Exploring the applicability of blockchain in lowering transaction costs in the commercial real estate due diligence process: a case study research

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Abstract - The global market for real estate has experienced a significant growth since the financial crisis in 2008. The current global value amounts to more than $200 trillion and comprises nearly 60% of the value of all global assets, including equities, bonds, and gold. Yet, the commercial real estate market is inefficient and opaque due to its complicated due diligence processes and strategic behavior in complex multi-actor environments. Blockchain technology is often suggested as a disruptive technology that could increase efficiency, transparency and minimize transaction costs in various markets. Studies on blockchain point out that the technology has enormous potentials in the financial and real estate sector, but obviously has to overcome obstacles both business-, technological-, and adoption-wise. Even though the technology is still nascent, potential disintermediation of intermediaries such as notaries, banks, escrows and in particular brokers is a significant threat for them as they might no longer be necessary, at least in the same way. A qualitative explorative case study research combined with the application of Transaction Cost Economics is used to construct a decision path that can be followed to assess the applicability of blockchain technology and subsequently its impact on the sources of transaction costs. Following this decision path, we found that as of now, blockchain appears not to be the most suitable technology to function as a real-time, up to date database during commercial real estate transactions. Future research is suggested to focus on identifying the potential application and implications of property-specific building passports using smart contracts.

Keywords: *Blockchain, Due Diligence, Commercial Real Estate, Case Study, Transaction Cost Economics*

I. INTRODUCTION

Approximately 10 years after the notorious financial crisis in which the housing bubble burst, the global commercial real estate (CRE) market now seems to have grown stronger again. However, some believe that this market could be significantly bigger if major inefficiencies could be eliminated from transaction processes (Lusht, 2001). Compared to exchange-traded securities such as government bonds and equities, real estate markets are ill-organized with high transaction costs, lack of information transparency, time consuming due diligence (DD) processes and less efficient price discovery mechanisms, which have implications for the overall efficiency of the market (Deloitte, 2017; Dijkstra, 2017). The CRE industry tries to maintain competitive advantage by not revealing certain strategic information (Levitt & Syverson, 2008), such as comparable transaction prices or lease rates, information about (potential) buyers, valuations and other relevant knowledge (Maurer, 2016; Deloitte, 2017). This has resulted in an increasing demand - from investors - for transparency, efficiency and lower transaction costs in the global real estate market.

Technological advancements, such as the online Dutch cadaster, are increasingly automating brokerage and leasing tasks and activities, gradually bringing down the barriers between potential investors and real estate owners (Sheth, 2015; Dijkstra, 2017). As a result, property-related information is increasingly available in both digital and paper form. However, a significant portion of the digitized information is hosted on disparate systems, still lacking in transparency and efficiency, and a higher incidence of inaccuracies that makes involved parties particularly susceptible to fraud or tampering (Deloitte, 2017). The currently muchdiscussed and researched blockchain technology could enable the CRE industry to address these inefficiencies and inaccuracies and expedite several processes such as the due diligence process (Zheng et al., 2016). Automation of the DD process would imply that blockchain could drastically change the role of brokers, notaries and other middlemen, and consequently lead to decreasing transaction costs (Ngo, 2016; Lawrence, 2018).

In essence, a blockchain is a type of shared database of which the contents are verified and agreed upon by a network of independent nodes. In order to add a new piece of data (such as the last transaction price and date of a property) to the blockchain, the independent verifiers must come to consensus as to its validity (Zheng et al., 2016; Carlozo, 2017). A distinctive characteristic of blockchain is that this peer-to-peer (P2P) platform solves the so-called 'double spend'-problem, and in that way allows transactions without the need for intervention of a trusted third party, like a bank or a notary, in certain processes. Because each new set of transactions (called a "block") is cryptographically linked to the previous block, it is extraordinarily difficult to change data in a blockchain as any such change would be directly detectable by the independent verifiers. With this in mind, data entered into the blockchain can be considered as immutable and therefore serve as a fraud-resistant record of a proof of ownership (Fanning & Centers, 2016; Ngo, 2016).

The combination of the growing demand for an efficiently performing real estate market and the momently widely researched blockchain technology form the basis for this study. This paper aims at assessing the applicability of blockchain-based applications in lowering the transaction costs within the DD process of CRE transactions by impacting the sources of those transaction costs. This objective is addressed by designing a *decision path* that assesses the applicability (and most suitable type) of a blockchain-based solution. It also provides insight into the expected impact on the eventual transaction costs. An explorative case study research (CSR) approach as defined by Stake (1995) is used as a guideline to combine insights from both empirical and established academic literature in the design of the *decision path*. The objective of this study is achieved by answering the main research question, which is formulated as follows:

> "To what extent could a blockchain-based solution be applicable in a commercial real estate due diligence process and how could it impact the transaction costs?"

This paper is structured as follows: Section II introduces the CSR approach and concisely discusses its suitability for this study. Then, section III outlines the theoretical background on blockchain technology and how it can be seen through the lens of Transaction Costs Economics (TCE). Subsequently, Section IV combines the insights derived from previous sections and presents a decision path to assess the applicability of blockchain and its eventual impact on the sources of transaction costs. Also, in this section the findings of the case study are projected on the decision path in order to determine to what extent blockchain has the potential to minimize transaction costs of CRE DD processes. Section V concludes this paper and provides recommendations for further research.

II. Research Approach

In this paper, we follow a CSR approach as described by Stake (1995) to gain insight into the concept of the CRE DD process and to investigate the consequences of implementing blockchain technology for the eventual transaction costs of the CRE DD process. A CSR is a research strategy in which the researcher tries to gain a profound insight into one or several processes that are confined in time and space (Verschuren & Doorewaard, 2010, p. 178). Miles and Huberman (1994, p. 25) state that the *case* of the study can be defined as "a phenomenon of some sort occurring in a bounded context, which is, in effect, your unit of analysis". For this study, the due diligence process is the case to be studied within the context of CRE transactions. An extensive literature research on the potential of blockchain and the concept of due diligence within CRE transactions is conducted first, after which the case study outlines the current DD process. Combined with the findings from literature review, the case study is performed using expert interviews with institutional investors who are directly involved into due diligence processes during CRE transactions. By applying the findings of the case study to the decision path, we demonstrate on what aspects a blockchain-based solution stands or falls and thus to what extent such an application is expected to be suitable, given a specific use case.

III. THEORETICAL BACKGROUND

A. *Blockchain Technology*

In order to understand the world of blockchain, it is important to distinguish Bitcoin from blockchain. Bitcoin is digital cash: a P2P payment network that runs on a cryptographic *protocol*, whilst the underlying *technology* is called blockchain (Nakamoto, 2008). Blockchain as a technology has evolved rapidly over the past decade. Swan (2015, p. ix) distinguishes three generations of the blockchain since its invention; blockchain 1.0, blockchain 2.0 and blockchain 3.0. The first generation solely aims at *digital currencies:* the deployment of cryptocurrencies such as Bitcoin. Blockchain 2.0 is about *contracts*, which are economic-, market-, and financial applications that reach further than just cash transactions: stocks, bonds, shares, title, smart properties, and smart contracts. Finally, the third generation of blockchain indicates the *applications* beyond economic, financial and market applications: other market segments (such as health, automotive, supply chain, government, et cetera) are tapped into with this blockchain generation.

During literature study, five core components of blockchain technology are found (Swan, 2015; Tapscott & Tapscott, 2016; Düdder & Ross, 2017; Rabah, 2017; Tasca et al., 2017; Veuger, 2018):

1) ledger
2) P2P network
3) cryptography
4) consensus mechanism
5) validity rules

Blockchain is a distributed *ledger* that is updated synchronously among all participants of the network. This network requires no trusted third party to validate transactions, enabling participants to make direct, peer-to-peer transactions in a so-called *P2P network.* Transactions in this P2P network are validated according to the standards of a specific *consensus mechanism*, a means of achieving consensus as to the validity of a transaction. The consensus is reached if, the transaction complies with a predetermined set of *validity rules*. In order to achieve consensus, participants must be able to trust each other, even if they are mutually unknown. Trust is therefore created and based on *cryptographic* proof. Once consensus is reached about the validity of a transaction, a new block containing that transaction is added to the chain of blocks and cannot be altered or deleted anymore based on the applied cryptography.

B. *Commercial Real Estate and the Due Diligence process*

The real estate market is utterly important for the overall economy; it has been estimated to represent approximately one-half of the world's total economic wealth (Ling & Archer, 2012). But what is real estate? The Oxford Dictionary (2018) defines real estate as "*a property consisting of land or buildings*". Within the world of real estate, property assets can be assigned into different categories. Investopedia (n.d.) defines commercial, residential and industrial as the major categories. This study focuses on commercial real estate, which is ultimately used with the purpose of producing income. Instances of commercial real estate are office buildings, restaurants, hotels, shopping malls, leasing and renting of residential, et cetera.

If you would ask a real estate investor or transaction manager to their interpretation of 'due diligence', they will likely describe it as a time-consuming, boring, and expensive process in which a significant amount of money is spent to finally hear something that they already knew. The term 'due diligence' describes a process in which a detailed examination, analysis and assessment of the circumstances of the property in fact and in law are conducted (Stapenhorst & Just, 2018). As the DD process is increasingly getting important in capital markets, it increasingly resembles the corporate transaction, both in direct (asset deal) and indirect (share deal) investments. Hennessey (2015, pp. 8-9) defines the purpose of the DD process as "to discover the potential problems with a property, reveal any hidden profit potential, and verify all information that you have obtained". The starting point of a DD process is, according to Stapenhorst and Just (2018), the information gap between the potential parties to the transaction contract. A DD can be initiated by the seller, as well as performed by the potential purchaser. The function and objective of these DDs can be different due to potential conflicting interests: the seller is often tempted to not reveal strategic information about the property, whereas the buyer aims at obtaining as much relevant information as possible. With that in mind, the overall function of a DD process is "to determine, analyze, assess and control various risks and the opportunities connected with them" (Stapenhorst & Just, 2018). This is in line with the responses of the interviewees, who described the objective as 'risk management', 'know-what-you-buy', 'gaining insight into the real estate you wish to buy', and 'determining whether the real estate fits within the long-term perspective you have, as an institutional investor'.

C. Transaction Cost Economics

Since the early 80s, all kinds of privatization of government organizations have occurred in the Netherlands. Increasing the economic efficiency was regularly mentioned as an important argument for internal and external privatization. The economic efficiency is the relationship between the (monetized) means of production (inputs) and the products realized (outputs). The neo-institutional economics, which probably had its starting point with the classical economist Adam Smith's *Wealth of Nations* (Smith & McCulloch, 1838; Buitelaar, 2009, p. 19), tries to answer the question about which organizational structures perform optimally in a given situation, i.e. what organizational forms lead to maximum economic efficiency (Ter Bogt, 1998, p. 43). Three important organizational economics theories resulted from the neo-institutional economics, namely: property rights theory, agency theory, and transaction costs theory. The latter of these theories applies to this study, because the added value of a blockchain-based application can be determined and measured on the basis of (the extent of) decreasing transaction costs. Put simply, a transaction is the transfer of good (or services) on a market, i.e. between two economic units. The transaction costs are the costs associated with this transfer: all costs needed to facilitate the transaction between two economic entities. Buitelaar (2009, p. 30) defines the transaction costs as *"the costs that are made to increase the information available to us and to reduce uncertainty"*, which may be the best suitable definition in this case. These costs comprise for example the collection of knowledge about diverse products and the market, the costs of consultation experts or drafting contracts, or the costs of coordinating activities within or between organizations. The starting point of the transaction costs theory is that in addition to production costs, the transaction costs prevail in determining the organizational structure that is chosen: it is about finding efficient organizational structures.

Within the transaction costs economics, several types of transaction costs are distinguished. Firstly, all the costs that are made during a transaction and are considered transaction costs, can be categorized into three costs components (search and information costs, bargaining costs and monitoring deal compliance). Secondly, Williamson (1979) has defined bounded rationality and opportunism as sources of transaction costs, which in this research is supplemented with three dimensions of transaction costs according to Coase (1937), namely the extent of recurrence, uncertainty and interdependence.

Analyzing blockchain through the lens of a new technology raises the question: 'what type of technology is blockchain?' De Filippi et al. (2018) argue that there have been two categories of answers: some claim that blockchain is a general-purpose technology, meaning that it will be widely implemented and have a broad application in multiple market segments and contribute to a multiply productive growth. Not disagreeing, but approached from another (Coasian) perspective, are the economists who place the emphasis on how blockchain could reduce transaction costs through costless verification and disintermediation. The first approach understands blockchain as a production technology (general purpose view), where the latter approach regards blockchain as an exchange technology (market-enhancing or Coasian/Schumpeterian view). We approach blockchain from a TCE perspective, thus a Coasian 'market-enhancing' view, in order to gain insight into the efficiency gains of a potential blockchain-based application, which with this approach can be expressed in transaction costs. These insights are scientifically relevant because the combination between due diligence and transaction cost drivers together with the potential of blockchain has not been explored yet in academic literature. Moreover, the TCE approach enables us to not only look at the technological potential of blockchain, but also provides insight into the costs and benefits of a blockchain-based application.

IV. RESULTS

A. *Presenting a decision path to assess the applicability of blockchain technology*

Blockchain has allowed mutually mistrusting entities to transact with each other without relying on a trusted third party while at the same time providing transparency, integrity and protected (immutable) data storage. Although praised as a technological innovation that allows to revolutionize how the market and economy will perform, it is often questioned how applicable blockchain really is. Moreover, as ex-TPM student and now director of Axveco, a leading blockchain consulting firm, stated; *"even though we can think of multiple use cases, there are more cases in which blockchain is not adding value than cases in which it actually does"* (Rikken, 2018). So, when is blockchain useful in the sense that it adds value and when is it not? We established that blockchain-based applications demand certain case-specific requirements in order to be an adequate solution that outperforms conventional solutions. To determine whether blockchain is applicable, we designed a decision path (Figure 1) that can be followed to assess the suitability of blockchain.

The decision path comprises two components; a general component (delineated with a blue dotted line) and a case-specific component. The first component is inspired by a combination of frameworks as presented by Wüst and Gervais (2017) and Meunier (2018) (see Appendix), and can be followed for decision making processes entailing multiple actors and a type of database in order to determine whether blockchain is a suitable solution at all. If so, the decision path proceeds to a case-specific component that works towards a statement regarding the impact on transaction costs. The composition of this component depends on the objective of the researcher. For this study, the aim is to reduce the transaction costs of a business process, hence the inclusion of a transaction costs component. However, if the research for instance revolves around increasing efficiency, trust, transparency or customer experience, another component could be added to the delineated decision path. The steps and considerations of both components are step-wise elaborated below.

Firstly, it needs to be determined whether there is a need for a consistent, shared database. Blockchains provide a historically consistent data base as they are made immutable through applying cryptography. This is useful in cases where it is important to ensure that data cannot be altered. If this is not needed, e-mail or spreadsheets could be considered. Caveat: where a regular blockchain application requires a shared database, one can also opt for deploying a smart contract on the blockchain. In this case, the first question would be answered negatively, but it should still be proceeded to the next question if the answer to the following question is yes: *'Is there any form of agreement that can be captured using a contract?'.* Note that this only applies to the case of smart contracts.

Secondly, it is questioned if more than one entity needs to contribute to the data store. Since blockchain is a P2P-network with a key feature that any (permitted) entity can add data to the distributed ledger, cases with only one entity do not require a blockchain; a regular database would suffice here. Note that this question can be skipped in case of auditing, because this would also work for one entity as well as for multiple entities.

Thirdly, blockchains have the characteristic that they are immutable: once entered, the data cannot be altered. Because blockchains do not allow modifications of historical data, it must be questioned if the data should be able to delete or modify. If so, a regular blockchain would not apply. However, there are some ways to circumvent this, through for example working with hyperlinks to off-chain data that can be deleted or updated at will.

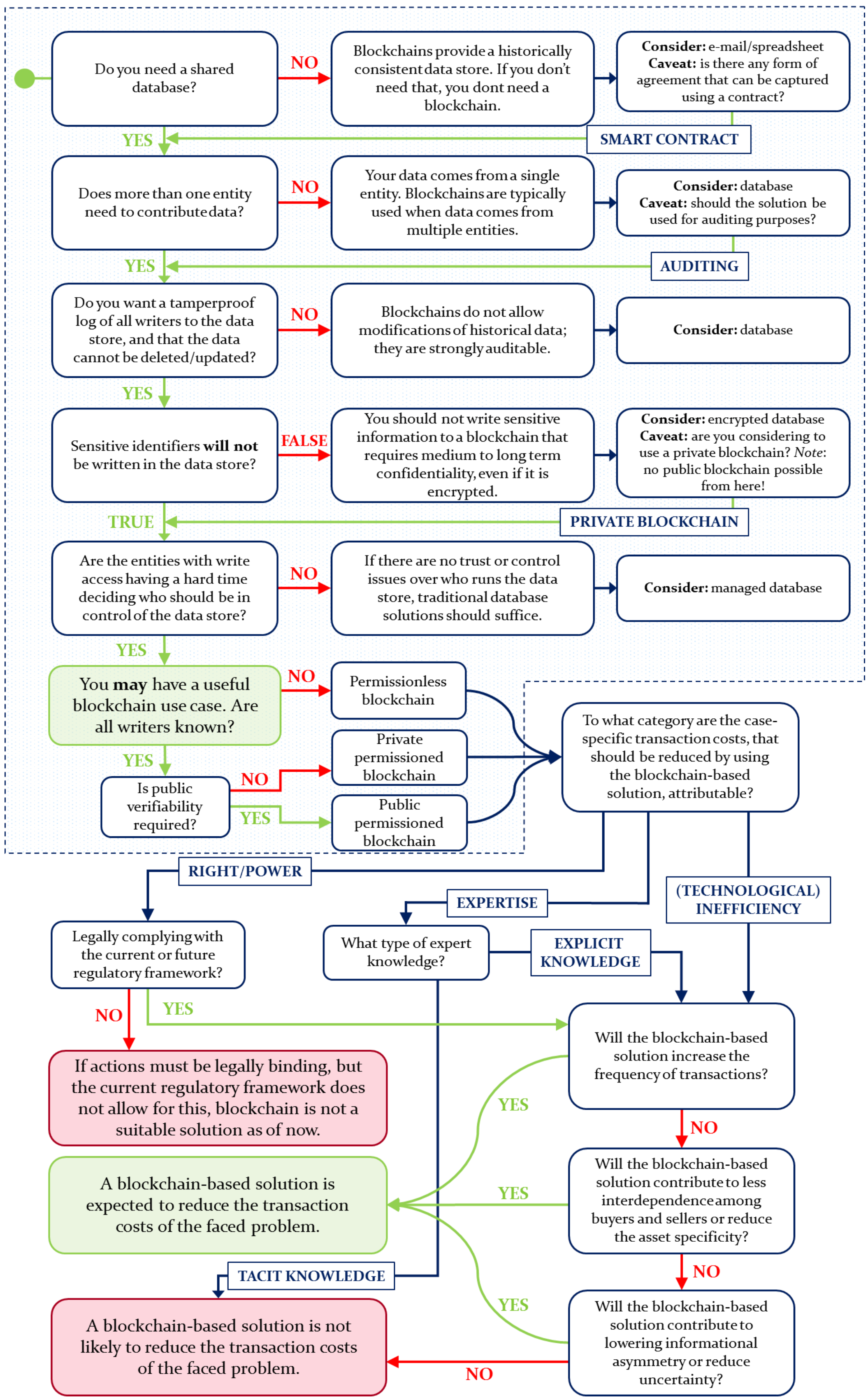

Figure 1 | Decision path to assess the applicability of blockchain in lowering transaction costs

A fourth question revolves around the sensitivity of the data, thus the context of the data that is to be recorded in the blockchain. Since the blockchain provides full transparency (assuming a public, permissionless blockchain, like the one of Bitcoin), sensitive data should not be stored on a blockchain, even when it is encrypted. An encrypted database, only accessible to permissioned entities, would be more suitable here. However, this would not account for a private blockchain because a private blockchain is not publicly accessible.

Fifthly, if the entities with write access can easily agree upon who should be in control of the data store, thus when there is trust among the participants, a blockchain would not be best-suited in this case. Blockchains are emphatically designed (and suitable) for trustless environments. A managed database would suit better in this case.

If until now all the questions have been answered with 'yes' (or 'true'), then a blockchain-based application is likely to be suitable for the concerning case. If the writers are known, a (public) permissionless blockchain would be most suitable. Lastly, it should be questioned if public verifiability is required. In that case, a public permissioned blockchain is recommended, and if not the case, a private permissioned blockchain. When the most suitable blockchain type is established, the first component ends and we can proceed to the second component concerning the impact on transaction costs. This is elaborated below.

First, it is asked to what category the case-specific transaction costs are attributable to. For CRE transactions, we identified and distinguished three categories of transaction costs: expertise, right/authority, and technological inefficiencies (Seuren, 2018, p. 72). In the case of expertise, a first distinction is made between tacit knowledge and explicit knowledge. Tacit knowledge cannot be expressed by definition, so it is presumed that this type of knowledge is not programmable in a blockchain, and therefore the decision path redirects to the red box stating that blockchain is not likely to reduce transaction costs in the case of tacit knowledge. When the transaction costs are attributable to the category 'right/authority', it must be determined whether the application fits within the regulatory framework. For instance, smart contracts are not (yet) legally binding and thus cannot (yet) substitute current contracts (McKinlay et al., 2018). If it does comply with current legislation, the decision path proceeds to three general questions that concern the sources of transaction costs according to Coase (1937). If the application is expected to increase the frequency of transactions, decrease the extent of interdependence, or reduce informational asymmetry, Coase states that the blockchain-based application will reduce at least a *part* of the total transaction costs. The more of these questions can be answered with 'yes', the more likely it is that assumption holds true and the higher the extent is to which it will eventually impact the actual transaction costs.

B. Determining the applicability of blockchain in the CRE DD process

In this section, we gradually determine whether the DD process in its entirety would fit the requirements for a blockchain-based solution, following the first component of Figure 1. If all questions are answered positively, we can proceed to the second transaction cost-specific component. For this DD-process, it is assumed that it concerns a regular CRE transaction of one large property (i.e. with a value exceeding €20 million) in the Netherlands, where purchaser and vendor know and trust each other. The stepwise answering of the questions in the decision path follows below.

Do you need a shared database?
Yes. Currently, the commercial advisor of the purchaser (i.e. the purchaser broker) manages and controls a data room in which all relevant documents about the property are shared. In this data room, the purchaser with his legal, commercial, and technical advisors work together and assess the data as presented by the vendor and his advisors. Hence, this shared database is crucial for the potential investor to be able to conduct a profound DD on the property.

Does more than one entity need to contribute data?
Yes. Large CRE properties in this study are multi-tenant buildings with usually a plethora of documents, certificates, permits and drawings. These should in theory be maintained and updated in databases, but in practice, as the interviews

reveal, are hosted on disparate systems and controlled by multiple entities. At the moment that a sales preparation commences (first identified phase of the DD process in Seuren (2018)), all these documents are collected and requested at multiple entities, in order to fill the data room. This means that multiple entities need to contribute data to the (shared) database, i.e. the data room.

Do you want a tamperproof log of all writers to the data store, and that the data cannot be deleted or updated?

No. Although a tamperproof log of all writers to the data store could be useful, the inability to update data hampers efficient data sharing and management. Unlike transactions or other information that should never be changed in order to maintain its validity, certificates, rental contracts, and certain permits expire and should be updated or deleted at will. The fact that blockchains do not allow for modifications of historical data is useful in case someone wants to proof the existence of a document, but not when someone wants to always have the latest up-to-date version of the cashflow calculation or a rent roll. However, let's assume that there will be new types of blockchains in which certain data fields can be overwritten.

Sensitive identifiers will not be written in the data store?

No, but it could if a private blockchain is used. The data room of a property as used by the purchaser and vendor (and their accompanying advisors) in principle contains all relevant data for a thorough assessment by the purchasing party. This means that also sensitive information such as rent rolls, rental contracts, creditworthiness checks, privacy-related data, and so forth is included. As blockchains are transparent and the content thus is visible to all participants of the network, privacy-related data should not be entered on a public blockchain. An alternative would be using a private blockchain, and would be suggested here with respect to securing the privacy of the data. If we assume that a private blockchain (or property-related smart contract) is used, we can proceed to the next question.

Are the entities with write access having a hard time deciding who should be in control of the data store?

No. Blockchains are particularly suitable for facilitating trust in a trustless environment with mutually unknown actors. In that case, writers cannot reach consensus about which party should be assigned to be in control over the data store, and a P2P-network based on blockchain would be ideal. However, as the interviews with institutional investors have revealed, this is not the case in CRE transactions. The purchaser and vendor trust each other, and the writers of the data (i.e. the vendor and its advisors) have no reason for mutual mistrust. If there are no trust issues over who controls or maintains the database, traditional database solutions should just suffice.

Quite surprisingly and somewhat in contrast to earlier expectations, a CRE DD process in its entirety appears not to be a suitable use case for a blockchain-based intervention as of now. We found that this is mainly because of three reasons:

Firstly, the actual sources of transaction costs in CRE DD processes are largely caused by the need for the knowledge, network, assessment skills, negotiation skills and experiences of professional intermediaries. Blockchain technology is not capable of assessing complex information and making strategic considerations like professional intermediaries do based their expertise and experience. It could at most support investors (or experts) in auditing whether certain documents have existed and at what time.

Secondly, with respect to the 'technological inefficiencies' as indicated by the respondents, the main problems revolve around inefficient data sharing systems, un-updated databases, incomplete/inaccurate/missing documents, in short: property owners fail in properly maintaining all property-related documents up-to-date and are only incentivized to do so when the moment of disposition commences. Blockchain is not the right solution to updating information or making 'wrong information right' (a common misconception), because blockchain does not have the ability to assess whether entered data is right or wrong; garbage in, garbage out. It is thus not true that 'everything on the blockchain is just right'; this can only be assumed in case the writing party is fully trusted by the other participants of the blockchain.

Thirdly, even though blockchain would have the ability to update information, or in other words:

writers would be permitted to overwrite certain data fields in the blockchain such that the new data has precedence over the old data, the blockchain would be *mutable*, which in turn challenges the 'immutability'-core component of blockchain. Use cases for which blockchain is eminently suitable are those in which a tamperproof record of historical data is required in environments without trust, and *not* in cases where a mutable database is requested in environments where no trust-related issues exist.

V. Conclusions and Recommendations

In this paper, we presented a decision path that can be followed to firstly assess the applicability of a blockchain-based solution and secondly to determine whether and to what extent the application is expected to impact the eventual transaction costs of the given use case. Using a CSR approach, the decision path was followed with the DD process within CRE transactions as a use case. Previous section has demonstrated that blockchain appears not to be the most suitable technology to remedy the problems and transaction costs that are associated with current DD processes. It appears that a conventional (distributed) database, without the incorporation of blockchain, in theory should suffice. This does not automatically mean that blockchain is of no good at all in DD processes. Even though is does not store documents (but hashes) and even though tacit knowledge is required for proper assessment of information, blockchain should not be entirely written off directly.

We have analyzed properties that are usually worth over €20 million and include multiple tenants. Managing the cashflows of these large properties (or portfolios) entails a high administrative burden. However, we expect that by using smart contracts for rental payments and tenancy overviews, this process can be partly automated with blockchain. Smart contracts add value because it enables property owners to spend less time reconciling transactions for rent payments and property expenses, it provides full transparency and control for overseeing (and approving) property expenses and finally it reduces the costs of accounting, compliance and property management. It is interesting to think about the impact of such an application on the transaction costs of the DD. This can be assessed by determining the impact on the sources of transaction costs. Will it reduce uncertainty? Probably, as the basic information is captured in the blockchain. Will it reduce asset specificity? Not really, as the properties will retain their asset-specific complexity, but the *process* is expected to be simplified with a higher quality of the provided documents. Lastly: will it increase the frequency of transactions? Although it is debatable, we expect that the barriers (in terms of money, time and process complexity) to acquire and sell properties can be significantly lowered, resulting in a shorter throughput time of the DD process and shorter intervals between transactions of a property. In the end, we see a reasonable chance that the eventual transaction costs can be significantly lowered. However, this is open for discussion and deserves further research.

This paper has paved the way for both blockchain- and real estate experts to start investigating the potential of blockchain-based applications in real estate. We identified a variety of conceivable application fields and research topics that can be scrutinized in future research, among which are mainly the applicability and validation of the presented decision path, a greenfield-oriented research approach in order to redesign the DD process with the incorporation of blockchain, extending the scope by adding legal and technical DD, private investors, sell-side DD and non-Dutch markets, and a final research topic could be the technological standardization of document management systems as the lack of standardization currently significantly contributes to the transaction costs of DD processes.

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APPENDIX – MODELS USED AS INSPIRATION FOR DECISION PATH

The first component of Figure 1 is composed of a combination of two different frameworks. The first part until the green box is inspired by the framework of Meunier (2018), depicted in Figure 2, and is slightly adapted. It combines the questions '*Data records, once written, will never be updated or deleted'* and *'Do you want a tamperproof log of all the writers to the datastore?'* into one question as blockchains do not allow for modifications of the log, nor for modifications of the historical data (i.e. the hashes) as recorded on the blockchain. Combining these questions result in: '*Do you want a tamperproof log of all writers to the data, and that the data cannot be deleted/updated?'.*

Two caveats added after the first and fourth question, which are not included in Figure 2. Firstly, the first question '*Do you need a shared database?'* can in the case of a smart contract be answered with 'no', depending on the way a 'shared database' is interpreted. A smart contract is a contract that has to be signed by more than one party, but not necessarily requires a shared database in the sense that multiple actors need to add data or documents to the smart contract. Therefore, we assumed that in some cases, the first question could be answered with 'no', while it concerns an actual use case for smart contracting. Hence, the caveat 'smart contract' is added. Secondly, sensitive information should indeed not be stored on a *public* blockchain, where the information is accessible to anyone participating to the network. However, if the designer aims at using a *private* blockchain, the question can be ignored as the information on the blockchain is protected against unauthorized use, thus excluded from the outside world. Hence, in the case a private blockchain is aimed to be used, it can be proceeded to the next question. Note that if the answer is 'yes' to the next question, the only possible option is a private permissioned blockchain, and thus the writers should be known and there may not be any public verifiability required.

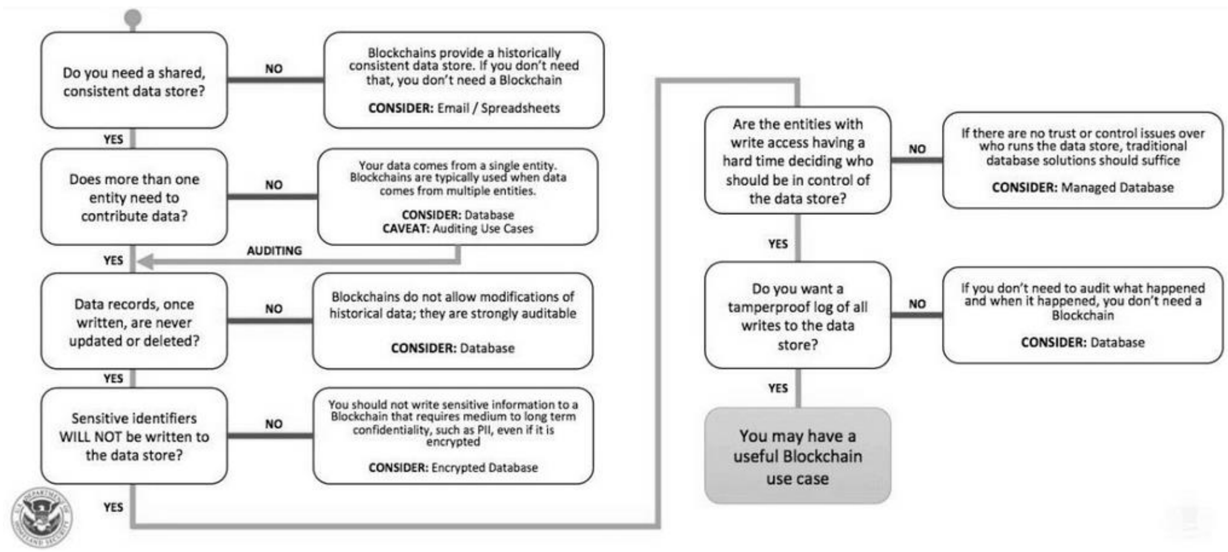

Figure 2 | Original blockchain decision path, retrieved from Meunier (2018)

The second part of the decision path in Figure 1, from the green box onwards, is inspired by the framework of Wüst and Gervais (2017), depicted in Figure 3, and specifies the type of blockchain that could be suitable for the specific use case. One question is left away, namely '*are all writers trusted?',* which had an answer '*don't use blockchain*' if the answer was 'yes'. The last question before the green box already addresses this problem and therefore, the question became obsolete and is thus left out.

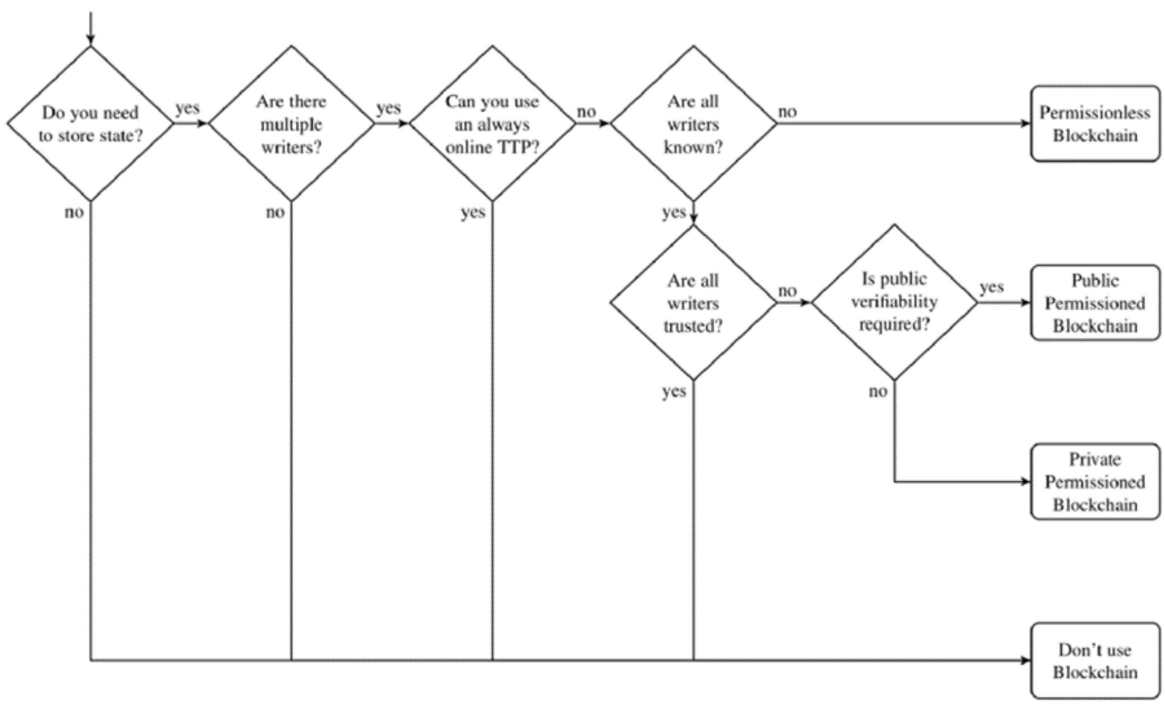

Figure 3 | Original blockchain decision path. retrieved from Wüst and Gervais (2017)