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Blockchain-Augmented Organizations

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Completed Research

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Abstract

Blockchains can be used to enable new kinds of organizations, especially Decentralized Autonomous Organizations (DAO). In DAO, governance rules and transaction processing provided by traditional centralized authorities to support intermediation are completely replaced by the automated execution of trusted smart contracts to realize secure and immutable transactions. However, DAO may not be suitable for many business cases. Nevertheless, blockchains provide many unique functions, such as immutability, security, trust, and traceability, so that they can be used to augment existing software solutions. We introduce the concept of Blockchain-Augmented Organizations (BAO), in which traditional, Non-Blockchain Organizations (NBO) are augmented by the blockchain-based organizations. We compare BAO with DAO and NBO, and propose a model-based, process-driven engineering approach for constructing blockchain organizations and applications. Experience gained on a pilot blockchain prototyping experiment on an aerospace Model-Based Systems Engineering project using Hyperledger's Fabric is used to elaborate and exemplify the paper.

Keywords

Blockchain, Decentralized Autonomous Organizations, Organizations, Governance, Model-Based Engineering.

Introduction

At its core, blockchains are a tamper-resistant Distributed Ledger Technology in which all relevant transactions are immutably recorded to provide a single source of truth (Xu et al. 2017, Zheng et al. 2017, Zheng et al. 2018). Using smart contracts, transaction information in blockchains is identically and securely stored in multiple nodes in peer-to-peer networks through agreed-upon consensus algorithms (Zheng et al. 2017, Beck, Avital, Rossi & Thatcher 2017). Many have regarded blockchains to be a foundational technology that serve as a central part of the fifth and current disruptive computing paradigm: decentralized inter-connection of the world (Swan 2015).

From the governance perspective, blockchains can be viewed as an institutional technology that enables new kinds of organizations, governance, and contracts (Davidson, De Filippi & Potts 2016). Much attention and excitement has been placed on Decentralized Autonomous Organizations (DAO), which are considered as a key focal point of the blockchain economy (Beck, Müller-Bloch & King 2018). In DAO, the organizations and their governance rules are fully specified and implemented in the blockchain by smart contracts, which are executed to complete transactions. DAO is thus entirely digital. Many traditional organizations use centralized authorities to support intermediations between participating partners. These centralized authorities represent bottlenecks creating serious inefficiency, opacity, and security problems (Swan 2015). The decentralization and automation nature of DAO holds great promise for a more effective, transparent, and secure economy: the blockchain economy (Beck, Müller-Bloch & King 2018).

However, DAO are known to be difficult to develop (Porru, Pinna, Marchesi & Tonelli 2017) and may not be suitable for many business cases (Takagi 2017). We use the term Blockchain Organizations (BO) to refer to the digital organizations created in blockchains with the uses of smart contracts. BO may not need to be pure DAO. Effective blockchain solutions can be used to create what we termed as Blockchain-Augmented Organizations (BAO), in which traditional Non-Blockchain Organizations (NBO), are augmented by BO to form a new kind of hybrid organizations (Ménard 2004). This paper discusses the characteristics and nature of BAO, and proposes a model-based, process-driven engineering approach to effectively develop them.

The remainder of the paper is organized in the following manner. The Background section provides a brief background of blockchain. It also describes a pilot prototyping experiment for investigating applying blockchains on an aerospace Model-Based Systems Engineering (MBSE) project using Hyperledger's Fabric. This project will subsequently be used to elaborate and exemplify the paper. The next section discusses DAO, introduces the concept of BAO, and elaborates BAO by comparing it to DAO and NBO. The 'A Blockchain Development Model' section proposes a model-based, process-driven approach for constructing blockchain organizations and applications. We draw our conclusions in the last section.

Background

Blockchain Technology (BCT)

A blockchain is a distributed, decentralized digital ledger stored in a peer-to-peer network (Zheng et al. 2018). The entire history of all transaction records is stored in blocks which are cryptographically linked in a chain. A block contains the hash of the previous block and a timestamp. Any retroactive alteration of a transaction will change the block, its hash, and thus the subsequent blocks in the chain. The resulting immutability allows users to effectively verify and audit transactions. Blockchains are managed by nodes in peer-to-peer networks in which decentralized consensus algorithms are used to determine governance, including the confirmation and recording of transactions, and the creations of blocks. These consensus algorithms are technically complicated in order to satisfy the required security of the underlining trust models, ensure adequate performances, and provide incentives (such as Bitcoin mining) for the maintenance of the blockchain networks.

Blockchain was proposed and first successfully implemented by Bitcoin as a cryptocurrency (Nakamoto 2019). Ethereum represents the next major enhancement in BCT by introducing smart contracts using a Turing-complete language called Solidity (Wood 2014). Although Bitcoin supports elementary scripting operations, they are not Turing-complete, and it was not designed for fulfilling general transaction requirements other than the transfers of Bitcoin. While Ethereum is a cryptocurrency, it is also a platform (Wood 2014) for developing blockchain applications. In Ethereum, developers can use transferrable tokens to manage non-fungible assets as required by the problem domains. Ethereum may also be perceived as a distributed state machine in which immutable data can be stored and tracked.

Both Bitcoin and Ethereum belong to the class of public, permissionless blockchains. They are open to the public participants to join without the need of any permission. Public blockchains are based on a trustless security model in which participants have no trust on each other (Zheng et al. 2018). As a result, exceedingly strong security mechanism must be put in place, resulting in large performance tradeoffs. Furthermore, even though participant accounts are represented by hash addresses, transaction records are open to public, and data analytics can be conducted to mine the transactions and account hash addresses with external data. Privacy in public blockchains is not fully guaranteed and participants are known to have pseudonymity, not complete anonymity. As a result, public blockchains are not suitable for many business cases that are based on semi-trust models, but not a trustless model.

Accordingly, permissioned blockchain platforms supporting smart contracts, such as Hyperledger's Fabric and Corda (Valenta & Sandner 2017), started to appear. Participants need permissions to join permissioned blockchains, and have some but not full trusts on each other. Permissioned blockchains are thus based on semi-trust models. The security mechanism in place is still a central concern, but is less demanding than those of the trustless models of the public blockchains, in which they need to be strongly tamper-proof. For business cases that require semi-trust models, privacy, and fast performance, permissioned blockchains can be a better choice.

In summary, developers can now select from a list of many permissioned or permissioned platforms to develop their blockchain applications (Chowdhury et al. 2019) to satisfy diverse requirements.

An Aerospace MBSE Project's Blockchain Pilot Prototyping Experiment

Systems Engineering focuses on the design, implementation, and management of complex systems throughout the entire lifecycles. Many ideas in this paper are the results of our experience on a pilot prototyping experimentation funded by NASA on investigating the use of BCT to support Model-Based

Systems Engineering (MBSE) (Estefan 2007). MBSE is the "formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases. (Hart 2015)" Models are developed using modeling languages such as SysML (Hart 2015) and UML, or tools, such as CAD. The goal of MBSE is to move the record of authority from document repositories to digitalized models to enhance better understanding of the design changes, communicate design intents, analyze design impacts, enable automation and optimization (Hart 2015), and cumulatively build digital twins to aid the entire lifecycle (Heber & Groll 2017). Many SE projects have consortia of large numbers of organization participants, complex governance structures based on semi-trust models, and existing Systems Engineering Environments (SEE) that are hybrid, complicated, legacy, and possibly isolated even within the same organization because of security and privacy controls. Effective versioning controls for providing a real-time consistent current state of the models to all participants and software (such as the digital twins) is a major challenge in migrating from document-centric development processes to MBSE processes. With the ability to provide a single source of truth and support complicated governance rules through smart contracts, blockchains have the potential to be an important contributor to MBSE.

In a typical MBSE project, an organization is led by a Chief Systems Engineering (CSE) to develop component models, such as SysML models, using modeling tools, such as Magic Draw. A consortium of collaborating organizations is usually headed by a lead organization. The Chief Systems Integration Engineer (CSIE) of the lead organization is charged with integrating all component models, assuring that requirements and functions are satisfied, seeking approvals of component changes, and ensuring the entire system models function correctly. Our investigation included many meetings with the CSIE and a support organization of an aerospace MBSE project. We developed use cases and business process models for the project to identify opportunities and challenges for applying BCT. Some of these challenges of blockchain-supported MBSE include:

1. It must work in a complex and hybrid SEE (Hart 2015), interacting with many kinds of users and software.
2. It should provide the support of a single source of truth with complicated version control mechanisms (Estefan 2007) and governance policies.
3. Unlike cryptocurrency, MBSE artifacts are fungible (Lu, Weber & Staples 2018) and have complicated internal structures and relationships.

We designed and implemented a pilot prototype to experiment with these identified opportunities and challenges using the popular permissioned blockchain platform Hyperledger's Fabric. Fabric was selected as it provides good support of needed features and performance requirements (including flexible member services), private data collections, and smart contract development using multiple high level languages. It is open sourced and relative maturity, and has strong community and industrial supports.

BO, DAO, and BAO

BO and DAO

BCT enables digital organizations for users to interact and conduct transactions directly. These Blockchain Organizations (BO) are virtual in nature, and support decentralized governance and trusted peer-to-peer transactions. BO can replace traditional centralized authorities for intermediation. Known as the vanguard of Blockchain 2.0, Ethereum (Wood 2014) introduced and popularized Smart Contracts (SC) in blockchains which can be used to fully automate decentralized governance rules and transactions. This enables the development of Decentralized Autonomous Organizations (DAO), in which decentralized governance rules are fully encoded in SC. Ethereum played a key role in DAO. In fact, a well-known example of DAO, called 'the DAO,' was launched in 2016 using Ethereum (DuPont 2017).

We use the term Blockchain Organizations (BO) to refer to the digital organizations created by using blockchains and SC. We loosely refer to organizations that do not use any blockchain technology as Non-Blockchain Organizations (NBO). NBO can be physical, digital (as other information technologies may be used), or a mixture of both. Figure 1 shows a DAO being constructed to replace and enhance the functionality and performance of an NBO. Note that the BO in the DAO is specified by the original NBO and any expected enhancements. It is also constrained by the functions provided by the selected blockchain platform. Thus, the organizational structures and governance policies of the DAO will not be the same as that of the original NBO, as depicted in Figure 1.

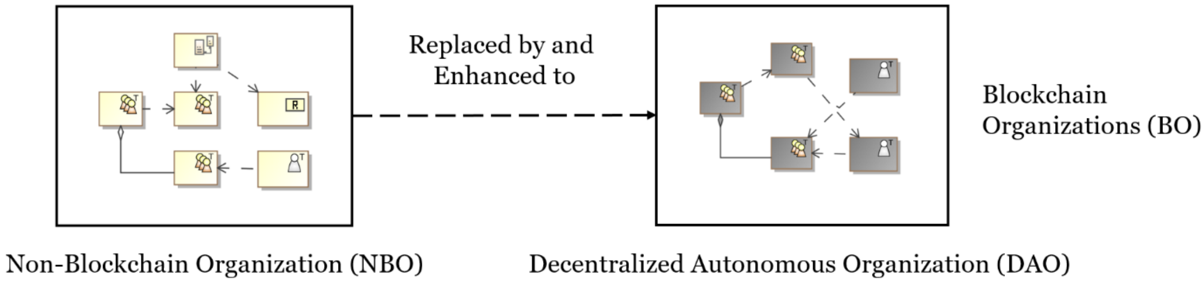

Figure 1. DAO to Enhance and Replace Non-Blockchain Organizations (NBO)

Even though the opportunities provided by DAO is huge, it faces many challenges (Beck, Müller-Bloch & King 2018). This includes the enormous complexity of decentralized and algorithmic governance (DuPont 2017), performance, security and privacy issues of SC (Alharby & van Moorsel 2017), difficulty in SC development (Alharby & van Moorsel 2017), and the lack of experienced developers (Beck, Müller-Bloch & King 2018). Since DAO is the only organizational structure, DAO developers may need to modify or develop the selected blockchain platform in the system level to fully support all required governance rules. If the security of a DAO is compromised, drastic measures, including the use of hard forks, will need to be taken as there are no other organizational means to remediate the problems. This is clearly exemplified by the infamous hacking of 'the DAO,' the aforementioned famous DAO (Mehar et. al. 2019).

As another example, the detailed case study on the DAO Swarm City elaborated by Beck, Müller-Bloch & King (2018) epitomizes both the immense potential and challenge of DAO. It can disrupt disruptive yet centralized Web applications for shared economy such as Uber (Huckle, et al, 2016). However, despite much technical progress, as of April 17, 2020, the market capitalization of Swarm City's coins is less than $0.2 million USD, dwarfed by the market capitalization of Uber at about $47.5 billion.

Blockchain-Augmented Organizations (BAO)

One useful perspective is to consider BCT as a *radical* technological innovation (Beck & Müller-Bloch 2017) that provides new functionalities for disrupting and replacing current ways of operations. However, it is known that an innovation may be disruptive to one group but sustaining for another group (Nagy, Schuessler & Dubinsky 2016). Thus, for business models that can effectively be implemented by DAO, blockchains can indeed be disruptive. For others, it may still be effective to apply BCT. In fact, blockchains have been used to augment many application areas and development platforms (Zheng et al. 2018). For example, Takagi (2017) developed a DAO index to measure the suitability of using DAO on occupations. It resulted in a wide range of DAO suitability index values from 3.79 to 10.91 among 964 occupations.

Complementary to the radical technological innovation perspective is the concept of *General Purpose Technology* (GPT). Filippova (2019) studied available Blockchain-related patent data from PATSTAT and concluded that blockchain is indeed a GPT that can spawn downstream innovations, including the creation of organizations. We use the term of Blockchain-Augmented Organizations (BAO)[1] to refer to hybrid organizations created by applying blockchains in conjunction with NBO[2].

Figure 2 shows a NBO being replaced by a BAO. Some parts of the NBO are modified. Others are replaced by BO, and the BAO is composed of NBO and BO working in tandem. The requirements of the BAO are split to be implemented by NBO, BO, and proper coordination between them. Thus, the organizational structure

[1] One may also regard BAO as Blockchain-Assisted Organizations.

[2] There are some resemblances between the relationship between BAO and DAO, and the relationship between Augmented Reality (AR) and Virtual Reality (VR). As opposed to physical reality, VR provides a complete and full reality that is entirely digital. AR augments the physical reality with digital reality. Likewise, a DAO is a complete and full blockchain organization that is entirely digital. BAO augments non-blockchain organizations with blockchain organizations.

of BAO can be intrinsically more complicated as cooperating organizations are maintained, and their boundaries need to be well understood and defined.

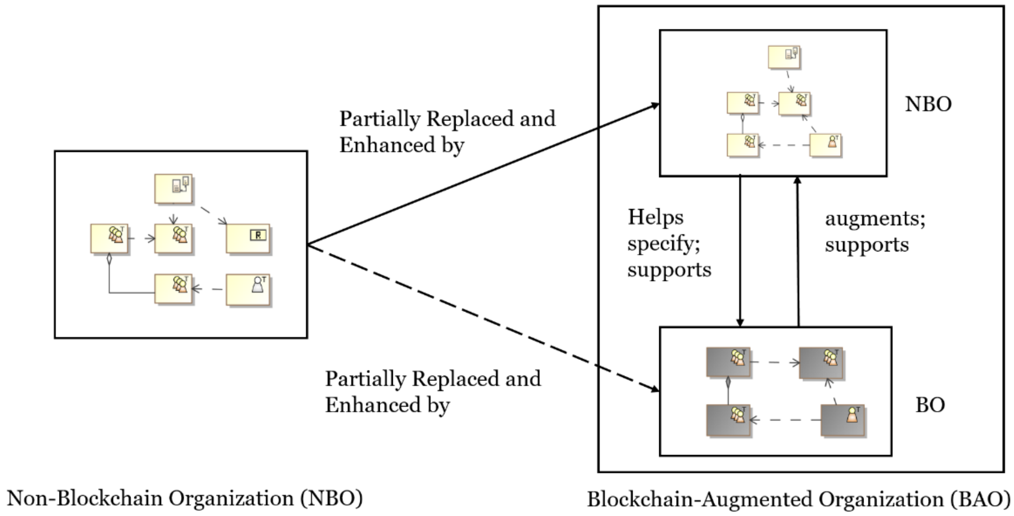

Figure 2. BAO to Enhance and Replace Non-Blockchain Organizations (NBO)

Figure 3 shows the nature of use cases of DAO and BAO. In (a), all users interact with DAO through SC (dotted lines) in a uniform and autonomous manner, which is a major advantage of DAO. On the other hand, there are concerns that many existing blockchain systems are isolated in silos and cannot interact with other blockchain systems (Dinh, Datta & Ooi 2019). In the not too distance future, it is perceivable that the need for two DAOs to interact with each other may arise. This interaction will be hard to accomplish through SCs especially if the two DAOs do not use the same blockchain platform. In contrast, in (b) where BAO is used, actors can interact with BAO either through SC or other means (solid lines in Figure 3.) This can add organizational complexity and reduce the degree of automation. On the other hand, interactions between BAO can be handled through NBO and not through SC, providing an alternative route that can be more suitable.

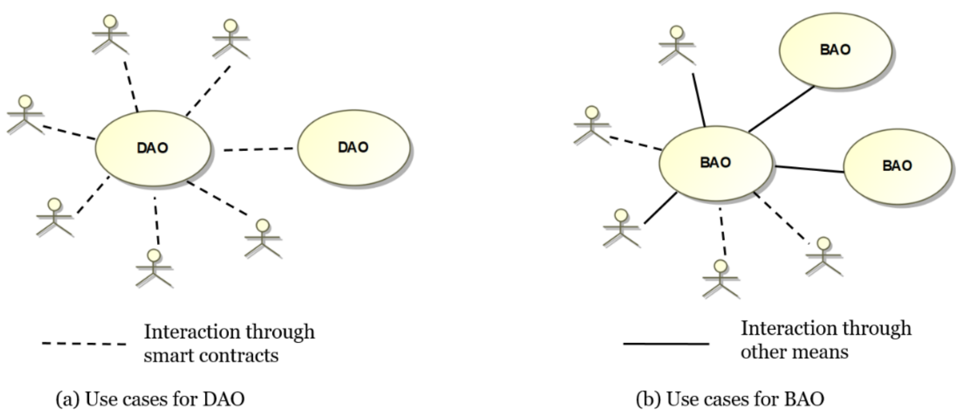

Figure 3. Use Cases for DAO and BAO

Using our MBSE prototype project as an example, unlike a DAO that has no central authority, the CSIE and the approval board represent certain kinds of central authorities for many processes. They serve as a single point of communications for these processes, which may not be effectively supported by SC of current BCT. A hybrid BAO solution is more suitable.

To highlight the traits of BAO, Table 1 compares several characteristics of BAO with DAO and NBO. This list of characteristics is geared towards DAO and thus they are of high values for DAO. NBO covers a large class of organizations, and different NBOs may have varying values for many characteristics.

Characteristics	DAO	BAO	NBO
Digital or Physical Organizations	Digital	Mixed/Hybrid	Varying
Governance Structure	Blockchain	Integrated	Mostly traditional
Decentralized Decision	Yes	Varying	Varying, usually low
Blockchain Utilization	Very High	High	No
Workflow and Transaction Automation	Complete	Varying, high	Varying
Blockchain Security Requirement	Very High	High	NA
Required Blockchain Maturity Level	Very High	High	No
Blockchain Platform's System Development	High	Low	No
Suitability of Model-Driven and Process-Driven Development	High	High	Varying

Table 1. Comparisons of DAO, BAO, and NBO

Some observations on Table 1 are collected below.

1. Compared to DAO, BAO are hybrid organizations with integrated governance structures.
2. Decision making in DAO is decentralized. BAO can have different degrees of decentralized governance.
3. Processes and transactions are fully automated in DAO. In contrast, BAO can automate them to varying degrees.
4. It is more likely for DAO to require system level development of the blockchain platform, and the blockchain expertise are thus more crucial.
5. Model-based, process-driven development seem to be appropriate for both DAO and BAO.

A Blockchain Development Model

BCT is complicated and rapidly evolving, and has a unique set of distinguishing characteristics. There is thus a recognition of the need of specialized methods, tools, and techniques (Porru, Pinna, Marchesi & Tonelli 2017). We present a model-based, process-driven approach for both DAO and BAO here.

Model-Based Engineering

Model-Based Engineering (MBE), or Model-Driven Engineering (MDE), is about elevating models in the engineering process to a central and governing role in the specification, design, integration, validation, and operation of a system (Estefan 2007). In MBE, models of various kinds and levels are developed in the engineering lifecycle (Lu, Weber & Staples 2018). Models of low level of abstraction and high fidelity can be executable for code generation, testing, constraint checking, and other activities. Models of high level of abstraction and low fidelity are useful tools for business and requirement analysis. MBE has been proposed as a suitable methodology to develop blockchain applications. Advantages include the potential uses of automated tool for generating high quality SC code (Tran, Lu & Weber 2018, Weber et al. 2016), being blockchain platform-agnostic, ease of understanding (as comparing to SC code), and facilitation of communications between domain experts and blockchain engineers to ensure effective design and development (Lu, Weber & Staples 2018).

Process-Driven Blockchain Application Development

The purpose of Business Process (BP) management is to optimize business processes to achieve better performance and higher effectiveness (Viriyasitavat et al. 2018). In this context, processes are recognized as important assets, and should be managed and continuously improved, while using information technology as an essential enabler (Chang 2006). Effective BP management is based on the development of optimal BP Models (BPM) with a high-quality graphical modeling language (Krogstie 2016), such as the Business Process Modeling and Notation (BPMN) (Allweyer 2016). For example, in the implementation phase, tools for parsing and converting BPMN models to SC, such as using the language Solidity in

Ethereum, have been developed to partially automate blockchain solutions for BP (Tran, Lu & Weber 2018, Weber et al. 2016). There are also preliminary suggestions for using BPMN and UML to develop Blockchain software (Jurgelaitis et al. 2019, Rocha & Ducasse 2018).

We propose a refined model-based, process-driven approach for developing both DAO and BAO applications to put the emphasis on the processes that define the governance structure. BPM are constructed in the early stage to drive the subsequent phases of the lifecycle. Figure 4 shows the proposed process in BPMN.

Step 1. Define the BPM. From the IT perspective, governance involves the identifications of the participants, the data and tools used, and the kinds of processes and decisions made in BP. Thus, the goal of this step is to use a BP model language like BPMN to define these processes in enough fidelity to drive the subsequent steps. For example, in our pilot prototyping experiment, we work with the CSIE to develop UML models (mostly use case diagrams and class diagrams) and BPMN models. As an example, Figure 5 shows a simplified lifecycle of a MBSE model component, which is mostly self-explanatory. In Figure 5, both organizations have their own MBSE repositories (storing the MBSE models) and SEE. Furthermore, many processes are refined into sub-processes to achieve the needed fidelity.

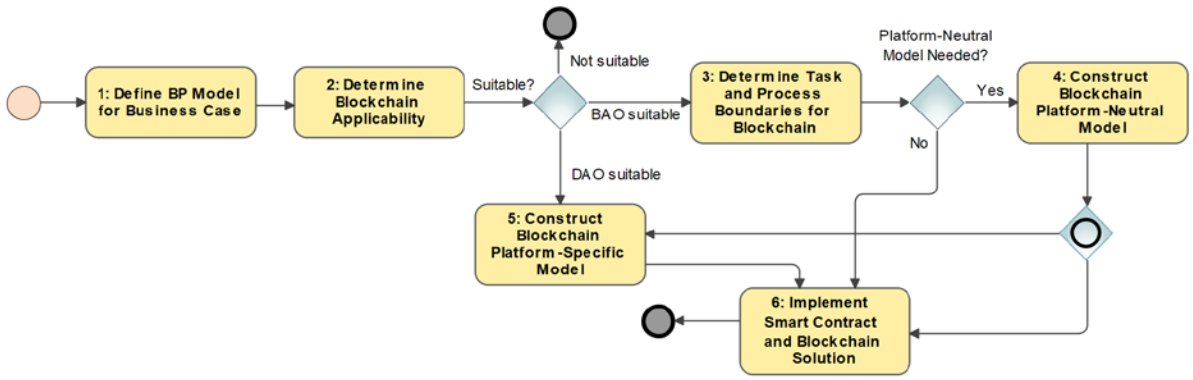

Figure 4. A Model-Based Process-Driven Approach for Constructing Blockchain Solutions

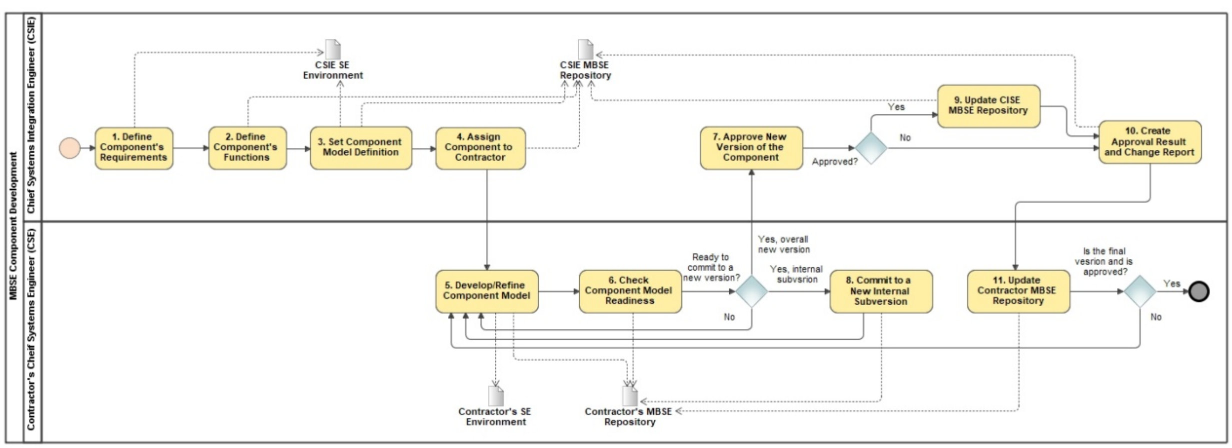

Figure 5. The Lifecycle of a MBSE Model Component

Step 2. Determine blockchain applicability. The decision can be no blockchain, DAO-suitable, or BAO-suitable. Many proposed frameworks to address the issues of blockchain suitability (Casino, Dasaklis, & Patsakis 2019, Lo et al. 2017, Wüst & Gervais 2017) can be used in this step. These frameworks usually include a collection of questions, requirements, determinants or flowcharts to decide suitability.

For our prototype, blockchains provide a secured single source of truth of the current version of the MBSE model, which is important to construct a digital twin (Heber & Groll 2017). However, many of the high order processes in the BP, especially those of CSIE, are very difficult to be replaced by SC, especially at the current stage. Thus, BAO, and not DAO, is the suitable choice.

Step 3. Determine process boundaries if BAO is the suitable choice. The primary purpose of this step is to identify which processes and tasks should be implemented by the NBO or BO portions of BAO, and how NBO and BO should be structured to work in a complementary way. It is in general cost effective to maximize the uses of blockchains to provide as much automation as possible. However, there are tasks that BCT are not appropriate. For examples, tasks 1, 2, 3, 5, 6, 7 and 10 in Figure 5 are deemed currently unsuitable for automation by SC. There are other more suitable software in the SEE, and the high-order activities of the tasks require direct input of centralized domain experts, such as the CSIE.

Step 4. Construct a Blockchain Platform-Independent Model (PIM). A PIM can be constructed to help bridging the gap between a more general model geared towards problem requirements, and a specific implementation model for a selected blockchain platform (Jurgelaitis et al. 2019). PIM can include data models of the asset structures, SC architectures, boundary and behavioral models, transaction's behavior, blockchain state definitions and change mechanism, security models of roles and privileges of participants, etc. Advantages of PIM include enhanced communications between domain experts and blockchain engineers, better understanding of problem requirements and what and how decisions should be made for actual implementation, and better portability between different blockchain platforms. Nevertheless, PIM represents extra amount of work and may thus be intentionally bypassed, especially for DAO where system level development of a specific blockchain platform is likely, as indicated in Figure 4.

In our prototyping project, an example of an asset structure PIM is the significantly simplified UML class diagram for the MBSE's model and components in Figure 6. Both the MBSE model and the components constructing the model will need to be stored in the blockchain as assets to ensure a single source of truth. In our design, a MBSE model is defined as a collection of prescribed components which are high level components explicitly defined in the model. Components have a hierarchical structure and lower level components may be included in the model through an ancestor component. A component may also have many kind of relationships with other components.

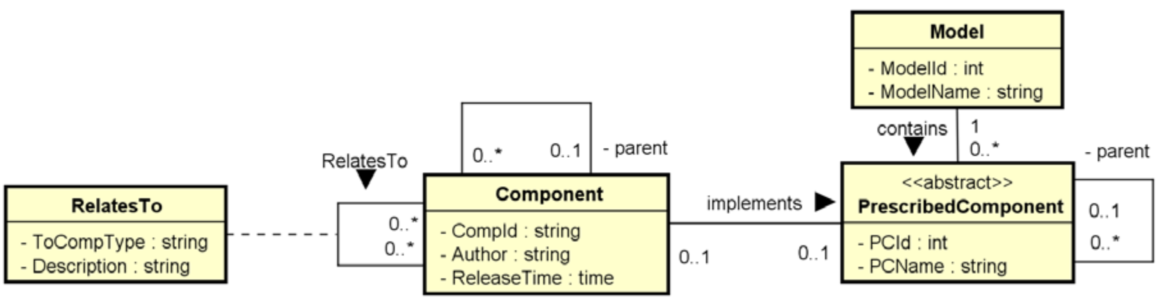

Figure 6. A Simplified UML Class Diagram for MBSE Model and Components

Step 5. Construct a blockchain Platform-Specific Model (PSM). In this step, blockchain platform-specific design elements are either added to the PIM model in step 4, or the PSM is constructed directly. PSM allows the design to be implemented directly, taking advantages of the features while working around limitations of the selected blockchain platform.

Step 6. Implement the blockchain solutions and the SC. This is the last step in the process that include verification and validation. For example, the Go language is used for our prototype, and classes and relationships in Figure 6 are implemented as struct, nested struct, arrays, or references in Go.

Conclusions and Future Directions

We proposed BAO to refer to hybrid organizations that are constructed with mutually supporting NBO and BO. We discussed key characteristics of BAO by comparing it to DAO and NBO. A model-based, process-driven approach for identifying and developing DAO and BAO was proposed, elaborated, and exemplified by an aerospace BAO prototype example. The paper provides only an overview of an initial proposal on a quickly evolving technology. Much more extensive work should be done to investigate the validity and nuance of the conceptualization and the development process.

From the governance perspective, hybrid organizations represent trade-offs between decentralized market models and centralized hierarchical models (Ménard 2004). Williamsons (1991) proposed three generic forms of economic organization: market, hybrid, and hierarchy. He indicated that "cost effective choice of organization form is shown to vary systematically with the attributes of transactions." By supporting immutable and automated transactions, BCT makes possible a new kind of hybrid organizations. An in-depth study on the mutual effect of hybrid organization theory and blockchain will not be of both theoretical importance, but also provide practical benefits on the blockchain development process.

Our proposed blockchain development approach is model-based and process-driven. There are other approaches, including identification of the participants, their trust relations, and interactions (Wessling et al. 2018), and an agile development process based on user stories (Marchesi et al. 2018). There are much room for cross-fertilization of various development methodologies. There are also many other gaps to be filled. For instance, in building both blockchain PIM and PSM, modeling guidelines and notations may need to be extended to include blockchain features (Falazi et al. 2019). For example, in BAO development, application data may be distinguished by the need of immutability, such as using stereotype in UML Plug-ins and extensions can be added to CASE tools to support our proposed approach. Furthermore, we will adapt, refine, and apply our proposed process under different organization contexts.

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REFERENCES

Alharby, M., & van Moorsel, A. (2017). "Blockchain-based smart contracts: A systematic mapping study," arXiv preprint arXiv:1710.06372.

Alharby, T. (2016). *BPMN 2.0: introduction to the standard for business process modeling*. BoD–Books on Demand.

Alharby R, Avital M, Rossi M, Thatcher JB (2017) "Blockchain technology in business and information systems research," *Bus. Information Systems Engineering* (59:6), pp.381–384.

Beck, R., & Müller-Bloch, C. (2017). "Blockchain as Radical Innovation: A Framework for Engaging with Distributed Ledgers as Incumbent Organization," in *50th Hawaii International Conference on System Sciences* (HICSS 2017). Waikoloa, Hawaii, USA

Beck, R., Müller-Bloch, C., & King, J. L. (2018). "Governance in the blockchain economy: A framework and research agenda," *Journal of the Association for Information Systems* (19:10), pp.1020-1034.

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). "A systematic literature review of blockchain-based applications: current status, classification and open issues," *Telematics and Informatics* (36), pp.55-81.

Chang, J.F. (2006), *Business process management systems*, Auerbach Publications, Boca Raton.

Chowdhury, M. J. M., Ferdous, M. S., Biswas, K., Chowdhury, N., Kayes, A. S. M., Alazab, M., & Watters, P. (2019). "A Comparative Analysis of Distributed Ledger Technology Platforms," *IEEE Access*, (7), pp.167930-167943.

Davidson, S., De Filippi, P., & Potts, J. (2016). "Economics of blockchain," *SSRN Electronic Journal*, 2744751.

Dinh, T. T. A., Datta, A., & Ooi, B. C. (2019). "A Blueprint For Interoperable Blockchains," arXiv preprint arXiv:1910.00985.

DuPont, Q. (2017). "Experiments in algorithmic governance: A history and ethnography of "The DAO," a failed decentralized autonomous organization," in *Bitcoin and Beyond*, pp.157-177. Routledge.

Estefan, J. A. (2007). "Survey of model-based systems engineering (MBSE) methodologies," *Incose MBSE Focus Group* (25:8), pp.1-12.

Falazi, G., Hahn, M., Breitenbücher, U., & Leymann, F. (2019). "Modeling and execution of blockchain-aware business processes," *SICS Software-Intensive Cyber-Physical Systems* (34:2-3), pp.105-116.

Filippova, E. (2019, June). "Empirical Evidence and Economic Implications of Blockchain as a General Purpose Technology," in *2019 IEEE Technology & Engineering Management Conference (TEMSCON)*, pp. 1-8. IEEE.

Hart, L. E. (2015, July). "Introduction to model-based system engineering (MBSE) and SysML," in *Delaware Valley INCOSE Chapter Meeting (30)*. Mount Laurel, New Jersey.

Heber, D., & Groll, M. (2017). "Towards a digital twin: How the blockchain can foster E/E-traceability in consideration of model-based systems engineering," in *DS 87-3 Proceedings of the 21st International Conference on Engineering Design (ICED 17)* (3) Vancouver, Canada, 21-25.08, 321-330.

Huckle, S., Bhattacharya, R., White, M., & Beloff, N. (2016). "Internet of things, blockchain and shared economy applications," *Procedia computer science* (98), pp.461-466.

Jurgelaitis, M., Butkienė, R., Drungilas, V., Vaičiukynas, E., & Čeponienė, L. (2019). "Modeling principles for blockchain-based implementation of business or scientific processes," in *Proceedings of the international conference on information technologie*s, Kaunas, Lithuania, April 25, 2019

Krogstie, J. (2016). Quality in business process modeling. Springer, Heidelberg.

Lo, S. K., Xu, X., Chiam, Y. K., & Lu, Q. (2017, November). "Evaluating suitability of applying blockchain," in *2017 22nd International Conference on Engineering of Complex Computer Systems (ICECCS)*, pp.158-161. IEEE.

Lu, Q., Weber, I., & Staples, M. (2018) "Why Model-Driven Engineering Fits the Needs for Blockchain Application Development," *IEEE Blockchain Technical Briefs*.

Marchesi, M., Marchesi, L., & Tonelli, R. (2018, October). "An agile software engineering method to design blockchain applications," in *Proceedings of the 14th Central and Eastern European Software Engineering Conference Russia*, pp.1-8.

Mehar, M. I., Shier, C. L., Giambattista, A., Gong, E., Fletcher, G., Sanayhie, R., ... & Laskowski, M. (2019). "Understanding a revolutionary and flawed grand experiment in blockchain: the DAO attack," *Journal of Cases on Information Technology (JCIT)* (21:1), pp.19-32.

Ménard, C. (2004). "The economics of hybrid organizations," *Journal of Institutional and Theoretical Economics JITE* (160:3), pp.345-376.

Nagy, D., Schuessler, J., & Dubinsky, A. (2016). "Defining and identifying disruptive innovations," *Industrial Marketing Management* (57), pp.119-126.

Nakamoto, S. (2019). "Bitcoin: A peer-to-peer electronic cash system," *ManuboFt*.

Porru, S., Pinna, A., Marchesi, M., & Tonelli, R. (2017). "Blockchain-Oriented Software Engineering: Challenges and New Directions," in *2017 IEEE/ACM 39th International Conference on Software Engineering Companion (ICSE-C*), pp.169-171.

Rocha, H., & Ducasse, S. (2018, May). "Preliminary steps towards modeling blockchain oriented software," in 2*018 IEEE/ACM 1st International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB)*, pp. 52-57.

Swan, M. (2015). *Blockchain : Blueprint for a New Economy*, O'Reilly Media, Sebastopol.

Takagi, S. (2017). "Organizational Impact of Blockchain through Decentralized Autonomous Organizations," in *International Journal of Economic Policy Studies*, 12(1), 22-41.

Tran, A. B., Lu, Q., & Weber, I. (2018). "Lorikeet: A Model-Driven Engineering Tool for Blockchain-Based Business Process Execution and Asset Management," in *BPM*, pp. 56-60.

Valenta, M., & Sandner, P. (2017). *Comparison of ethereum, hyperledger fabric and corda*, Frankfurt School, Blockchain Center.

Viriyasitavat, W., Da Xu, L., Bi, Z., & Sapsomboon, A. (2018). "Blockchain-based business process management (BPM) framework for service composition in industry 4.0," *Journal of Intelligent Manufacturing*, pp.1-12.

Weber, I., Xu, X., Riveret, R., Governatori, G., Ponomarev, A., & Mendling, J. (2016, September). "Untrusted business process monitoring and execution using blockchain," in *International Conference on Business Process Management*, pp.329-347. Springer, Cham.

Wessling, F., Ehmke, C., Hesenius, M., & Gruhn, V. (2018, May). "How much blockchain do you need? towards a concept for building hybrid dapp architectures," in *2018 IEEE/ACM 1st International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB)*, pp.44-47.

Williamson, O. E. (1991). "Comparative economic organization: The analysis of discrete structural alternatives," *Administrative science quarterly*, pp.269-296.

Wood, G. (2014). "Ethereum: A secure decentralised generalised transaction ledger," Ethereum project yellow paper, (151), pp.1-32.

Wüst, K., Gervais, A., 2017. "Do you need a Blockchain?" *IACR Cryptology* ePrint Archive 2017, 375.

Xu, X., Weber, I., Staples, M., Zhu, L., Bosch, J., Bass, L., ... & Rimba, P. (2017, April). "A taxonomy of blockchain-based systems for architecture design," in *2017 IEEE International Conference on Software Architecture (ICSA)*, pp. 243-252.

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017, June). "An overview of blockchain technology: Architecture, consensus, and future trends," in *2017 IEEE International Congress on Big Data (BigData Congress)*, pp. 557-564.

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* (14:4), pp.352-375.