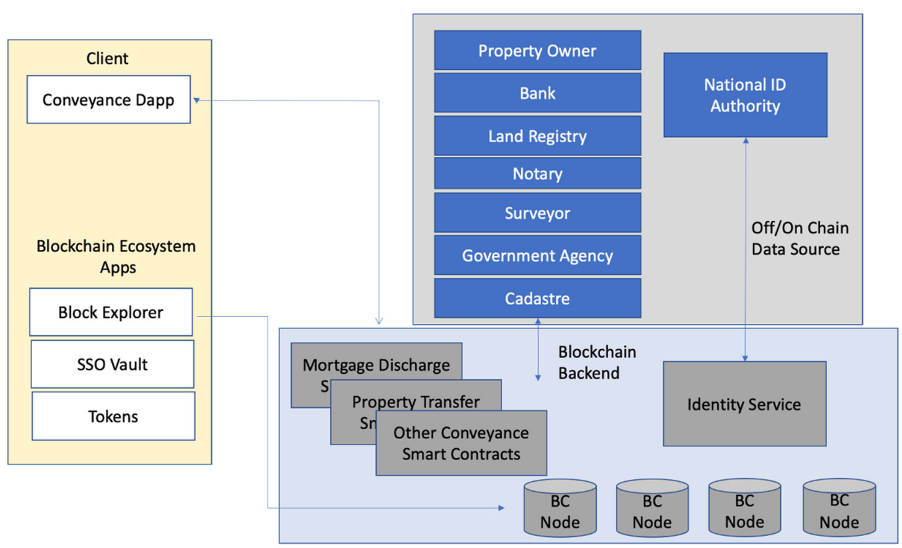

Figure 2. Hybrid smart contract/blockchain information/application architecture.

The smart contract in a land registration transaction employs digital signatures (typically through the use of cryptographic key pairs) that provides the signed transactions that are submitted to the blockchain ledger; specifies the data required by network partners to process/approve a transaction; enables automated processing of escrow payments or other types of actions based on predetermined rules; describes the definition of a completed task(s) (e.g., signatures, collected data, etc.) that permits the contract to proceed;

enables participants with a user interface (e.g., as a smartphone) or systems (e.g., application servers) to complete the tasks required by the codified contract.

Technology Architecture: In each study, ChromaWay utilised a technology called Esplix. Esplix is non-Turing complete (not a fully operational program to avoid loops which enabled the DAO (decentralised autonomous organisation) hack [57]) and operates as a system for exchanging signed messages. The ChromaWay Esplix solution, like other similar frameworks, allowed the smart contracts to operate in a more settled legal space defined by laws like the US's Uniform Electronic Signatures Act ("UETA") and Electronic Signatures in Global and National Commerce Act ("ESIGN") that already recognise, enable, and validate the use of electronic signatures and electronic records. The Postchain module for Esplix allows one to utilise the Postchain consortium database as a consensus (witness) component of an Esplix system. Postchain provides a reliable message store and guarantees that once a message is confirmed its position relative to other messages is certain and that the message chain is unambiguous. Note that Postchain can also be used as the consensus-based blockchain data repository for a distributed application (Dapp) client.

4.2. The Swedish Case—Property Sales

The Swedish proof-of-concept was completed between June 2016 and June 2018 and was primarily sponsored by Lantmäteriet—the Swedish mapping, cadastral and land registration authority. Lantmäteriet is a government agency primarily providing information on Swedish geography and property. The project was sponsored by a consortium, including business consultants, technology providers, and financial institutions. Respectively, these were Kairos Future (business), Telia (ID Provider), ChromaWay (technology provider), SBAB Bank, and Landshypotek. SBAB Bank is a state-owned bank that borrows funds to support the Swedish mortgage market. It provides loans to private individuals, tenant-owner associations, and real estate companies. Landshypotek is a bank owned by farmers and foresters, almost forty thousand, and reinvests profits back into those enterprises.

The proof-of-concept focused on all of the phases of the property sales process including property transfer (or land conveyance). In the Swedish system, this includes a buyer, seller, real estate agent, buyer bank, seller bank, and the land registry. Perceived problems with the existing process are generally related to complexity, duration, duplication, and documents being physical. That is, the existing process was found to: include thirty-four (34) steps; take weeks or months to complete; only involved the land registry very late in the process; make use of only limited data re-use between steps; still be largely paper based, with signed documents sent by regular email; and to require manual identity checking.

The technology suite applied by ChromaWay included the Esplix Smart Contract, and Postchain Blockchain solutions. An excerpt of the smart contract developed for the real estate consortium formed in Sweden to process property transactions is shown in Figure 3. The developed smart contract dictates that the buyer's bank must sign-off (with its key pair) that it has (1) received the purchase sum and (2) sent the contract to the land registry. The land registry, in turn, must sign that it approves the purchase contract received from the buyer's bank. In this way, the smart contract defines and orchestrates and enforces the actions they must take to advance the contract and associated processes towards completion. The demonstrator illustrates the potential to use the smart contract in the context of established land transfers in a developed economy context.

```
:actions
    (offer ((property-id string :description "Official ID of the property"))
        "Offer the property on the market (pending description of the property by the broker)"
            (guard
                    (signatures seller)
                    (eql state nil)
            )
            (
                update property property-id
                state :register-broker
            )
    )

    (register-broker ((broker-pk pubkey))
        "Invitation of broker to the contract"
            (guard
                  (signatures seller)
                  (eql state :register-broker)
                  (eql broker nil)
            )
            (
                 update broker broker-pk
                 state :describe
            )
    )

    (describe ((description-param string :description "Description of the property, including it's state"))
        "Describe the property, including its extent and state"
            (guard
                (signatures broker)
                (eql state :describe)
```

Figure 3. Smart Contract Excerpt.

Features of the solution included that only parties to the contract were privy to the data in the contract; that the contract would not fully execute without satisfaction of the data and signing requirements; and that the contract protocol could be distributed through third party vendors or directly through registry developed apps. Given the number of actors involved in the conveyance process, this last feature was considered highly beneficial in the Swedish case.

The results of the proof-of-concept revealed a significant reduction in the number of manual steps needed for a property transaction (down from 34 to 13); greater transparency into the process for all parties (including the banks, land registry, etc.), in terms of being able to view the status of a transaction at any time during completion; and a simpler, less expensive distribution of the standard property transfer protocol using a smart contract. A major challenge identified during the proof-of-concept assessment is that Swedish law does not allow for the use of electronic signatures for property transactions, obviously a major constraint in terms of scaling the project to production level.

In terms of current status, the blockchain network and smart contract proof-of-concept protocol were trialled and externally tested. Further progress can start once the digital signature restrictions are addressed.

4.3. The Australian Case—Mortgage Discharge

The Australian proof-of-concept was completed from January 2018–October 2018 and led by New South Wales Land Registry Services (NSW LRS), supported by ChromaWay Asia Pacific and ChromaWay AB. NSW LRS operates the NSW land registry for the NSW State Government. It is a private company and has a 35-year concession to run the registry, commencing in July 2017. Part of the concession involves ensuring improvement and upgrade of the technology infrastructure underpinning the registry, in terms of service and security. In this vein, the 2018 proof-of-concept provided an ideal opportunity to trial the use and potential integration of blockchain enabled smart contracts.

Unlike the Swedish case, focused on the complete case of land conveyance, the Australian case focused on an even more specific land administration process. The core land administration process focused upon was "Discharge of Mortgage Lien". The Discharge of Mortgage Instrument is used to remove the recording of a mortgage from a land title. It usually applies to a whole parcel. Mortgage discharges are the most common transaction supported by NSW LRS, with between 20K to 25K completed per month. In comparison, there are usually from 13–17K land transfer transactions (or land conveyance). The core participants in the process are the mortgagor (usually an owner), mortgagee (usually a financial institution), and the land registry (NSW LRS).

In the NSW context, the existing lien removal process was considered to be overly complicated and included more steps than were seen to be necessary, particularly given the possibilities provided by digital lodgement and processes. Due to the complexity, it has been found that, in some cases, even when debts are settled, liens removals have neither been appropriately lodged nor processed. In these cases, mortgage holders may not even be aware that the lien still exists on the property.

Similar to the Swedish technology solution, the NSW LRS Discharge of Mortgage case utilised Esplix Smart Contract and the Postchain Blockchain. The latter enabled the hybrid solution—an interaction between the existing NSW LRS technology infrastructure and the Explix Smart Contract: the smart contract could automatically call the NSW LRS system to return the title data into the smart contract, without demanding radical changes to the NSW LRS land registry databases. In addition, the new approach would enable the mortgagor to initiate the lien release, and not be dependent on the mortgagee, via automated enforcement. This contracting protocol could easily be distributed through third party vendors or directly through other NSW LRS apps, again without disrupting the underpinning and existing technology infrastructure.

The Australian NSW LRS case also revealed implementation and scaling challenges. Australia is a federation, divided into 6 States and 2 territories, and land administration responsibilities reside with those federated jurisdictions. This creates challenges for developing a national standard for e-conveyance and land transactions. For example, PEXA, the national e-conveyancing platform, not based on blockchain, took more than a decade to develop, and even still, many transactions in many States are completed outside PEXA. In law and regulations, it is considered an ELNO (electronic lodgement network operator) and could be open to competition from other ELNO. Whilst this creates competition, it also created inefficiencies, potential duplication of effort, and disaggregated market data. In such a small market (e.g., Australia has a population of ~25M people), it is generally desirable to build a consensus around standards and processes between States/Territories; otherwise, getting buy-in and interest from private sector operators (e.g., software vendors; financial institutions), is more difficult. Therefore, any blockchain based solution, even if just for a limited number of land transactions, would need to address this issue.

That said, numerous future benefits were evident from the proof-of-concept work. In 2016–2017, NSW LRS processed 930,809 conveyance transactions, of which 25% (237,964) were mortgage-related. At the time of the study, less than 20% of mortgage lien releases were submitted fully electronically. A better "uptake" could be possible through decentralised smart contracts.

In terms of current status, the Discharge of Mortgage Lien process prototype was completed and approved as addressing technical requirements by NSW LRS.

4.4. The Canadian Case—Re-assignment Reporting in British Columbia

The Canadian proof-of-concept was completed between June 2018 and October 2018. Like the Swedish work, a consortium approach was used, with the Land Title and Survey Authority of British Columbia (LTSA) the sponsoring organisation. LTSA was setup as a statutory corporation under the Land Title and Survey Authority Act 2005, giving it delegated authority over land title and survey systems in British Columbia. This allowed LTSA to focus on efficiency using a digital first approach. In this vein, it was a leader in developing online electronic filing, search, and parcel map services for land sector stakeholders in the 2000s. Other partners for the proof-of-concept included ChromaWay AB and Landsure Systems Ltd. Landsure is a wholly owned subsidiary of LTSA, and primarily supports the continued improvement of the LTSA via the development and management of LTSA's core technology infrastructure.

Like the other cases, rather than seeking a big bang whole-of-sector transformation solution, the LTSA focused upon a new land administration process that could benefit from a smart contract approach, whilst also providing for minimal disruption of the existing technology infrastructure. In this regard, the transaction focused upon was "Re-Assignment Reporting". This activity addresses the reporting of a re-sale of previously assigned condominium properties (primarily) prior to sale. An assignment is a right (and commitment) to purchase a property in the future. Typically, this occurs when a new condominium property is being built and the builder needs to presell a percentage of the properties before banks release funds for the formal build activity to commence. The new process involves numerous stakeholder bodies, including the assignee, assignor (new buyer), and realtor, property developers, LTSA (land registry), and the government planning branches.

The Re-Sales Assignment Reporting process is a new business function of LTSA and the smart contract alternative approach was evaluated in parallel to the development of the "traditional" approach using a central database. Note that the overall goal of the business function was to inject more transparency into condominium re-assignment for tax and planning purposes.

In terms of the developed technology infrastructure, use was made of the Esplix Smart Contract solution and Postchain Blockchain solution. The developed solution considered the planning agency (OSRE) to "push" a pre-sale filing number to LTSA for database storage. Moreover, when an assignor requested assignment of the property, the platform utilised the filing number in the smart contract. Like the NSW case, the contract protocol can be distributed through third party vendors or directly through registry apps.

In terms of the proof-of-concept results, the project experienced no significant challenges. The LTSA project team was primarily comprised of their technology and business analysis organisation—LandSure Systems. This greatly facilitated the technology knowledge transfer and development process.

Further key benefits, as against the more conventional database prototype, were identified as the property taxation branch (PTB) being able to query the smart contract data ledger at any time to view the state of transfers. The solution envisioned the property developers reporting these transfers, as they are in a better position to provide that information. Asking the buyers and sellers to report was considered as well.

In terms of the current status, the prototype project was completed, but due to scaling and change management constraints with all the stakeholders and various agencies, the prototype approach was not deployed, and a more traditional approach was used. LTSA is now evaluating other opportunities for the use of smart contract/blockchain technology.

5. Discussion

Moving beyond individual case examinations, this section undertakes comparative analysis against the core principles of land dealings, technology readiness/maturity, and strategic grid analysis. The accompanying interpretations help to shed light on the relative merits of the hybrid approach at both an organisational and sector level, update the status of smart contract application in the land sector, and enable hypothesis development for future development trajectories.

5.1. Business Requirements Adherence

The core business requirements for land dealings, outlined in Section 2.1, regardless of system antecedence being deeds or title, included the principles of: (i) registration; (ii) publicity; (iii) consent; and (iv) specialty. For all three (3) proofs-of-concept examined, it was shown that each of these principles can be met. That is, the smart contract approach, underpinned by blockchain, and offering integration with existing technology infrastructure (e.g., via APIs), enabled the registration of transaction details (i.e., parties, dates, transference details), and could be configured for wider public reading/viewing. Moreover, the consent principle could be realised through the developed Esplix code and subsequent automation. The principle of speciality, that is, the unambiguous identification of parties and parcels, can also be observed via the integration with pre-existing land registry databases, enabled with Postchain. In this way, achievement of the speciality principle is reliant on how land parcels and parties are identified within the jurisdiction.

Other core business requirements, also outlined in Section 2.1, those associated with titling systems—including curtain, mirror, and insurance—can also be shown to be supported. However, these principles demonstrate the limitations of only undertaking a technical assessment: the hybrid approach can certainly be shown to support obedience towards the principles, but it does not guarantee it. That is, adherence to the land dealing business requirements is not only dependent on technology, but broader socio-technical arrangements (e.g., specifics in legislation). Moreover, it could be argued that with a smart contract approach, the insurance principle becomes redundant altogether: the idea being that the technology confounds the possibility of land dealing fraud altogether. In the hybrid approach, the fraud protection benefits of blockchain exist within the transaction system, but, dependent on existing controls, unauthorised changes could still be made to the land registry itself. The use of hybrid approach provides an immutable record of transactions against which changes in the land registry can be checked. This will be more effective where all transactions are processed through the blockchain transaction system.

Looking beyond core business requirements, Section 2.1 also outlined limitations of existing systems for land dealings. These included perceived excesses in time, cost, duplication, complexity, and fraud with regards to land dealings. Across the three (3) cases, within the controlled hybrid test environments, it was illustrated that the integration and automation, enabled by the Esplix and Postchain solution, could result in reductions in time, complexity, and duplication. Less manual handling of a single dealing should also result in lower costs (i.e., less actors involved) for responsible agencies. However, this does not necessary equate to reduced costs of transacting parties: costs are often associated with set fees or duties, and these are not necessarily determined in simple cost recovery terms. Finally, as already mentioned, a key tenant of the smart contract and blockchain approach, is the reduction of fraud, via publicity, and in this regard, the hybrid solutions provide for this.

Putting aside the limitations of a technology-centric assessment, each of the hybrid proofs-of-concept were shown to support adherence to the core business principles of land dealings. Moreover, the hybrid approach also appears to deal with some of the limitations of existing technological approaches. In this regard, for the unit of analysis of "land dealing", evidence of the benefits of smart contract and blockchain approaches is apparent, beyond earlier theoretical espousals.

The positive results again raise the question as to why uptake has not been more apparent in the land sector? An immediate answer, in the framework of busines requirements, is that whilst the existing technology solutions may not be perfect, they largely already enable adherence to the same core principles. Why take on the risks of a new and potentially immature technology implementation, when existing systems work? This question invites analysis of the actual maturity level of the hybrid approach (e.g., TRL), and whether anecdotal perceptions that the technology is not yet matured, are valid.

5.2. Technology Readiness and Maturity Levels

Against the TRL adapted framework from [38], all three (3) proofs-of-concept reviewed appear to reflect relatively early phases of readiness and maturity with respect to and in terms of blockchain and smart contract maturity. That is, having moved beyond conceptualisation and early experimentation, the Swedish, Australian, and Canadian projects all appear to be at the TRL 4 (Component validation in a laboratory environment—or technical "Proof of Concept") levels. The cases have progressed further towards technological readiness than previously documented proposed applications of blockchain and smart contracts (e.g., see [1]). These earlier efforts were more worthy of TRL 2 designation (Conceptualisation of a new potential application for the technology) or TRL 3 (i.e., Analytical "Proof of Concept" without progressing to demonstrating technology proof of concept [1]). The technical proof of concept projects demonstrate that the hybrid solutions proposed can meet the technical functional requirements of land transaction applications explored.

Technical proofs-of-concept are important to understand the potential benefits and implications for processes and roles [46]. They are also important for communication between technologists, academics and practitioners (registry operators and intermediaries) (adapted [58]). From a systems supplier perspective, proofs-of-concept enable IT experts to highlight issues to be solved; potential clients to verify IT supplier capabilities and supports pre-sales process of IT providers [58]. However, while the technical proofs-of-concept are a step forward and are important to potential adoption of blockchain technology at a jurisdiction and industry level, there is significant further work required before this technology is likely to be adopted as a dominant approach to administering land records.

Going further, from a blockchain maturity perspective [46], see Table 2, all three (3) proofs-of-concept are assessed to be moving from Phase 1 (initial) into Phase 2 (structured). The land registry operators used the projects to explore how blockchain and smart contracts could be used to improve processes and governance structures. The more nuanced approaches of examining how a hybrid approach could utilise blockchain and smart contracts integrated into the existing land registry database technology reflects an advancement in maturity. While the proofs-of-concept successfully showed the technical feasibility of such solutions, none of the operators have yet moved to a formal technology assessment process to select and finalise an appropriate platform or have finalised partner network and governance frameworks. While the potential roles and actions of intermediaries were explored with differing levels of stakeholder engagement across the projects, substantial institutional work is required to move towards implementation of automated smart contracts (maturity phase 3) and business collaboration (i.e., DAOs) (maturity phase 4) in land registry and land transaction space. Government responsibility for land registry functions may limit the viability of moving to the DAO phase for this application of Blockchain.

The proofs-of-concept considered here also provide some insights on TOE for the adoption of smart contracts and blockchain hybrid solutions in land dealing applications. From a technology perspective, the examples indicate that hybrid solutions can meet technology requirements of different transactions that interact with land registries. The proofs-of-concepts did not progress to prove full integration of the technology used by existing registries. However, such integration is relatively straightforward with the analytical design, including interface to existing registry APIs. The cases suggest substantial potential benefits in the hybrid technical solutions explored compared to the existing manual, paper-based transaction systems. Potential benefits in terms of time, cost, duplication, complexity and potential fraud were identified. Many of these benefits flow from digitalisation and the cases did not compare the potential benefits and costs of the prototype blockchain solutions versus other forms of digital technology. This last one was demonstrated by the NSW case with the national PEXA solution (non-blockchain), already providing many of the digitalisation benefits identified and the Canadian case, resulting in the client selecting a more traditional solution.

Furthermore, the cases provided insights into organisational and environmental considerations of the TOE framework for the adoption of hybrid blockchain solutions for land registry transactions. From an organisational perspective, the proofs-of-concept increase organisational knowledge of the technology and how it can be integrated into existing strategies and processes [39]. From an environmental perspective, the cases show the complexity of land registry environments with Sweden halting their project due to legislation requiring wet signatures for land transactions; NSW being part of a broad national environment for which a national solution was available and the Canadian case did not proceed, partially due to change management issues with stakeholders.

In summary, the proofs-of-concept analysed show that in terms of readiness and maturity, blockchain and smart contract technologies, applied to land dealings and land administration more generally, have progressed towards more structured and analytical proofs-of-concept than previously observed. Finally, for further confirmation of these findings, or otherwise, we briefly consider where the case applications lie on the IT strategic grid.

5.3. Strategic Grid Positioning

The IT strategic grid [59] was previously used to assess blockchain adoption, amongst other database technologies, in the land sector [1,60]. The approach considers the impact a specific technology has on an organisation or its business processes from two perspectives: operational and strategic. In this vein, for any technology adoption, four (4) categories (represented graphically as quadrants) of impact can be identified: support; turnaround; factory; and strategic [59].

For the three (3) proofs-of-concept assessed, it is seen that despite the furthered maturity of the technology application, like [1], the adoption still remains within the turnaround quadrant. That is, the technology is being experimented with, with a view to understanding longer-term strategic impacts, but is not yet significantly impacting on day-to-day operations, production, and service delivery of land agencies.

Given the coarseness of the strategic grid analytical categories, it is not unsurprising that the three cases have not moved into the strategic categories in the intervening period since the work in [1] was undertaken: progress towards the strategic or operational quadrants most likely will require more lead time.

Nonetheless, despite the development trajectory shown in Section 5.2, it can be argued that there are still very real barriers to more scaled implementation of blockchain and smart contracts within the land sector. In the final part of this discussion, we further hypothesise the nature of these barriers, and the necessity for alternative adoption approaches, if not techniques for assessment.

5.4. Necessity for Sector-Wide Approaches

The three (3) comparative approaches illustrate that: (i) blockchain and smart contracts are viable solutions for delivering on the business requirements of land administration processes; (ii) whilst blockchain and smart contract uptake has progressed in the land administrations sector beyond mere conceptual work, it remains very much at the level of structured proof-of-concept work; and (iii) implementation and assessment tools focused on specific technologies and organisations, whilst able to reveal levels of socio-technical alignment and uptake, cannot explain the full context in terms barriers (if not benefits) to adoption. The first two points directly respond to the aims of the paper; however, the last point has the most significant implications for furthering work—and in this regard, several points are made.

First, it should be explored whether the barriers are discrete in nature, being able to be responded to with isolated interventions. Several hypotheses can be made for such discrete barriers, but each would require its own independent validation work. As one example, is uptake merely an issue of economics? In more developed contexts, although transaction fees may be the equivalent of hundreds or thousands of USD, comparatively, these amounts are still often very small against the total cost of a property[5]. As another example, the technology risk may be too high for conventional land sector players: new technological approaches bring new risks, and for mandated government monopolies, risk control and business continuity often trumps innovation or efficiency gains as an organisational driving force. The decentralised approach to data management is also a step away from the controlled centralised data approach of conventional land agencies. That is, the risk versus reward ratio is considered too great[6]. Legislative and regulatory barriers

[5] It should be noted that the transaction cost to property price ratio, in developing contexts, may make the technology more economically viable. This helps explain the numerous blockchain property starts-ups observed in those contexts.

[6] Again, in this regard, land sector smart contract solutions may come from outside the existing institutional frameworks, as demonstrated in [1], with start-ups offering alternative registration approaches.

are other examples of discrete blockers. If, for example, barriers like these are shown to be highly influential blockers, then furthering the implementation pathway appears to be more straightforward (i.e., revisit the business model; modify laws; or examine the risk appetite or an individual agency).

Second, if the above is not the case, it could be that the discrete examples are mere fragments of a broader sector-level or even societal level resistance. If this is the case, having proven the technical and local validity via the proofs-of-concept, it becomes necessary to return to sector-wide perspectives, or even broader analysis of societal trust. That is, "sector-aware" approaches for organising and assessing smart contract implementations appear more relevant than ever. Whilst a consortium approach, with a sector-wide mindset, was appropriately taken in each of the three proofs-of-concept, it seems any furthering or expanding of those cases will require more structured attention to sector-wide awareness raising, communications, and partnership building activities: the major benefits of the blockchain solution are likely found from a sector level analysis, rather than firm level analysis. Likewise, greater attention to policy, legal, financial, cross-institutional, capacity, and educational aspects appears necessary. Interestingly, it is these aspects and activities, alongside more technical aspects such as "data" and "standards", that the recently endorsed Framework for Effective Land Administration (FELA) [61], developed by UN-GGIM (United National Global Geospatial Information Management) (August 2020), argues as being essential for effective land administration in member countries. Indeed, the framework may act as a guide or blueprint for the land sector with regards to further scaling blockchain and smart contract implementation.

Third, in the same vein, with regards to assessment of implementations, as was already outlined in Section 2.3, mere consideration of business requirements adherence, technology readiness, or strategy grid, at the firm level, is not enough. More useful assessment of blockchain and smart contract implementations demands sector-wide (if not society-wide) tools and techniques. Here, the TOE framework and equivalents were already shown to have previous utility [39,42,43], and even in this study, with regards to blockchain application, however, arguably a greater focus on "processes" over "states" (or entities) is needed, as is an easily and simply applied analytical tool. This is no small challenge in the context of complex industry settings.

6. Conclusions

This article commenced by arguing that the emergence of "blockchain" technology spawned conceptual and design work across multiple sectors aimed at realising the earlier "smart contract" concept. These developments were also occurring in the land administration domain: researchers had actively investigated conceptual and logical designs, with sector-wide digital transformation often driving the thinking. It was also shown that less reporting of actual implementations of land sector blockchain solutions was evident, particularly those undertaken in collaboration with practicing land sector actors.

Building on these assumptions, this paper continued the discourse, giving an updated and more nuanced view of example applications, opportunities, and emerging blockers. In contrast to the earlier sector-wide transformative visions, this work focused on examining emerging hybrid solutions—those that mix the use of smart contract technologies with more conventional, and pre-existing, database and internet technology infrastructure. The approach appeared to offer a way to overcome blockers by minimising disruptions, whilst maximising the benefits of the new technological approach.

Through the examination of multiple multi-actor industry proofs-of-concept case studies from Sweden, Australia (State of New South Wales), and Canada (Province of British-Columbia), and subsequent comparative analysis, against the core principles of land dealings, strategic grid analysis, and technology readiness/maturity levels, the hybrid approach was shown to be technically feasible, whilst also ensuring adherence to the core business requirements of land sector actors. The tangible artefacts of the proofs-of-concept, including code development, and resultant data and document outputs, served as stronger forms of evidence for the capability smart contract approach, for system stakeholders, as opposed to mere conceptual descriptions. In this regard, the hybrid proof-of-concept solutions can be understood as an important and necessary step in any scaling process.

In terms of strategic grid analysis, the hybrid approach within land applications can be said to sit within the "turn-around" quadrant: the hybrid approach offers the pathway to move towards more scaled operational and production level implementation. This aligned with the technology readiness and maturation analysis, where the hybrid solutions suggest the technology readiness has moved firmly into more considered proof-of-concept stages (e.g., level 3 or 4), and blockchain maturation to be at the level of "structured" inquiry (e.g., level 1 or 2). However, cross-cutting issues still requiring research attention with regards to scaled implementation and continuation of the development trajectory will depend on reverting and broadening to a whole-of-sector (if not societal-wide) perspective, and re-examining concepts of institutional trust, legal and policy issues, sustainable business models, stakeholder awareness, partnership building, and data decentralisation and security, in the light of these findings.

Author Contributions: Conceptualisation, R.B., T.M., A.K. and M.P.; methodology, R.B., T.M. and M.P.; software, T.M., A.K.; validation, T.M. A.K., M.P. and R.B.; formal analysis, R.B. and M.P.; investigation, T.M. and A.K.; resources, A.K. and T.M.; data curation, T.M. and A.K.; writing—original draft preparation, R.B. and T.M.; writing—review and editing, A.K. and M.P.; visualisation, T.M. and R.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors wish to acknowledge the support of colleagues at ChromaWay (Sweden/USA), Land Title and Survey Authority of British Columbia (Canada), Kadaster International (Netherlands), and Swinburne Business School during the research and writing phases of this article. They also acknowledge that an abstracted version and less developed version of this work was previously presented at the 2019 Annual World Bank Conference on Land and Poverty.

Conflicts of Interest: The authors declare no conflict of interest, but acknowledge and declare members of the authorship team maintain affiliation and connection to several of the organisations included in the study. The potential for these affiliations to influence the representation or interpretation of reported research results is acknowledged.

References

1. Bennett, R.M.; Pickering, M.; Sargent, J. Transformations, transitions, or tall tales? A global review of the uptake and impact of NoSQL, blockchain, and big data analytics on the land administration sector. *Land Use Policy* **2019**, *83*, 435–448.
2. Olsen, B.L. Beyond the Hype: Exploring Blockchain Technology in Land Administration—A Case Study of Ghana and Property Rights. Masters's Thesis, Copenhagen Business School, Copenhagen, Denmark, 17 September 2020.
3. Pisa, M.; Juden, M. *Blockchain and Economic Development: Hype* vs. *Reality*; Center for Global Development: Washington, DC, USA, 2017; Volume 107, p. 150.
4. Thomas, R.; Huang, C. Blockchain, the Borg collective and digitalisation of land registries. *Convey. Prop. Lawyer* **2017**, *81*, doi:10.2139/ssrn.3324828.
5. Martyn, A. The Concept of Land Plot as a Combination of Smart Contracts: A Vision for Creating Blockchain Cadastre. *Balt. Surv.* **2018**, *8*, 68–73, doi:10.22616/j.balticsurveying.2018.009.
6. Karamitsos, I.; Papadaki, M.; Al Barghuthi, N.B. Design of the blockchain smart contract: A use case for real estate. *J. Inf. Secur.* **2018**, *9*, 177–190.
7. Ameyaw, P.D.; de Vries, W.T. Transparency of Land Administration and the Role of Blockchain Technology, a Four-Dimensional Framework Analysis from the Ghanaian Land Perspective. *Land* **2020**, *9*, 491.
8. Zevenbergen, J.; Frank, A.; Stubjkaer, E. *Real Property Transactions. Procedures, Transaction Costs and Models*; IOS Press: Amsterdam, The Netherlands, 2008.
9. Szabo, N. Formalizing and Securing Relationships on Public Networks. *First Monday* **1997**, *2*, doi:10.5210/fm.v2i9.548.
10. Lauslahti, K.; Mattila, J.; Seppala, T. Smart Contracts How Will Blockchain Technology Affect Contractual Practices? *SSRN Electron. J.* **2017**, doi:10.2139/ssrn.3154043.
11. Vos, J.A.; Lemmen, C.H.; Beentjes, B.E. Blockchain based land administration feasible, illusory or a panacea. In Proceedings of the 2017 World Bank Conference on Land and Poverty Washington, DC, USA, 20–24 March 2017.

12. Lemmen, C.; Vos, J.; Beentjes, B. Ongoing Development of Land Administration Standards: Blockchain in Transaction Management. *Eur. Prop. Law J.* **2017**, *6*, 478–502.
13. Larsson, G. *Land Registration and Cadastral Systems; Tools for Land Information and Management*; Longman Scientific and Technical: Norfolk, UK, 1991.
14. Zevenbergen, J. *Systems of Land Registration Aspects and Effects*; Publications on Geodesy: Delft, The Netherlands, 2002.
15. Simpson, S.R. *Land Law and Registration*; Cambridge University Press: Cambridge, UK, 1976.
16. Williamson, I.; Ting, L. Land administration and cadastral trends—A framework for re-engineering. *Comput. Environ. Urban Syst*. **2001**, *25*, 339–366.
17. Griffith-Charles, C. The application of the social tenure domain model (STDM) to family land in Trinidad and Tobago. *Land Use Policy* **2011**, *28*, 514–522, doi:10.1016/j.landusepol.2010.10.004.
18. Henssen, J. *Land Registration and Cadastre Systems: Principles and Related Issues*; Technische Universität München: Munich, Germany, 2010.
19. Barry, M.; Augustinus, C. Property theory, metaphors and the continuum of land rights. In *Securing Land and Property Rights for All*; UN-Habitat/Global Land Tools Network Nairobi: Nairobi, Kenya, 2015.
20. Lemmen, C.; Van Oosterom, P.; Bennett, R. The land administration domain model. *Land Use Policy* **2015**, *49*, 535–545.
21. Zevenbergen, J.; Augustinus, C.; Antonio, D.; Bennett, R. Pro-poor land administration: Principles for recording the land rights of the underrepresented. *Land Use Policy* **2013**, *31*, 595–604, doi:10.1016/j.landusepol.2012.09.005.
22. Zakout, W.; Wehrmann, B.; Torhonen, M.P. *Good Governance in Land Administration;* World Bank: Washington, DC, USA, 2006.
23. Dale, P.; McLaughlin, J. *Land Administration*; Oxford University Press: Oxford, UK, 2000.
24. Burns, T.; Grant, C.; Nettle, K.; Brits, A.M.; Dalrymple, K. Land Administration Reform: Indicators of Success and Future Challenges. *Agric. Rural Dev. Discuss. Pap.* **2007**, *37*, 1–227.
25. Bennett, R.; Wallace, J.; Williamson, I. Organising land information for sustainable land administration. *Land Use Policy* **2008**, *25*, 126–138.
26. Griggs, L.; Thomas, R.; Low, R.; Scheibner, J. Blockchains, Trust and Land Administration–The Return of Historical Provenance. *Prop. Law Rev.* **2017**, *6*, 180.
27. Zevenbergen, J.; De Vries, W.; Bennett, R.M. (Eds.) *Advances in Responsible Land Administration*; CRC Press: Boca Raton, FL, USA, 2015.
28. The Law Handbook 2020. Available online: https://www.lawhandbook.org.au/2020_00_00_05_glossary/ (accessed on 20 January 2020).
29. Ryan, F. *Round Hall Nutshells Contract Law*; Thomson Round Hall: Dublin, Ireland, 2006.
30. Hemmo, M.; Sopimusoikeus, I. *Uudistettu Painos*; Talentum Media Oy: Helsinki, Finland, 2003.
31. Hemmo, M. *Sopimusoikeuden Oppikirja*; Talentum Media Oy: Helsinki, Finland, 2006.
32. Nakamoto, S. Bitcoin: A Peer-to-Peer Electronic Cash System. Manubot. (from 2008). Available online: https://nakamotoinstitute.org/bitcoin/ (accessed on 20 November 2019).
33. Buterin, V. A next-Generation Smart Contract and Decentralized Application Platform. White Paper. Available online: https://cryptorating.eu/whitepapers/Ethereum/Ethereum_white_paper.pdf (accessed on 3 January 2014).
34. Christidis, K.; Devetsikiotis, M. Blockchains and smart contracts for the internet of things. *IEEE Access* **2016**, *4*, 2292–2303.
35. Wang, S.; Ouyang, L.; Yuan, Y.; Ni, X.; Han, X.; Wang, F.Y. Blockchain-enabled smart contracts: Architecture, applications, and future trends. *IEEE Trans. Syst. Man Cybern. Syst*. **2019**, *49*, 2266–2277.
36. Webster, A.; Gardner, J. Aligning technology and institutional readiness: The adoption of innovation. *Technol. Anal. Strateg. Manag.* **2019**, *31*, 1229–1241.
37. Sauser, B.J.; Ramirez-Marquez, J.E.; Henry, D.; Di Marzio, D. A system maturity index for the systems engineering life cycle. International. *J. Ind. Syst. Eng.* **2008**, *3*, 673–691.
38. Hicks, B.; Larsson, A.; Culley, S.; Larsson, T. A methodology for evaluating technology readiness during product development. In Proceedings of the 17th International Conference on Engineering Design (ICED'09) *Design Has Never Been This Cool*, Stanford University, Stanford, CA, USA, 24–27 August 2009.
39. Janssen, M.; Weerakkody, V.; Ismagilova, E.; Sivarajah, U.; Irani, Z. A framework for analysing blockchain technology adoption: Integrating institutional, market and technical factors. *Int. J. Inf. Manag.* **2020**, *50*, 302–309.
40. Ammous, S.H. Blockchain Technology: What is it Good for? *SSRN Electron. J.* **2016**, 2832751, doi:10.2139/ssrn.2832751.
41. 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, doi:10.1016/j.giq.2017.09.007.
42. Depietro, R.; Wiarda, E.; Fleischer, M. The context for change: Organization, technology and environment. *Process. Technol. Innov*. **1990**, *199*, 151–175.
43. Clohessy, T.; Treiblmaier, H.; Acton, T.; Rogers, N. Antecedents of blockchain adoption: An integrative framework. *Strateg. Chang.* **2020**, *29*, 501–515.
44. Humphrey, W.S. *Managing the Software Process*; Addison-Wesley Longman Publishing Co., Inc.: Boston, MA, USA, 3 January 1989.
45. Paulk, M.C.; Curtis, B.; Chrissis, M.B.; Weber, C.V. *Capability Maturity Model for Software*, Version 1.1; Software Engineering Institute: Pittsburgh, PA, USA, February 1993; CMU/SEI-93-TR-24, DTIC Number ADA263403.

46. Osterland, T.; Rose, T. From a Use Case Categorization Scheme Towards a Maturity Model for Engineering Distributed Ledgers. In *Blockchain and Distributed Ledger Technology Use Cases*: Springer: Cham, Switzerland, 2020, pp. 33–50.
47. Kaczorowska, M. Blockchain-based Land Registration: Possibilities and Challenges. *Masaryk. Univ. J. Law Technol.* **2019**, *13*, 339–360, doi:10.5817/mujlt2019-2-8.
48. Tashakkori, A.; Teddlie, C.; Teddlie, C.B. *Mixed Methodology: Combining Qualitative and Quantitative Approaches*; Sage: Thousand Oaks, CA, USA, 24 June 1998.
49. Steudler, D.; Rajabifard, A.; Williamson, I.P. Evaluation of land administration systems. *Land Use Policy* **2004**, *21*, 371–380, doi:10.1016/j.landusepol.2003.05.001.
50. Çağdas, V.; Stubkjaer, E. Design Research for Cadastral Systems. Comput. Environ. *Urban Syst*. **2011**, 35, 77–87.
51. Mitchell, D.; Clarke, M.; Baxter, J. Evaluating land administration projects in developing countries. *Land Use Policy* **2008**, *25*, 464–473, doi:10.1016/j.landusepol.2007.10.004.
52. Cete, M.; Yomralioglu, T. Re-engineering of Turkish land administration. *Surv. Rev.* **2013**, *45*, 197–205, doi:10.1179/1752270612y.0000000027.
53. Ramadhani, S.A.; Bennett, R.M.; Nex, F.C. Exploring UAV in Indonesian cadastral boundary data acquisition. *Earth Sci. Inform.* **2018**, *11*, 129–146.
54. Polat, Z.A.; Alkan, M. Design and Implementation of A LADM-Based External Archive Data Model for Land Registry and Cadastre Transactions in Turkey: A Case Study of Municipality. Land Use Policy 2018, 77, 249–266.
55. Asiama, K.O.; Bennett, R.M.; Zevenbergen, J.A. Participatory Land Administration on Customary Lands: A Practical VGI Experiment in Nanton, Ghana. *ISPRS Int. J. Geo-Inf.* **2017**, *6*, 186, doi:10.3390/ijgi6070186.
56. Unger, E.M.; Bennett, R.M.; Lemmen, C.; de Zeeuw, K.; Zevenbergen, J.; Teo, C.; Crompvoets, J. Global policy transfer for land administration and disaster risk management. *Land Use Policy* **2020**, *99*, 104834.
57. Mehar, M.I.; Shier, C.L.; Giambattista, A.; Gong, E.; Fletcher G, Sanayhie R, Kim HM, Laskowski, M. Understanding a revolutionary and flawed grand experiment in blockchain: The DAO attack. *J. Cases Inf. Technol.* **2019**, *21*, 19–32.
58. Jobin, C.; Le Masson, P.; Hooge, S. What does the proof-of-concept (POC) really prove? A historical perspective and a cross-domain analytical study. In XXIXth conference of the International Association of Strategic Management (AIMS), Baku, Azerbaijan, 11–13 June 2020.
59. Applegate, L.M.; Austin, R.D.; McFarlan, F.W. *Corporate Information Strategy and Management: Txct and Cases*; McGraw-Hill/Irwin Custom Publishing: New York, NY, USA, 2006.
60. Bennett, R.M.; Wallace, J.; Williamson, I. Integrated Land Administration in Australia: The need to align ICT strategies and operations. In Annual SSSI Conference, Melbourne, Australia, 25 August–1 September 2005.
61. UNGGIM, The Framework for Effective Land Administration. In Proceedings of the United Nations Global Geospatial Information Management—Expert Committee, New York, NY, USA, 26–27 August 2020.