Blockchain-Based Land Registers: A Law-and-Economics Perspective

Georg von Wangenheim

Abstract Both land registration and blockchains pursue the production of immutable information. Land registration is hence among the most often suggested use cases of the blockchain technology. However, only a very small number of successful large-scale applications exist in the wild. This chapter aims at explaining why this number is so low despite blockchain's *prima facie* suitability for land registration. After laying technical and legal foundations, we argue that trading shares of real estate investment funds on a blockchain has little to do with land registration. This allows us to concentrate on the benefits that the blockchain technology may provide for land registration in a proper sense. We show that "anchoring" land registers in public blockchains by regularly writing hash values of their content in one or several of those blockchains can overcome lack of trust in the immutability of digitized land registers without affecting the latter's rules and organization. In contrast, implementing the entire land registration system on a blockchain and change rules and governance accordingly may result in high efficiency and effectiveness. This may be a big leap forward for many jurisdictions. In jurisdictions with already well-functioning land registration systems, the gain from a transition to the blockchain technology tends to be small for both deeds recordation and title registration systems, in fact often too small to justify the costs of transition. The major reason is that many inevitable links between real-estate reality to its blockchain representation require human decisions to balance the diverging interests of affected parties.

Keywords Blockchain · Land registration · Real estate investment · International comparison · Cost-benefit analysis

G. von Wangenheim (✉)
Faculty of Economics, University of Kassel, Kassel, Germany
e-mail: g.wangenheim@uni-kassel.de

A. Lehavi, R. Levine-Schnur (eds.), *Disruptive Technology, Legal Innovation, and the Future of Real Estate*, https://doi.org/10.1007/978-3-030-52387-9_6

1 Introduction

Despite the hype about blockchain technology in late 2017 and early 2018, successful use cases for the technology are still rare. Land registration and, more general, exchange of real property is one of the few cases, for which a small number of, at least seemingly, successful examples exist and for which many advocates of the technology expect more successful examples to arise. They believe that blockchains and the underlying distributed ledger technology will be able to substantially accelerate and facilitate the procedure of transferring property in real estate, reduce fixed costs of these procedures and thus open real estate for divided and small scale investments and crowd funding, obsolesce notaries for transferring real property and at the same time increase the reliability of land registration.

In fact, several administrations like those of Sweden and Georgia have endeavored to implement land registration or parts of the underlying procedure on a blockchain (Benbunan-Fich & Castellanos, 2018; Kaczorowska, 2019). Some US American counties (Teton County, Wyoming, and South Burlington, Vermont) are collaborating with Blockchain firms to move their deeds registers to blockchain applications (Hamilton, 2019). Attempts of other jurisdictions, like e.g. Honduras, have failed (Benbunan-Fich & Castellanos, 2018)–probably not the least due to the threat of secure registration that was unwelcomed by land-grabbing politicians. In countries where land registration is feeble and developing slowly, private organizations have been and still are striving for a blockchain-based registration system to complement and, eventually, substitute the official government system (e.g. Kenya's *Land Layby Listing*, see LandLayBy, 2018) and development aid organizations like the German *GIZ* suggest to rely on the blockchain technology to implement workable land registration systems.

However, none of the attempts to bring land registers to a blockchain has been completed yet. Many proposals to establish blockchain-based land registration appear to neglect many of the intricacies of land registration. This chapter aims at clarifying why moving land registration to a blockchain is so difficult or not worthwhile at all. At the same time, the chapter also attempts to look at the problem from a positive angle by asking how blockchains and the underlying distributed ledger technology can improve land registration.

To answer these questions, I will clearly distinguish between four different modes of connecting real estate to a blockchain: blockchain-based real estate funds, anchoring digitized land registers in blockchains, digitizing deeds registers in a blockchain including the Swedish case of pre-registration of deeds, and, finally, tokenization of rights in real estate. Only the latter two are moving land registration to a distributed ledger *sensu stricto* and can be applied only to deeds registration systems and, respectively, title registration systems. Hence these two approaches deserve more detailed discussion than the former two. Before diving into this discussion, I will provide some technological background of the blockchain and distributed ledger technology, the understanding of which is prerequisite for a sound discussion of land registers on a blockchain. Similarly, I will briefly recall some features and distinctions of land registration law.

Other authors like Arruñada (2018), Kaczorowska (2019) or—most pessimistic—Barbieri and Gassen (2017) have also discussed the prospects of using the blockchain technology to improve land registration. What this chapter adds to the literature is that it carefully distinguishes modes of combining blockchain and land registration and at the same time considers the variations of land registration in many dimensions.

2 Technical Background

Assessing the merits of various approaches to connect land registration to blockchains requires some central elements of the underlying technology. This is not the place to review blockchain and distributed ledger technology in general (see Biais, Bisière, Bouvard, & Casamatta, 2019; Chen, Cong, & Xiao, 2019; Zheng, Xie, Dai, Chen, & Wang, 2018 for concise overviews). I will rather concentrate on the elements of the technology that are indispensable for discussing the pros and cons of registering land on blockchains. As the Bitcoin blockchain is prototypical for all blockchains on distributed ledgers and relatively simple to understand, I will use this blockchain to introduce the technology.

In the Bitcoin system we must distinguish two chains. One is the chain of blocks of information, which produces immutability, and the other is the chain of transactions, which secures correctness of ownership of bitcoins or shares thereof (*Satoshis*). Blocks of information are chained to each other by the hash value of the previous block. As the hash value is like a fingerprint and extremely hard to reproduce by an alternative block of information, it is impossible to alter any information in a past block of a blockchain without altering all subsequent blocks as well. To make such a reproduction of an alternative chain difficult, Satoshi Nakamoto, the unknown inventor of Bitcoin, stipulated requirements for the validity of a block which can only be fulfilled if the worldwide computing power used to work (honestly) on the Bitcoin blockchain is busy for about 10 min (Nakamoto, 2008). Inventing an alternative chain then requires at least half of this hashing power—whence the label "51-percent attack"—or chances to catch up with the ongoing calculations of new blocks in the correct chain are extremely low. Garay, Kiayias, & Leonardos (2015) suggest that other types of attacks also require a majority of the computing power used for mining in the relevant blockchain.

All (full) nodes of the system—during the last 2 years about ten thousand—store this chain of blocks of information and compare their information to the chain of others. As storing and working on the production of valid new blocks is only valuable if one stores the same chain that most others accept, every owner of a node (a "miner") aims at working with the version of the chain that he expects others to work with. On first sight, this seems to be what economists call a beauty contest (first introduced by John M. Keynes, 1936, p. 156). However, there is a strong empirical signal of what chain other miners will work with if there are more than one branches: the longer a branch, the harder it is to change ex post and thus the better it is to work with this branch. As a consequence, if the blockchain forks

(which it does from time to time), very quickly the miners re-coordinate on one of the branches, namely the one that grew longer the fastest. This "consensus mechanism" is called "proof of work" because a branch grows faster if more work (i.e. hardware and energy to run it) is invested in it. The consensus mechanism has been strong enough to forestall any ex-post mutations of the Bitcoin blockchain since its start some 11 years ago.

The chain of transactions secures a proof of ownership of Bitcoins and Satoshis, where the word "ownership" is loosely used and not in a strict legal sense.[1] This chain allows to trace back the transfers of the currency from owner to previous owner to the original producer of the Bitcoins—again a miner. In that respect, the Bitcoin blockchain resembles the very idea of land registers, the more so, if they record deeds rather than register titles.

This combination of (1) a chain of information blocks, (2) a distributed ledger with a self-enforcing consensus mechanism, and (3) a chain of ownership transfers implies a number of desirable properties of the Bitcoin blockchain. These properties induce many to seek solutions to numerous problems, in particular to problems of land registration, in the blockchain technology.

Foremost among these properties is immutability. To change the information that is stored in a block which is older than an hour or so, one would need command of more than half of the total worldwide computing power to calculate hash values or a tremendous amount of luck. As this computing power does not only have to be under one's command but also needs to be fueled by an amount of electricity which is similar to half of the average consumption of Denmark, attacking the Bitcoin blockchain is extremely expensive–which usually turns working for the security of the Bitcoin blockchain far more profitable in expectation than working against it. Hence only very few have attempted to alter information in the Bitcoin blockchain, and no one has ever succeeded during the 11 years that the Bitcoin blockchain exists when this book will be printed.

One should be aware though, that this security of the Bitcoin Blockchain is a consequence of its underlying characteristics. A successful attack is so costly because it requires command of a large proportion of the worldwide computing power—and the corresponding electricity. If the Bitcoin blockchain consumed less computing power—and less electricity—an attack would be far cheaper. Thus, immutability results from Bitcoin's proof-of-work consensus mechanism only because Bitcoin collects a large proportion of the worldwide computing power to calculate hash values and consumes a lot of energy. The number of immutable blockchains based on proof of work hence cannot be large, at most three or four in the world.[2]

A second property of the Bitcoin Blockchain, that makes it so attractive, is its resilience. As the information is stored by about ten thousand nodes all over the

[1] In some jurisdictions Bitcoins as virtual commodities cannot be owned as property nor can they be object of any other legal right.

[2] With five competing blockchains, the smallest one would use less than 20% of the computing power. Redirecting computing power from other blockchains would make a 51-percent attack relatively easy.

world, even a worldwide power outage cannot destroy the immutable ledger. As soon as power is back, the nodes will restart to use, exchange and compare the information and only unaltered chains will become generally accepted.

The third property of the chain is its accessibility for both reading and writing new information to it. The latter, writing accessibility, requires a fee large enough to induce miners to include the new information in the block they are working on. As storage space and the number of transactions that the Bitcoin blockchain can perform is scarce, nobody claims that entire land registration systems could be brought to the Bitcoin blockchain.

Proponents of other blockchains do not simply replicate the Bitcoin blockchain. They rather claim to improve on the technology by altering some of Bitcoin's features. Obviously, that may affect the properties that make Bitcoin so immutable, resilient and accessible. To distinguish between different blockchains, one should look at the following characteristics carefully.

Blockchains may be public ("permissionless") or private ("permissioned"). One should note that a blockchain run by a single firm or a single government body—or consortia thereof—is by definition a private blockchain.

Proof of work as the mechanism making an instance of a chain reliable, may be replaced by other "consensus mechanisms", provided these mechanisms are as hard to circumvent as proof of work. Proof of stake has often been discussed as a candidate because ownership of a chain's currency or other values enshrined in the chain are stakes that will deter any fiddling around with the reliability of the chain. However, proof of stake has not yet been implemented in any large public blockchain until today.

What many people seem to accept as an alternative to proof of work is proof of authority, where endorsement of the chain by one or several authorities secures immutability. These authorities may be powerful firms, like IBM's blockchain based on hyperledger, or a trustworthy government. Proof of authority obviously becomes more reliable if more than one institution runs a blockchain and their consensus (or majority) is required for including the next block into the blockchain. The more these institutions distrust each other, the less likely they collude and thus the safer a consortium-run blockchain becomes. Of course, proof of authority contradicts the idea of a permissionless blockchain and excludes unrestricted access at least to writing to the blockchain.

Scalability is a feature of blockchains that Bitcoin is lacking. However, when talking about land registration on a blockchain, then scalability is of utmost importance.

Finally, blockchains (other than Bitcoin) need not be restricted to storing static information but may also be able to execute programs. While these programs are misleadingly called "smart contracts" (the name "chaincode" used by hyperledger fabric seems to be more appropriate), they are most relevant for registering rights in land, because they allow for conditional transfer of rights which are inevitably executed once the conditions are met.

With this basic understanding of the most relevant properties of the Bitcoin blockchain and of other blockchains, it makes sense to take a brief look at the vast

variation of land registration systems we observe in the world before we turn to alternative approaches to bring land registration to a blockchain.

3 Legal Background of Land Registration

The idea of land registration is obvious and simple. Transfer of property as a right *in rem* requires some sort of evidence for the public because *in-rem* rights are valid against all persons (see Baird & Jackson, 1984). Two sources of evidence are traditional to produce publicity of the transfer of property: possession and chain of title (e.g. Arruñada, 2003). While possession and transfer thereof is sufficient information for most movables, possession in land is much harder to observe and to uphold. Hence, land registration either in the form of recordation of deeds of transfer or as registration of titles in land replaces possession for the transfer of ownership (and other rights) on land in most jurisdictions. Land registration in both its variants is similar to blockchains inasmuch as both are append-only ledgers. Land registration therefore suggests itself as a use case for blockchains and corresponding projects are abundant.

However, such projects and suggestions have to survive in, and adapt to, specific legal environments. Few legal concepts aiming at one common objective, though, differ so much in their details across jurisdictions as does land registration. At least a dozen dimensions in which such differences prevail should be considered relevant (see for example Zevenbergen, 2002, pp. 47–82, for an overview on many of these dimensions). Not all are completely independent of each other, but none of them determines the specification of another without any degree of freedom.

First and foremost is of course the distinction between deeds recordation and title registration. While countries like France and most counties in the US record deeds and rely on a long enough chain of recorded deeds for proof of ownership, countries like Germany and Australia register titles and allow ownership to be proven by reference to the title registered. Other countries rely on a combination of both systems (e.g. Sweden) or are in the course of a transition from deeds recordation to title registration (e.g. England and Wales as well as Israel have completed the transition for the vast majority of their territory). Closely related to this dimension is the distinction between what interests in land are registered. On the one hand, England and Wales register all rights including temporary transfer to tenants. On the other hand, most counties in the US only register transfer of property and contractual mortgages while other interests like easements or usufructs in the same real estate may be registered elsewhere or not at all (see Spielman, 2016, pp. 17–19, for an interesting report of the typical procedure), which is the main reason for the existence of the industry of title searchers and title insurance. Most jurisdictions lack registration of administrative-law interests.

Further dimensions are

- the power of the information the register contains: this information may provide conclusive evidence, it may be indefeasible, it may produce good faith or it may be merely informative;
- whether the register provides only positive or also negative evidence: in the former case, the aforementioned power of the information refers to what is actually registered, i.e. anyone can rely on the information included in the register being correct; in the latter case, it also refers to what is not registered, i.e. anyone can rely on the information included in the register being also complete;
- the legal quality of entries into the register: they may be constitutive for the transfer of rights or only declaratory;
- the accessibility of the register: it may be open to anyone, to anyone who is willing to pay a fee (typically per real estate on which he or she seeks information), to anyone who claims or can prove a legitimate interest in the information, or only to notaries;
- the degree of digitization: the register may be based on paper, may be a mere digitization of a paper version, may be a publicly accessible databank, or it may be a platform on which outsiders (like sellers or buyers of real estate, possibly only if represented by a notary or so) can directly alter the content of the databank;
- whether the land register contains a cadaster or refers to a cadaster or is independent of any cadaster;
- the existence of priority notices (warning notes, caution remark, *caveats*, *Vormerkung*), which guarantee that a certain future transfer of rights legally precedes all transfers of rights which are performed after such a notice;
- the role of notaries;
- the reliability of the list of pending registration applications, if such a list exists;
- the share of the land of a jurisdiction that is covered by the register: in particular in countries like England and Wales that have introduced the register only in the recent past (which includes some one hundred years in the case of England and Wales) not all land is already registered.

Given this wide range of possible legal differentiation, writing about, or even doing business in, bringing real estate to the blockchain requires careful consideration of the exact project and how it fares in specific legal environments. While such considerations have to remain far from complete in a mere book chapter, the first two subsections of the next section aim at drawing the reader's attention to the most severe inaccuracies that one should avoid in a discussion of real estate on the blockchain.

4 Different Ways of Moving Land Registers to a Blockchain

Based on the technical and legal background of land registration on blockchains, we study the four different approaches very briefly alluded to in the introduction. We start with a closer look at real estate investment funds or trusts. As this approach

does not change land registration but only alters the market for shares of these funds or trusts, the idea will only be briefly discussed. The second approach we look at is what we observe in Georgia, where a digital title register has been newly implemented and connected ("anchored") to blockchains to "borrow" the latter's immutability. This approach may constitute a disruptive change of land registration in jurisdictions currently lacking trust in the immutability of its registers. However, using a blockchain in this way does not interfere with the essence of land registration. Consequential legal questions remain minor.

This is different for a complete transfer of land registration to a distributed ledger. As legal consequences of such "blockchainization" of land registration depend crucially on the type of land registration, this chapter first considers how systems of deeds recordation could be implemented on a blockchain. We can again refer to a prominent example, this time from Sweden. However, the example seems to be less of a success than the Georgian one. Finally, the chapter turns to systems of title registration which imply far more legal problems which seem to require interference with the very idea of a blockchain, its immutability. The difference between the systems becomes most important, if it goes along with the registration being constitutive for the transfer of rights and not only declaratory.

4.1 Reals Estate Funds

Real estate funds organized on a blockchain are by far the most prominent example of business endeavors bringing together real estate and the blockchain technology. From a legal perspective, however, such ideas have hardly anything to do with moving land registration to the blockchain. If they would, severe incentive problems would quickly trim down any profits of the fund and eventually destroy it.

Advertisements of such firms, most often start-ups with little real business, claim that property of real estate can be tokenized in their blockchain application and then splitting property into small shares and trading them is claimed to become as easy as using a smart phone for transferring money. Imagine this were actually so and whoever had a token representing property in a real estate were co-owner of it. Then any decision on the property would require some form of consent of all owners. Unless otherwise agreed upon, unanimity of all co-owners would be required in many jurisdictions, at least when decisions concern transfer of property of the real estate. This would result in severe anti-commons problems as each and every co-owner would be tempted to extract as much as possible from any profitable decisions requiring his consent. If decisions only required majority votes, administering the real estate would still be far too inflexible. Or owners would have to transfer major decision rights to a manager, which would diametrically contradict the very idea of ownership. It is thus no surprise that tokenization of real estate hardly ever takes this legal route.

What the proponents of the approach actually think of, is tokens representing indirect ownership, i.e. ownership of shares of a fund or a company which then in

turn is the *sole* owner of the real estate. It is only these shares of a fund or a company that are traded on a blockchain, not ownership of real estate. While this solves the problems associated with multiple ownership in resources, the idea has nothing to do with land registration on a blockchain. Only company or fund shares are traded on the blockchain. Doing so may of course be advantageous on the one hand and raise intricate corporate law questions on the other, but these questions are far beyond the scope of this chapter on blockchain base land registers.

4.2 Digitizing Registers and Anchoring Them in Blockchains

A second approach to linking the blockchain technology and land registration which has actually been applied in the real world is anchoring an existing or newly created digitized land register to an existing blockchain. The idea of the approach is simple: The state of the register (or parts thereof) are fixed and stored from time to time. Hash values of the states are saved in one or several blockchains which are generally accepted as being immutable—like for example the Bitcoin Blockchain or the Ethereum blockchain. As a consequence, anybody who can compare the hash of the state of the register with the hash value stored in the blockchain easily detects every ex post alteration of the content of the register. By anchoring the register to one or several blockchains in this way, the register "borrows" the immutability of blockchains to prove its own reliability.

The most prominent example for this approach is Georgia, where the government collaborated with Bitfury, originally a Bitcoin mining company but later a general blockchain technology firm, to anchor an already digitized, but until then notoriously unreliably title register in the Bitcoin blockchain (for a detailed overview see Shang & Price, 2018).

This approach combines the obvious advantages of digitization on a central register with the immutability of blockchains. The advantages of digitization on a central register are manyfold. On the legal side, the approach does not restrict the details of the land registration system in any way. Legislators need not alter a well-functioning system of land registration in any way or may import or newly design whatever they think to be an ideal system of land registration.

Digital land registers are much more easily accessible than paper-based registers for collecting information on transfers or the state of rights for systems of deeds and, respectively, title registration. Accessibility can easily be restricted or opened up to any desired degree. For example in Germany, no one has access to the information contained in the land register, unless he or she has a legitimate interest, while countries like Austria or Israel grants access to anybody willing to pay the fee. If such access is restricted to information on parcels of land—as is the case in Austria–the fee becomes prohibitive for searching what real estate an individual person owns—a restriction that may be imperative for data protection rights.

Central ledgers allow for far more efficient storage of data while at the same time back-up files can easily be stored with the central authority. In particular for title

registration systems, old data on transfer of rights may be deleted without loss of conclusiveness of the information contained in the register.

The approach hinges, of course, on how resistant the blockchains to which one anchors the land register is against attacks and for how long this can be guaranteed. For the time being, only blockchains based on proof of work or proof of authority seem to be sufficiently immutable. Proof of stake has been proffered frequently as an alternative, but no big blockchain is based on this consensus mechanism to date. The reason seems to be that only proof of work is self-enforcing. For any other consensus mechanism large amounts of computing power may be abused to forge the criteria on which the allocation of mining rights is based. Proof of work guarantees at least, that large amounts of computing power can only be used according to the idea of the consensus mechanism. Hence, attacks against the immutability of a blockchain require more than half of the worldwide computing power used for the respective blockchain.

Obviously, this is a severe obstacle for potential attackers only if this computing power covers a large proportion of the overall worldwide computing power. Hence only those three or four proof-of-work blockchains which accumulate the largest share of the worldwide hashing power are relevant candidates for anchoring. In fact, Georgia has chosen Bitcoin as anchor.

Blockchains based on proof of authority derive their trustworthiness and immutability from the promises of the providers that they will keep the blockchain unaltered and that they will control each other. If the individual providers are themselves sufficiently trustworthy and the entire group of providers is sufficiently averse to collude with each other, proof of authority constitutes a valid alternative to proof-of-work blockchains. Capturing a sufficiently large proportion of the nodes to alter the content of the blockchain ex post becomes equally difficult as accumulating more than half of the hashing power of the largest proof-of-work blockchains.

Chromia, the blockchain on which the Swedish approach to connect real-estate property transfers to a blockchain (for details see below) is based, aims at taking this route at least in the long run (ChromaWay, 2019).[3] To further add to the immutability of their blockchain, they reinforce the power of proof of authority by anchoring several such blockchains to each other and combine proof of authority with anchoring their blockchains to the Bitcoin and the Ethereum blockchains.

4.3 Deeds Recordation in Blockchains

Instead of anchoring an existing or newly developed electronic land register to one or several blockchains one may consider implementing the entire land registration on a blockchain in order to fully benefit from the advantages and potentials of the

[3] Outside the area of land registration, proof of authority underlies several major blockchain projects, such as the academic blockchain-based repository “bloxberg” or facebook’s “libra” currency.

blockchain technology. In this section we consider the most relevant legal questions and problems that entail for such blockchain-based deeds recordation systems. Title registration systems will follow in the subsequent section.

First and foremost the blockchain underlying the register has to be carefully selected. Public blockchains such as the Bitcoin blockchain may currently look very stable, but for land registration life expectancy of the selected blockchain must be extremely long. Time horizons that appear close to eternal in computer science are far too short when it comes to the durability of land registration. As a consequence, public blockchains that appear and evolve on a voluntary basis of private individuals exhibit too large a chance of being replaced by an even better alternative. To avoid expensive migrations of a blockchain-based land register from one blockchain to another and to avoid phases of unsecure registration when an "old" blockchain is at the edge of being abandoned by most of its users, government-backed private blockchains appear to be the superior choice.

As mentioned earlier, such blockchains tend to use proof of authority as consensus mechanism. However, if there is only one authority running the land registration blockchain, there is little reason to rely on the blockchain technology at all. Either authority is trustworthy enough to make everyone believe in the authorities' restraint from any temptation to change the content of the blockchain retrospectively and thus to believe in the immutability of the register. But then this trustworthiness will not be increased by using the blockchain technology and it will in itself be sufficient to create a high degree of trust in land registration. Using a blockchain in this case is superfluous.

Or the authority is not trustworthy enough to implement a land registration system. But then it is also not trustworthy enough to guarantee the immutability of the blockchain underlying the land registration system. If this is the case, building the blockchain on proof of authority of the members of a larger consortium of authorities is likely to solve the problem. As mentioned earlier, such a consortium of authorities may provide a sufficient degree of trustworthiness if each of the authorities are sufficiently trustworthy and if they mutually mistrust each other. Such consortia for setting up blockchains across several local, regional or even national authorities are likely to be beneficial in other fields than land registration as well.

Whatever the choice of blockchains is, a deeds recordation system requires linking the chain of deeds inside the blockchain to the chain preceding it. As any other electronic register, blockchains may render title searching unnecessary, or a very simple task, if at least registration numbers of deeds are searchable. Obviously, this can only apply to deeds registered in the blockchain system. As they eventually have to refer to the previously existing chain, the latter becomes irrelevant only after a very long time. One could of course consider registering ownership and other rights in land whenever such rights are transferred for the first time by making use of the blockchain-based register. Any person claiming rights in that property would then have to produce a chain of title only lasting to this initial legal status—which would be an easy endeavor given appropriate search functions of the blockchain-based register. However, such a registration of rights would be tantamount to changing the entire system to a title registration system. We abstract from this possibility in this

section and refer to the discussion of title registration in the next subsection. Without such a substantial change in the nature of the land registration system benefits from using the blockchain technology for digitizing the deeds records are small and become relevant only after a large number of years or decades.

Further questions, which are not really specific to blockchain-based deeds records but have to be decided for every change of the land registration system, are the interests to be covered by the register, whether the register will have negative or only positive publicity, and—closely related—whether registration is compulsory. In particular if many interests are to be registered, if publicity of the register is both positive and negative, and if registration is compulsory, technicalities of the underlying blockchain become relevant again.

All in all, benefits from implementing a deeds recordation system on a blockchain seem to be too small in countries with a well-functioning system (Arruñada, 2018). Jurisdictions newly introducing land registration cannot and need not refer to pre-blockchain chains of registered deeds. To make the new land registration system reliable, titles thus have to be registered. We will come back to this solution in the next section.

Before, we take a closer look at the example of Sweden with its well-developed land registration system. In the public land-registration-and-blockchain discussion, this country provides an oft-cited example for a realistic and actually to be realized use case of the distributed ledger technology for the purpose of improving public administration. We use this example to show that in countries with a well-developed land registration system, the benefits from blockchaining parts of the registration system are too small to make the transition worthwhile.

In fact, Sweden, like many other countries, has a hybrid land registration system based on declaratory but compulsory registration of deeds that works smoothly. The only problem that many complained about is the delay of several days, weeks or even months between the signing of the deed and its actual registration. As registration is not constitutive for the transfer of property (or other rights), the true legal situation and the legal situation expressed in the register fall apart during the time between signing of the deed and its registration. Since registration is compulsory only within 3 months of signing the deed and the process of registration takes additional time—historically up to 4 months, currently about a week according to the registration authority's homepage (Lantmäteriet, 2020)—and lack of registration fails to interfere with the effectiveness of a land transfer, property is often unregistered when consecutive transfers of the same real estate follow each other within a short time span.

The Swedish authority for land registration—Lantmäteriet—together with ChromaWay, a blockchain startup aiming at developing blockchain technology for public administration, and Kairos Future, a consultancy, have explored how blockchain-based technologies may overcome these problems (Snäll et al., 2018). The consortium saw the solution in electronic deeds to be completed in an app on smartphones and automatically registered in a private blockchain set up by the Swedish land registration authority (to be complemented by other authorities) and anchored in the Bitcoin and Ethereum blockchains. To secure reliable information

about the ownership of the concerned land, the app was designed to draw information directly from the land register and the blockchain containing information on deeds yet to be recorded in the register.

The consortium took first steps successfully up to a completed exemplary transfer of property in real estate in the summer of 2018 (Snäll et al., 2018). Since then, news about the project seem to wither. A major obstacle to further realization of the project allegedly is the lack of a reliable system of electronic identification, which is somewhat surprising as Sweden does have a working e-identification system. From an economic perspective, the problem apparently is more grounded in a sound comparison of costs and benefits. Given the well-functioning Swedish system of (hybrid) deeds recordation and the substantial acceleration of the registration process the benefits of the blockchain registration for deeds before inclusion of the deed in the conventional register seem to be minute. Cases where a registration process requiring only a week lasts too long for smoothly transferring property for the next time are too rare for drawing any relevant economic benefits from prepending the conventional records by a blockchain register (Arruñada, 2018, p. 90).

4.4 Tokenization of Property in Real Estate

The most radical way to move land registration to a blockchain-based system is tokenization of property in real estate. The basic idea parallels title registration and is thus most easily implemented with this form of land registration: All rights in real estate are represented by a so-called token the ownership of which is registered and transferred in the blockchain very much like ownership of Bitcoins. Since the initial owner of a Bitcoin is clearly defined as its miner, i.e. the first miner who produced a valid block at a certain stage of the blockchain, immutable registration of all transfers of a Bitcoin allows everyone to unambiguously identify the current owner. Hence registration of transfers is enough to identify the current owner even without explicit registration of the identity of the owner. In the words of land registration, one could say that deeds recordation and title registration are thus equivalent inside the Bitcoin blockchain.

For tokens representing rights in real estate this is not true, because the identification of the initial owner of the token is not implied by the setup of blockchain. On the contrary, the initial owner either has to be deduced from the land registration system preceding the blockchain system or someone—typically the land registration authority—has to deliberately enter the information on the identity of the initial owner into the blockchain. The former alternative would transfer the idea of deeds registration into the blockchain-based land register. The latter, however, is much closer to title registration. To make a blockchain-based land registration ledger resemble title registration, the blockchain could also include information on the current owner of the rights in real estate. Different from current title registers, inconsistencies between transfer chains and registered titles would technically be excluded.

In the remainder of this section, we will concentrate on this replication of title registration on the blockchain.

In order to determine whether tokenizing real estate on a blockchain is economically beneficial, we will first discuss what rights in land can economically be tokenized. This will lead us to the question to what degree the blockchain technology does, or fails to, render land registration authorities redundant. After answering this question to the negative, we will study whether the unavoidable role of land registration authorities implies restrictions to the immutability of the land registration blockchain. The answers to these questions will help us to identify the economic advantages of tokenizing land registration.

The most extensive right in real estate, ownership, and direct derivatives thereof are obvious candidates for tokenization. In fact, mortgages and rights of preemption suggest themselves for tokenization, because they are neither more nor less than a conditional transfer of ownership. As such they can be perfectly represented by smart contracts, i.e. computer code embedded in a blockchain, that transfer ownership on the condition that some event occurs or does not occur. Such conditional transfer of property may be completely automatic or they may require a third party's consent, for example a judge's or an arbitrator's consent. Even the recipient need not be stipulated in person by the smart contract. The latter could also initiate an automated auction of the property, which would closely resemble the current legal situation in, for example, Germany's law on real estates and mortgages.

Rights in real estate that go beyond conditional transfer of the entire property as they exist and are included in land registration in most jurisdictions are harder to replicate in blockchain-based land registers. In principle, covenants, easements and servitudes can be tokenized like ownership. Once defined, transfer of their representing token apparently is a simple way of exchanging such rights. However, their initial definition goes beyond the technical possibilities of a blockchain system. As the amount of variation of such rights is effectively infinite, it is impossible to arrange for all potential covenants, easements and servitudes when designing the blockchain. Humans will be needed to include these rights into the blockchain-based land register long after its setup. We will come back to this problem when we discuss the role of government in a blockchain-based land registration system.

However, once the problem of initial definition of covenants, easements and servitudes is solved, blockchain-based land registration systems can deal with these rights at least as well as any paper-based or electronic register. Just as the existence of such rights is today registered with the information on the encumbered estate, tokenized encumbrances will include reference to the token representing ownership of the real estate. Their existence then becomes obvious to any interested party by an appropriate search in the blockchain. As long as the blockchain-based land register provides both positive and negative publicity, registration of covenants, easements and servitudes in such registers implies perfect definition of property rights in the Coasean sense. Whether free tradability of tokens representing these rights or fixing the tokens to the ownership token of a benefitting estate then maximizes economic efficiency depends on the specificities of the situation. Both are possible and

simple in a blockchain-based register (Graglia & Mellon, 2018, develop a similar list of criteria).

Similar arguments extend to lease or rental contracts, which many jurisdictions also include in the set of rights in real estate that can or have to be registered. The stronger tenants are protected in case of transfer of ownership of the real estate the more important becomes reliable information on the existence of lease or rent contracts for an efficient real estate market. Nevertheless, by far not all jurisdictions allow these contracts to be registered. Germany and Austria are prominent examples despite their sophisticated land registration systems and their strong protection of tenants. One reason for the reluctance of these jurisdictions to include lease and rent contracts into land registration is that sophistication of land registration system implies high costs of registration. Since in the end it is the tenants who bear these costs, opening land registration for lease and rent contracts would countervail these countries' objective to protect tenants.

Many of the advocates of bringing land registration to blockchain-based systems claim that administrative costs and the role of government as registration authority could dramatically decline. Whether this is true depends on the blockchain-based land register's ability to function without or with little support by such authorities. We therefore take a closer look to the necessary and desirable roles of government in a blockchain-based land registration system.

In countries where land registration is provided by government authorities, the first aspect where government is indispensable is the legal basis for transferring land registration to a blockchain-based system. Due to its obvious network economies land registration will not turn into a competitive market after moving to a blockchain but will remain a natural monopoly. Hence government will have to decide who runs the blockchain and which blockchain will underlie land registration (Arruñada, 2017a, 2018, pp. 96–97). The most important criteria will be the expectation of long-term existence of the blockchain, its immutability, its scalability and its ability to handle at least a small number of smart contracts.

Long-term existence is an immediate consequence of the time horizon of land registration. Land ownership and registration is probably the legal field with the longest time horizon. The perspective is decades and centuries. This stands in stark contrast to the 11 years that the Bitcoin blockchain—hitherto the most stable and longest existing blockchain—counts since its invention. Since moving a land-registration system from one blockchain to another may be expected to be extremely costly both in terms of administrative burdens and in terms of deteriorating trust in the system, the blockchain to be chosen cannot be based on a proof-of-work consensus mechanism. If it were, immutability would only be guaranteed as long as the blockchain is among the big three or four in the market of blockchains. Smaller blockchains are far too susceptible to 51-percent attacks, which become cheaper the less resources are employed in the mining of the blockchain. Taking market capitalization as a proxy for the resources used to operate the blockchain and thus for the resources needed to run a 51-percent attack, currently only Bitcoin with its 120 billion US$ market capitalization (i.e. 65 percent of the entire market of

cryptocurrencies) can be treated as a safe bet. But even Bitcoin is far from immune against better alternatives occurring within the next decades and thus losing its immutability.

To avoid having to switch the land register from one blockchain to another every decade or so, immutability should be supported by another consensus mechanism. At least for the time being, proof of stake has not been implemented successfully and thus proof of authority is without viable alternatives. If authority only stems from the institution operating the blockchain, use of the blockchain technology itself is hard to justify. However, if many institutions form a consortium to operate the blockchain and to control each other in operating it correctly, then their individual trustworthiness will add up and become reinforced by mutual distrust between them. Proof-of-work blockchains may still serve as a safe ground for anchoring proof-of-authority blockchains and thereby further increasing trust in their immutability (see Chromia blockchain as an example).

Beyond operating the blockchain underlying the land register or at least contributing to its operation, and beyond mutually reinforcing trustworthiness, public land registration authorities will have two more indispensable tasks in a blockchain-based land registration system: initiating and guaranteeing the connection between rights in real estate with the tokens representing them and enforcing the law against the blockchain, if necessary (see Arruñada, 2017a, b, for a similar argument).

Establishing and perpetuating the connection between reality and entries in the blockchain is one of the central challenges in most blockchain applications beyond cryptocurrencies. To have ownership in real estate represented by a token in blockchain, a cadastre—be it separate from or included in the land register—is required to define parcels of land that can be owned. With well-defined parcels of land, ownership may be represented by a token if uniqueness of the token is guaranteed. Both the uniqueness and the legally correct identity of the original owner of the token cannot be guaranteed by any programming code structuring a blockchain. What is needed here is the institutional guarantee by the land registration authority.

Once this guarantee exists, transferring the token from one owner to another inside the blockchain and thus transferring ownership in land is simple and may follow the same rules as the transfer of ownership of cryptocurrencies. Conditionality of such transfers can easily be backed by smart contracts and thus mortgages and rights of preemption are relatively simple to implement in a blockchain underlying the land register. No action of authorities is required here unless the parties to a contract so stipulate in their smart contract. The blockchain can take over all tasks that are restricted to control whether the conditions of a transfer of property are met. If the parties define conditions outside the blockchain, they will transform these conditions into actions inside the blockchain. For example, if the mortgage payments are performed outside the blockchain, the parties will define conditions such as “if three out of four clearly named arbitrators sign with their private key inside the blockchain that the debtor failed, then the smart contract triggers an automatic auction of the mortgaged land, the proceeds of which go to the lender”.

Other rights in real estate, i.e. rights that cannot be characterized as conditional transfers of ownership, however require actions of the land registration authority as

much as ownership itself. Such rights, covenants, easements and servitudes, need to be clearly defined and carefully and exactly added to the database contained in the blockchain. Not only these steps of creating new rights in real estate require human action from the authority's side. Consistency of all encumbrances of any specific parcel of land also has to be guaranteed—a task that cannot be performed by a machine, not even if it possesses artificial intelligence, since controlling for consistency of different encumbrances requires understanding their meaning. Even humans sometimes err here.

These and other possible errors bring us to the last, but not least missions of the registration authority, possibly in collaboration with the courts. Mistakes in registers, be they blockchain-based or not, do occur; the content of the register may deviate from the legal situation. The cause may run the full gamut from simple errors in transposing legal code into computer code via cases of illegal or unjust enrichment or eminent domain to unnoticed legal incapacity to sign a deed. In many of these cases a legal duty of the wrongful owner of a token representing an alleged right *in rem* to transfer the token to the legal owner of the right is insufficient to restitute the law. Transfer of a wrongfully owned token must also be possible without or even against the will of the current owner.[4]

This is not to say that the blockchain has to be corrected retrospectively and thus immutability to be destroyed. What is needed is the power of the registration authority or the courts to induce a transfer of tokens as if they were the owner. The protocol of the blockchain underlying the land register thus has to allows transfers of tokens either by signing the transaction by the private key of the owner or by the signature of the authority or the court. Such alternative signatures are not entirely new. The most relevant blockchains do already allow smart contracts that require n out of m signatures or even more complex combinations of signatures. This is what is needed here. On the first level, it must be possible to trigger token transfers by either of the two signatures of the owner or the authority or a court. To reduce the risk of abuse of this ability of the authority or the courts and to increase trust in the system the signature of the authority or the courts may again be subject to a so-called multisig requirement, for example allowing to supersede the lack of the owner's signature only by the simultaneous signature of, say, 14 of the 20 authorities forming the consortium to operate the land registration blockchain.

With these conditions—underlying blockchain proof-of-authority as consensus mechanism operated by several authorities; coverage of (almost) all legal rights in real estate; clear definition and guarantee of token-represented property rights by the competent authority; restricted (joint) power of authorities to induce transfer of tokens against the will of the token owner—satisfied, a blockchain-based title register is a legally and technically viable alternative to the existing title registers based on paper or a central database. But is it economically viable too? Proponents of tokenization of land registers proffer acceleration of transactions, increased

[4] The same is true for tokens that are assigned to a blockchain address for which the owner lost his private key. To keep these tokens and the assets the ownership of which they represent tradable, the land registration authority must be able to transfer them to an address that the legal owner controls.

trustworthiness of the land registration system and less red tape as most important economic advantages. While these advantages may be substantial in countries with less developed title registers, in countries with well-functioning title registers low speed, lacking trust and red tape are of only minor relevance, if at all. To admit, completing transactions of real estate may take weeks and months even in Austria, but hardly ever there exists any ambiguity on who has what rights in a parcel of land. And high frequencies of subsequent transactions of rights in real estate are too rare to produce a relevant problem.

Sometimes redundancy of title searches is added as an economic advantage, but this is more a difference between deed recordation and title registration and not so much between blockchain and standard ledger technologies.

In summary, bringing title registers to the blockchain by tokenizing rights in real estate produces economic advantages that justify the transition costs and the risk of failures in setting up a well-functioning system only in countries which so far lack a reliable title register. In countries that already benefit from efficient title registers, blockchain is not a technology that may bring about substantial improvements in real estate.

5 Conclusions

The central and most general insight of this chapter is that one should be very clear about what is meant by calls for moving land registers to a blockchain. Both the existing forms of land registration and the modes of representing them on a blockchain exhibit far too many different variations to measure all of them by the same yardstick. Such care is often lacking in the popular literature stemming from blockchain enthusiasts. The confusion becomes even larger when trading shares of a real estate investment trust on a blockchain is labeled as putting real estate ownership to the blockchain. We clearly separate the two approaches.

We also stress that one should distinguish between the digitizing land registers, anchoring a digitized land register to a blockchain, and implementing land registers on a blockchain. All three have their own virtues and some become relevant only if one combines two of these approaches. Digitizing registers has *per se* nothing to do with blockchains but is of course a prerequisite for anchoring a register to a blockchain. In addition, anchoring the digital register in a blockchain may be a precondition for making digitization worthwhile because it makes the digital register immutable, while pure digitization may even entail an increased risk of posterior mutations of the content of the register. Effective safeguard against ex-post alterations of the register is a relevant argument only in jurisdictions where such alterations are a relevant threat—or where they may become a relevant threat after digitization.

The main thrust of the chapter has been on recordation of deeds in a blockchain and on tokenization of rights in real estate. They are the two approaches to really get land registration on blockchains and thereby extract economic benefits.

The former may substantially facilitate title search in the very long run, but here exactly lies the problem: which blockchain has a long enough life expectancy? If the answer is: private blockchains run by government, then immutability becomes at least debatable and it becomes thus hard to argue why such a private blockchains should have any advantages over any other digitized register run by the same authority. Only if the blockchain is run by a *consortium* of registration authorities, trust in the register will increase by blockchaining the register.

Tokenization of rights in real estate may be a viable alternative to existing paper-based or digitized title registers. That requires proof of authority as the consensus mechanism of the underlying blockchain. In addition, nearly all possible legal rights in real estate should be covered by tokenization. Still, tokenization requires an active role of registration authorities and the court system, and it requires their benevolence, however to a lesser degree than registers without tokenization. Two functions of the registration authorities and the courts are essential. On the one hand, only they can clearly define token-represented property rights and guarantee their enforcement outside the blockchain. On the other hand, immutability of blockchain-based registers necessitates the possibility to transfer tokens without or against the will of the token owner to correct legally false information in the blockchain. Only a carefully selected combination of the registration authorities and the courts, probably of several jurisdictions combined, should be able to perform this task.

Even if all these conditions for making tokenization a viable alternative are met, the use of blockchains in land registration seems to be of very limited merit in jurisdictions with an efficient system. However, there are less efficient systems. And blockchainization of land registers may go beyond the mere transition of an existing system to a blockchain. Once this transition is underway, substantive changes to the system itself may become possible, as was the case in Georgia where a completely ineffective land registration system was at least partly turned into a functioning system under the disguise of blockchainization.

Acknowledgements Thanks for helpful comments go to the participants of the Conference on *Disruptive Technology, Legal Innovation and the Future of Real Estate* at IDC Herzliya and of the Law and Economics Research Seminars at the Universities of Kassel and of Vienna. All remaining errors are mine, of course. This work received support by a generous grant of Metamorphoses GmbH, Baunatal.

References

Arruñada, B. (2003). Property enforcement as organized consent. *Journal of Law, Economics, & Organization, 19*, 401–444.

Arruñada, B. (2017a). Property as sequential exchange: The forgotten limits of private contract. *Journal of Institutional Economics, 13*, 753–783.

Arruñada, B. (2017b). How should we model property? Thinking with my critics. *Journal of Institutional Economics, 13*, 815–827.

Arruñada, B. (2018). Blockchain's struggle to deliver impersonal exchange. *Minnesota Journal of Law Science & Technology, 19*, 55–105.

Baird, D., & Jackson, T. (1984). Information, uncertainty, and the transfer of property. *The Journal of Legal Studies, 13*, 299–320.

Barbieri, M., & Gassen, D. (2017, March 20–24). *Blockchain—Can this new technology really revolutionize the land registry system?* Paper prepared for presentation at the "2017 World Bank Conference on Land and Poverty". Washington DC: The World Bank. Retrieved from https://www.notariato.it/sites/default/files/Land_Poverty_Conference_Blockchain.pdf, last visited April 1st, 2020.

Benbunan-Fich, R., & Castellanos, A. (2018). Digitalization of land records: From paper to blockchain. In *39th International Conference on Information Systems (ICIS 2018) San Francisco, California, USA 13–16 December 2018* (Vol. 2, pp. 1024–1032).

Biais, B., Bisière, C., Bouvard, M., & Casamatta, C. (2019). The blockchain folk theorem. *The Review of Financial Studies, 32*, 1662–1715.

Chen, L., Cong, L., & Xiao, Y. (2019). *A brief introduction to blockchain economics* (August 10, 2019). Available at SSRN: https://ssrn.com/abstract=3442691

ChromaWay. (2019). *Chromia Platform Whitepaper, Version 0.11*. Retrieved from https://chromia.com/whitepaper-english.html, last visited April 1st, 2020.

Garay, J. A., Kiayias, A., & Leonardos, N. (2015). The Bitcoin backbone protocol: Analysis and applications. In E. Oswald & M. Fischlin (Eds.), *Advances in cryptology, EUROCRYPT 2015, Lecture notes in computer science 9057* (pp. 281–310). Berlin: Springer.

Graglia, J. M., & Mellon, C. (2018). Blockchain and property in 2018—At the end of the beginning. *Innovations, 12*, 90–116.

Hamilton, D. (2019, January 11). Blockchain land registry: The new kid on the block. *CoinCentral*. https://coincentral.com/blockchain-land-registry/, last visited April 1st, 2020.

Kaczorowska, M. (2019). Blockchain-based land registration: Possibilities and challenges. *Masaryk University Journal of Law and Technology, 13*, 339–360.

Keynes, J. M. (1936). *The general theory of employment, interest, and money*. London: Macmillan.

LandLayBy. (2018). *Land Layby Listing (LLL) Platform, Harambee Token [Hrbe], White Paper*. Retrieved from https://hrbe.io/images/WHITEPAPER_HRBE06022.pdf, last visited April 1st, 2020.

Lantmäteriet. (2020). *Handläggningstid för inskrivningsärenden*. Retrieved from https://www.lantmateriet.se/en/real-property/change-owner/Handlaggningstid-for-Inskrivningsarenden/, last visited April 1st, 2020.

Nakamoto, S. (2008). Bitcoin. *A peer-to-peer electronic cash system*. Retrieved from https://bitcoin.org/bitcoin.pdf.

Shang, Q., & Price, A. (2018). A blockchain-based land titling project in the Republic of Georgia. *Innovations, 12*, 72–78.

Snäll, M., Suomalainen, D., & Kempe, M. (2018). *Fastighetsköp och lagfart genom en blockkedja—governance och juridik*. Report of Kairos Future and the Swedish land registration authority (Lantmäteriet). Retrieved from https://www.lantmateriet.se/contentassets/8d2b5d7647634c02a329b01e46e61071/publikation-swe-fastighetskop-och-lagfart-genom-en-blockkedja%2D%2Dgovernance-och-juridik-2018.pdf

Spielman, A. (2016). *Blockchain: digitally rebuilding the real estate industry*. MS dissertation Massachusetts Institute of Technology. Retrieved from https://dci.mit.edu/s/spielman_thesis.pdf, last visited on April 1st, 2020.

Zevenbergen, J. (2002). *Systems of land registration–Aspects and effects* (PhD Thesis, Technical University Delft). Delft: Netherlands Geodetic Commission.

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