Engineering Sustainable Blockchain Applications

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ABSTRACT

Blockchain technology has attracted attention as emerging paradigm for business collaboration. Blockchain's consensus mechanisms allow partners to cooperate in a business network. However, many applications reported in literature present merely a proof of concept from an engineering perspective. An industrialization of blockchain requires an engineering framework, which assures the sustainability of the application and in particular its network partnerships, i.e. each participant has to act as an active peer in the network rather than being a mere consumer with a wallet for participation in the blockchain. This paper presents the skeleton of such an engineering framework starting with an ideation of partnerships and collaboration patterns to clarify the incentives for participation via business model design for sustainable network operations towards the selection of an implementation platform for the business processes re-engineered. Moreover, an initial version of an interactive tool for community-oriented capturing of know-how about characteristics of blockchain platforms is presented.

Author Keywords

Blockchain Engineering, Incentives for Sustainable Operations, Technology Platforms, Correctness of Code, Modell Checking

INTRODUCTION

The digital currency Bitcoin has originally been the starting point of blockchain technologies, i.e. the distribution of transaction management across a network of computing peers combined with methods for consensus finding. The management of transactions is spread across a network of business collaborators replacing traditional intermediaries. Hence, establishing collaboration protocol agreements such as for conventional business-to-business cooperation with ebXML [5] is replaced by consensus finding.

New governance structures emerge due to the substitution of intermediaries. This change in structure directly calls for new business models and allow for a radical re-engineering of process landscapes [4]. Such a (re-) distribution of concerns combined with methods for consensus finding makes blockchain attractive for many application domains that require a consolidation of inputs from different parties, e.g.,imagine the potential of blockchain for an open business-to-business collaboration [7].

However, sustainability of the partner network is decisive, i.e. incentives for the partners to participate actively in order to maintain network viability. Otherwise, once partners only participate in a consumer-oriented fashion just with a wallet for information exchanges, network diversity becomes deserted finally yielding to umpire control. Hence, incentives for network participation become vital as an incentive of equal importance compared to any foreground advantages. Moreover, the business model in place and the operational processes have an impact on the implementation options for the blockchain platform, e.g., visibility of transactions or provision of smart contracts.

Hence, our engineering framework progresses in steps:

- *Incentive assurance* – ideation of the application for assessing its blockchain potential while identifying particular advantages and incentives for sustainable participation in the network;
- *Partnership network* – draft a new governance structure by identifying (new) stakeholders and their roles in the business network;
- *Network experience and business model* – business model for operating new services amid the network partnerships;
- *Platform properties for process implementation* – specific blockchain characteristics that are determined by re-engineered business processes, i.e. the functional and non-functional requirements of the processes guide the selection of the platform.

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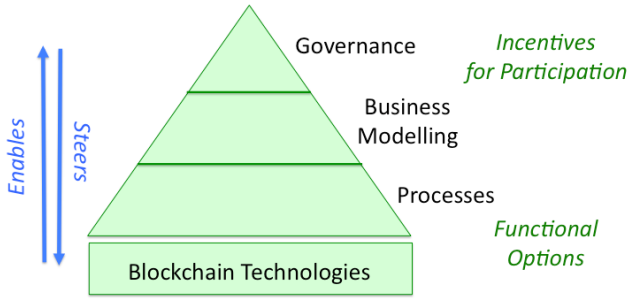

Figure 1: Blockchain Engineering Layers

SUSTAINABLE GOVERNANCE STRUCTURES – INCENTIVES FOR NETWORK PARTNERSHIPS

Trust in the transaction history of a blockchain is only as strong as the plurality of the community behind the blockchain network. A healthy incentive system for running the blockchain nodes is of essential importance for the sustainable operation of any blockchain network.

One important aspect for the sustainable operation of blockchain networks refers to the sustainability of network governance. The major advantage of blockchain is often described as the elimination of intermediaries. Strictly speaking, an intermediary is not eliminated, but replaced by consensus finding in a distributed network. Blockchain enables a fair collaboration between partners of different size and power independently from their available resources or institutional influence. Yet, once incentives to run nodes in blockchain network are not equally distributed, then there is no reason for every partner to run a blockchain node. As a consequence, the network will implode and finally a small number of members gains network sovereignty. Hence, it is a decisive engineering issue, whether a case constitutes a valid application for blockchains? Why not just create a conventional database between those partners?

The identification of incentives is not always apparent. Aspects such as increased freedom, improved security and potential fraud prevention are hard to assess economically. The slimming of business processes might be a measurable improvement in costs, as well as the replacement of several partners providing comparable functionality as an equally functional single blockchain application, but many effects are hard to assess in advance.

Blockchain is often advertised as means for securing the exchange of information in a way that no party can tamper with data that is maintained in the network. Moreover, smart contracts enabl a blockchain to introduce a new level of fairness into processes. Going down this avenue, business processes cannot only be automated on a blockchain, but also connect automatically to imposed enforcement fees that can make blockchain networks particularly more attractive for small partners. For instance, a bottler that depends on a certain type of bottles from a supplier can punish the bottle supplier, when she is not able to deliver the necessary amount of bottles. Although the bottle supplier is actually powerful enough to not care about a single bottler, the blockchain network will automatically punish the supplier. An active network node secures the tracking of situations of under-supply. Because the blockchain enforces this punishment against the unequal partner it becomes an incentive for the bottler to operate a blockchain node. Hence, there is a natural motivation to participate in the blockchain network, but not only as a consumer of transactions with no actual relevance regarding the process fairness from a personal perspective.

In a methodical stance, we propose a blockchain sustainability canvas for identifying incentives for active participation in a blockchain network. The sustainability canvas (displayed below) provides assistance in:

- Identifying incentives for different parties in a blockchain networks;
- Rating the incentives against each other and identify weak network partners;
- Rating the value and the quality of the network with respect to sustainability;
- Matching existing incentives with smart contract enabled business processes to enable the engineering of new incentives.

The canvas is organised into four areas. The upper left area covers the identification and assessment of incentives. In a first step the expected network participants can be collected in the box "*Network Participants*". For every network participant it is important to identify advantageous incentives that come with the network participation. These can be documented in the "*Participation Incentives*" box. Disadvantages for a certain party that origin from joining a blockchain network on the other hand, can be collected in the "*Participation Disadvantages*" box. The resulting aspects of these two sides can be invaluable assets in identifying weaknesses of a network or potential points of entry to start re-engineering an existing process.

After focusing on the sustainable operation of the blockchain network, the area in the upper center helps in analyzing the application of existing processes to a blockchain network and the identification of new potentials regarding collaboration and process optimization. In the box "*Trust Enabler*" we identify where a blockchain can provide trust in existing processes and how those processes profit from it. In general we observed two cases: In the first case, the existing process was defective and the blockchain can be used to provide trust in a way that previously was not feasible. In the second the blockchain can replace an existing source of trust. This often leads to the elimination of intermediaries.

"*Change of Governance*" covers the potential change in process governance by introducing a distributed blockchain network. For instance, who holds the sovereignty of a process when it is executed independently as a smart contract in the blockchain? But also who controls the access to the blockchain network? In case of a permissioned blockchain the requirements to join the network or to open it to

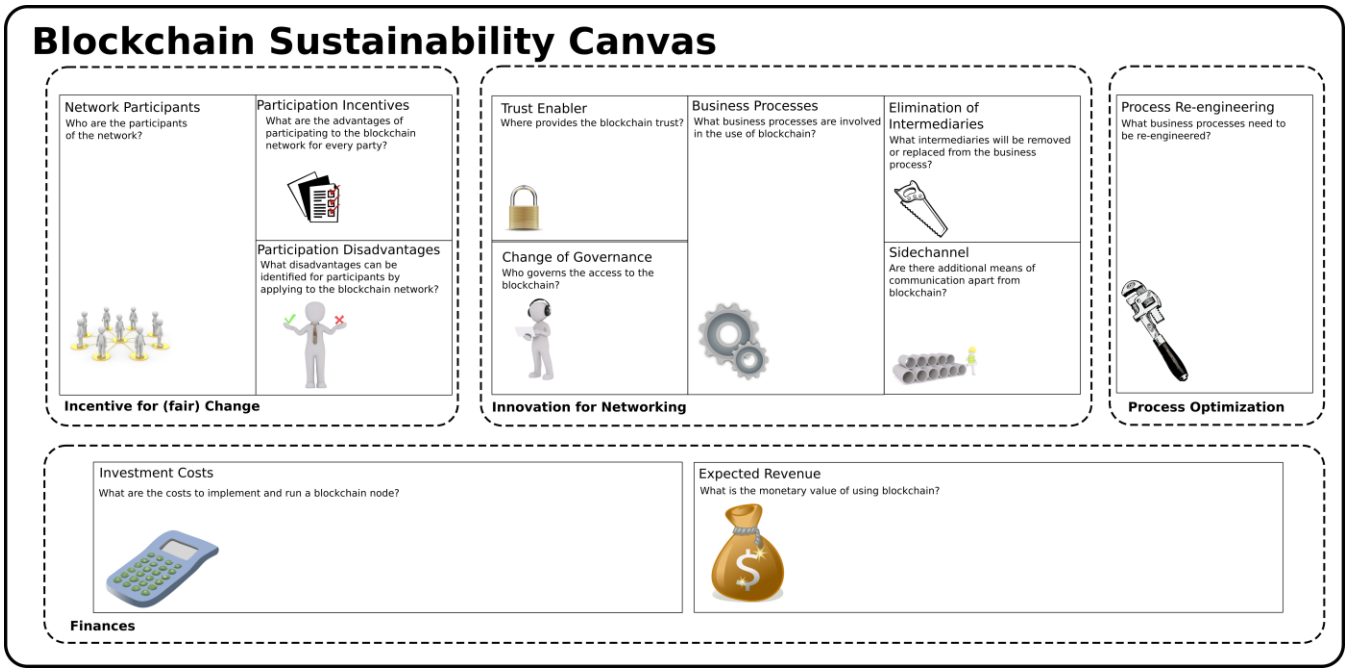

Figure 2: Blockchain Sustainability Canvas

additional parties must be specified. Does every member has the right to add a party or is it a voting based decision? Existing processes that might be supported, or that can be adapted to be used in the blockchain network are collected in the box "*Business Processes*". The potential loss of existing parties leads to immanent changes in the structure of a process. Those can be documented in the box "*Elimination of Intermediaries*". Complex processes often require the communication via multiple channels, e.g., it is still necessary to send paper documents due to legal conditions. Although not directly part of the blockchain these interactions are still part of the process. It must be evaluated how that affects the security of the blockchain and if it can be improved by re-engineering the process.

The upper right area covers the question whether processes can be re-engineered to be more suitable for the blockchain context after benchmarking existing business processes with respect to their applicability and performance regarding their application in a blockchain context. This might comprise the purposeful replacement of a party by a smart contract and thus the elimination of an intermediary or the slimming of exchange processes by utilizing the secured append-only ledger property of the blockchain.

Finally the lower area covers the aspects of costs regarding the operation of a blockchain network. In the left field operational costs can be documented. This can be energy costs, administration and maintenance costs, but also in case of public blockchains the costs of a transaction and an estimation about the volume of transactions.

The right field allows the documentation of expected revenues from the application of the blockchain. The slimming of processes decreases the number of involved parties and can crucially accelerate the processing time. But also costs for the audit of accounting processes can be decreased by allowing the auditing entity access to the blockchain network.

CRITERIA FOR TECHNOLOGY SELECTION

There exists a multitude of different blockchain platforms that are engineered with respect to different functional objectives. Some platforms focus on high transaction throughput that means the number of transactions that can be processed by a blockchain per second, e.g., Fabric, while others identified the visibility of data as major problem of existing blockchain platforms, e.g., Quorum. The development of new blockchain technologies is proceeding apace. The sheer volume of available technologies is often overwhelming when trying to get an overview. Similar to the engineering of software systems, it is important to choose the technology that solves a problem and not to find a problem that can be solved by a given technology the decision should be strongly based on dispassionate facts instead of personal preferences.

Starting with a large set of potential blockchain platforms, a subset of blockchain technologies being suitable for a given problem can be derived by considering the following aspects:

- *Access policy* – Permissioned vs. public blockchain;
- *Process integration* – Availability of smart contracts or chain code;
- *Scalability and transaction performance* – Transaction throughput;
- *Restricting data access* – Data privacy and visibility;

- *Network governance* – Ease of adding/removing nodes to the network;
- *Technology governance* – Open source, project management, development kits.

Figure 3: Technical Aspects

Access policy

A permissioned blockchain restricts the access to the blockchain network to only a selected number of people. Such a network is useful in case that known parties wish to cooperate and exchange data or participate on processes in a secured way, such that no party can tamper with it and the origin of transactions can be unambiguously dereferenced. The assumption is that data and processes that are stored in the blockchain are only of relevance for parties in the network.

In contrast, access to public blockchains is not restricted and can be easily acquired by creating a public/private key pair. In this case a large group of people can be addressed, but data is freely exchanged throughout the network. The decision for a public or a permissioned blockchain also depends on the targeted accessibility. A blockchain as a distributed ledger is not only a technology to securely store and enact transactions, but also a platform to enable the standardized communication of different parties.

Process integration

The next major criteria depend on the potential requirement for using smart contracts. Smart contracts allow the untampered execution of program code within the blockchain. Complex processes with a variety of execution options can be modeled by a single smart contract or a multitude of interacting smart contracts. However, if there is only the requirement to securely store and exchange data, then more lightweight technologies can be considered.

Scalability and transaction performance

The throughput of transactions determines the throughput of data that can be handled by a blockchain and this affects the potential number of people and interactions with the blockchain. For comparison: In Bitcoin the number of transactions per second (tps) is around 7 tps, in Ethereum it is around 15 tps and the permissioned blockchain Hyperledger Fabric claims a transaction throughput of 3,500 transactions per second [1]. Estimating the number of expected transactions that are applied on a blockchain can reduce the set of potential technologies drastically. Recently, many popular blockchain platforms are confronted with the problem of general scalability. Different solutions and approaches are proposed,, e.g., sharding [3] and it is a question of the future, which concept will prevail.

Restricting data access

Although these three aspects are of major importance by deciding for a blockchain technology there are additional aspects that must be considered: Data privacy and data visibility is important for many application scenarios. A user of a financial application does not want to share her income publically to every member of the blockchain and for transactions between companies even cartel considerations can influence the data visibility allowance. Depending on the project it must be ensured that only a subset of participating network members can access certain information. A fine-grained permission control systems must be supported.

Network governance

The ease of adding and removing nodes to the network influences the decision for a certain technology. Is there a high fluctuation of network members or is the network rather steady. In the first case the addition or removal of members should not lead to a necessary shutdown of the whole network to start the nodes with new configurations. Lightweight administration processes will increase the maintainability of the network and reduces configuration errors.

Technology governance

As a final aspect the governance of the technology is of major importance. Although in case that the selected technology is open source there is no secured guarantee about the future of the project, i.e. whether the selected technology will be periodically updated and in particular supplied with security fixes. High costs for exchanging the underlying blockchain technology or to continue the development with in-house resources must be considered in case of a non-continuation.

To support the methodical selection of suitable blockchain platforms we created a web based assistant that provides a structured questionnaire to assist in the selection of an appropriate platform. Platforms can be related, compared and analyzed with respect to different aspects. Considered platforms include smart contract enabled platforms as well

as merely transaction based technologies. Digital currencies are not part of it.

Currently we support only a relatively small number of 10 blockchain technologies. However, we provide interfaces so that users can propose or directly add further technologies. References to articles and sources are attached to the presented information to increase transparency. Hence, a community platform for knowledge exchange on blockchain technology elements and application-specific constraints is maturing.

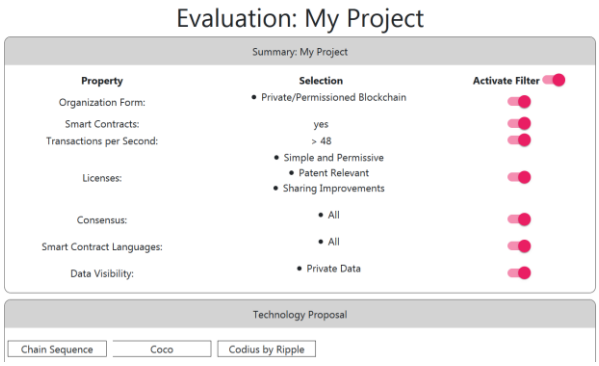

Figure 4: Blockchain Technology Assistant

Selecting the suitable technology for a blockchain project according to its requirements and based on dispassionate facts will ensure a strong technical foundation for a long living and sustainable operating blockchain network. By considering future usage behavior scalability problems can be identified or completely avoided.

ASSURING VALIDITY OF OPERATIONS BY SMART CONTRACTS

The security and strength of a blockchain strongly depends on the strength of the underlying network and thus on the network members that operate blockchain nodes. On the other hand the secure operation of blockchain nodes depends on the trust of network participants. There exists a mutual relationship. If a party does not trust a network she will not expend the work and costs to participate at the network. One might argue that the correctness of the blockchain is cryptographically ensured and that there is no reason for a party to not trust the blockchain. However, in case of smart contracts this is not always the case. Although the blockchain ensures that the program code is exactly executed as it is stored in the blockchain it is not always trivial to decide that a program code acts as expected. A popular example for a wrongly programmed smart contract is the splitting function of the DAO contract [6]. Although the program code is exactly executed the execution result does not match the expectations of the process participants. Such errors in the software can lead to advantages for one group and disadvantages for another. Thereby a simple replacement or update of a smart contract is not possible, since all parties need to accept this new version. If a party gains an advantage from a faulty version she might not be interested in switching to a new correct contract version.

As a consequence the correctness of smart contracts can affect the trust of parties into a blockchain and consequently affect the strength of the whole blockchain network.

There exists a multitude of methods for formally verifying program code. We suggest the use of model checking as a simple, potential one-click solution [2] for verifying the correctness of a smart contract. The idea is to model the expected behavior of a program with logical formulas as linear temporal logics (LTL) or computational tree logics (CTL). For model checking we analyze the state space of a program. The state space is the set of program states, where a program state represents the state, which is the valuation of every variable, of a program for a certain execution step. The state space of a program is examined whether one of the logical formulas is violated. In case of a violation a counter example is derived that supports the identification and correction of flaws in the program code.

Although the concept of model checking is easy to grasp the application of the technology imposes a major challenge known as the state space explosion problem. Even a small program can have a very large number of different program states and thus leads to an extremely large state space. A large state space can be unfeasible to analyze and by applying model checking it is one of the major challenges to reduce the state space. However, certain characteristics of smart contracts support the model checking process. So a smart contract is limited in the number of executional steps to prevent blocking the whole blockchain by for instance running into an infinite loop and secondly, the blockchain ensures the atomicity of transactions. The code called by a certain transaction is ensured to be executed without interruption, only the order of transaction execution cannot be predicted.

An additional idea for improving the quality of smart contracts and to simplify the formal verification during the development process is to provide repositories of formally verified libraries. Such a library can be integrated into a smart contract. During the model checking it can be assumed that this code is already correct (with respect to a certain set of logical formulas). This will crucially decrease the number of states that must be analyzed.

Although, formal verification will increase the quality of a smart contract and will ensure that a smart contract works correct with respect to the formally specified expectations, the formal verification is only as good as the specification of the expected behavior. Missing or incorrect constraints can lead to verified program code that still reacts unexpectedly in certain conditions.

To ensure a sustainable trust into the blockchain network and thereby a sustainable operation of the blockchain network, the correct functionality of smart contracts is crucially

important and using tools that are able to increase the quality of smart contract becomes a major requirement.

USE CASE EXAMPLE

In the following we apply the blockchain sustainability canvas to the use case of pool boxes. These are for instance boxes used to transport vegetables from a farmer to a retailer over a number of intermediate stations. There are four parties involved in the use case: *poolbox operator, filler*, *distributor* and *retailer*. The *filler* produces some sort of product and sells it to the distributor. The *distributor* wants the goods delivered in a certain type of box and makes a contract with the *poolbox operator* to provide these boxes to the filler. The filler pays a "refuel fee" to the poolbox operator and sends the filled boxes to the distributor. The distributor takes the boxes and pays a pledge to the filler. From the distributor the boxes will be delivered to the *retailer,* who again pays a pledge for receiving the boxes. The retailer empties the boxes and returns them back to the poolbox operator, who cleans and repairs them and then reintroduces them into the cycle.

This explanation represents the existing process and there are problems that motivate participants of the process to apply blockchain. Boxes often change ownership in an uncontrolled fashion, e.g. stolen from premises, because the ownership is not tracked and by returning a box to the box supplier the pledge is refunded. Also counterfeiting of boxes is a problem. Then pledge is refunded, although the boxes are potentially of bad quality or miss certain certificates allowing their use with food or dangerous goods. Another critical point is that fillers are hoarding boxes to prevent the lack of boxes for their (individual) peak times of production and hence delivery, while poolbox operators are interested in a continuous flow of the boxes to reduce the necessary number of boxes. On the other hand is it possible that fillers cannot bring goods to the market, since the poolbox operator is not able to deliver the necessary amount of boxes. In contrast to the poolbox operator there are multiple filler with relatively small influence in the process. So it is hard for filler to enforce potential claims.

The potential blockchain participants are the four parties, although in practice a role can be inherited by multiple entities. As a next step we need to identify the incentives and disadvantages for the parties to participate at the blockchain network. The governance of the unaltered process lies at the distributor and the poolbox operator. These two entities negotiate a contract and make the major decisions. When a poolbox operator does not deliver enough boxes to a filler the position of the filler is relatively weak. An incentive for a filler could be the smart contract based punishment of missing boxes. For every box that cannot be delivered the poolbox operator must pay a certain punishment fee to the filler. On the other hand the filler pays punishment fees back to the poolbox operator in case she is hoarding boxes. Of course introducing smart contracts in this way will reduce the supremacy of the poolbox operator what can be considered as a disadvantage.

In general by tracking and controlling the exchange of boxes with a blockchain every party gains the ability to take measurements of box distribution. This can be interesting for predicting the necessary amount of boxes for a given point in time. The tracking of box ownership will prevent stealing. Then a box can be only refunded, when the persons owns the box. Although a thief can still steal the box she is not able to refund it, since no clearing house will accept them when the person cannot proof the ownership with the blockchain.

The blockchain serves as trusted entity and partially transfers the process governance to the community. In this first approach only partially, since there is still the distributor that makes the decision about the box types and the poolbox operator. In this case we do not eliminate an existing intermediary, but enrich the process with box tracking abilities to eradicate flaws in the existing process. A consequent process re-engineering could additionally improve the fairness between different parties. By opening the process to arbitrary poolbox operators that are bound to deliver only a certain type of boxes and multiple distributors the supremacy of the two parties can be restricted and smaller entities as the filler and retailer can replace those in case of problems. That might be an additional incentive for the retailer to join a blockchain network.

Another potential extension is to completely replace the poolbox operator by a decentralized autonomous organization (DAO) where every party is a shareholder. The DAO works on a cost covering basis with the only target to provide the necessary amount of boxes to the different participants in the process. In this case the position of the poolbox operator is eliminated and replaced by a smart contract. Certain problems of the conventional process, as the hoarding of boxes, are naturally eliminated, since a high volume of circulating boxes increases the operation costs and thus provides a disadvantage for every stakeholder including the filler that hoards the boxes.

LESSONS LEARNT FOR INDUSTRIAL SCALE-UP

So far, reports on engineering paradigms are sparse. Papers are dominated by proof of concepts to propose blockchain as implementation vehicle for various domain applications. Any industrial scale-up will require the development of a methodological founded engineering paradigm that accompanies a blockchain' lifecycle from *the cradle to the grave*. To start with, the eligibility of business models for the application to blockchain is of major importance. The evaluation of existing business processes regarding its suitability for deploying a blockchain enables the re-engineering or the creation of new processes. Outgoing from these specifications it is important to engineer the sustainability of the emerging blockchain network. A mutable dialog allows updating a business process while increasing process fairness and thus optimizing the different party's incentives to participate at the blockchain.

The determination of the business processes will strongly affect the technology selection. Several aspects, such as the

scalability, visibility of data for different stake holders as well as interoperability of the blockchain network as a technology platform needs to be evaluated with respect to the process requirements. The great variety of existing technologies and the speed of development complicates the selection process and must be simplified by introducing standards for the blockchain technology. Besides the ease of comparing blockchain technologies this will also simplify the exchange of underlying platforms.

During the implementation phase of a blockchain in particular the quality of smart contracts is of major importance. A poorly engineered smart contract can ruin the user experience and more important, can sustainably affect the trust of users into the blockchain network. In case of a crucial failure most users will not blame the smart contract as an independent element, but the complete blockchain network or even the blockchain technology. A potential image loss is a big risk. Hence, the broad application of standardized smart contract libraries and paradigms for testing and verification will improve the overall quality of smart contracts, as well as, speedup the development process from an economical perspective.

Although stressing its distributed nature for transaction management, a blockchain is certainly not a highly performant repository technology for the management of mass data as in production processes for instance. However, the information sharing among manufactures and suppliers can be certified by a blockchain. Hence, a separation of concerns has to be decided: managing operational data of production processes by database management technology versus maintaining audit information between business partners by blockchain technology.

As a final step it is necessary to determine the estate administration of the blockchain. What happens to the data stored in the blockchain, when the blockchain lifecycle is at its end? There exist legal requirements like the "right to forget" that demands the loss of data. How can that be achieved by blockchain technologies.

Hence, there are several engineering issues to be researched in order to bring blockchain technology to industrial use and allow for an industrial scaling. One of the upmost challenges is certainly research on methods for consensus finding beyond a sole proof of work as well as proof of stake. Any wide-spread deployment of blockchain technologies will be tampered without any scaling of computing complexities for consensus finding.

CONCLUSIONS

This paper presents our approach to the engineering of blockchain applications with a particular emphasis on the sustainability of the partner network. Any public blockchain requires a lively and vivid network of partners actively supporting the network. Otherwise, the character of the collaboration has to be switched to a permissioned blockchain, which re-introduces the concept of umpires.

Moreover, the characteristics of the application have to be assessed carefully in order to select a platform from the array of available platforms. The structured questionnaire presented is only a first step to guide through this complex decision process. In addition, the questionnaire is connected with references for evidence-based decision making. An interactive editing component allows for a community-based capture of platform characteristics and implementation experiences.

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