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***Abstract*—Blockchain technology is argued to have the potential to facilitate the development and improvement of cross-organizational business processes, on various aspects of the business process management discipline. In this paper, we review existing work on the use of blockchain technology to support business processes with a focus on cross-organizational settings. Based on this, we suggest to view blockchain as a software connector helping organizations to integrate the IT systems they use to support business processes. In addition, this paper suggests to use a model-driven engineering approach for the development of such connectors. By doing so, the need to develop a methodology helping to model and implement blockchain-based software connectors supporting cross-organizational business processes is highlighted. By adopting such an approach, organizations would be able to facilitate and speed up the development of blockchain-based solutions. This in turn would facilitate experimentations with this technology, which is considered as an important phase for organizations to derive value from it.**

***Keywords*—cross-organizational business processes, business process management, BPM, blockchain, model-driven engineering, MDE, methodology, software connector**

I. Introduction

Organizations offering services as well as research on this topic has traditionally focused on the relationship between the organizations themselves and their customers. More recently, this view has expanded to consider the various service providers that are contributing to the delivery of what is called a customer journey [1]. In this context, service providers can take a leading or subordinate role in the organization of the customer journey, or leave the integration function up to the customer [1]. In that latter case, she will have to assemble and coordinate interrelated services herself to achieve a particular goal [1]. There are many cases where the journey followed by a customer involves interactions with multiple organizations. By looking into that set of interactions instead of looking at individual interactions alone, different insights can be gained [1]. The network of providers that are responsible for the delivery of services that, in the mind of the customer, are seen as one overall, integrated service can be considered as a unit of analysis for services [1]. Although the idea of optimizing customer journeys may seem focused on business-to-consumer (B2C) interactions, integrating Business Processes (BPs) across organizations is also valuable in business-to-business (B2B) interactions. A typical example is the integration of BPs along a supply chain, which can help improving the operational and the business performance [2].

Considering this, it is important for organizations to further develop collaborations and integrate their BPs. This is particularly relevant nowadays, considering that the majority of BPs are going beyond the organizational boundaries [3], [4], and hence are characterized as cross-organizational.

Services can be considered as a type of processes [5] and can be approached from a Business Process Management (BPM) perspective. BPM includes methods, techniques and tools aiming at supporting the design, the enactment, the management and the analysis of BPs [6]. Using this perspective, organizations can attempt to increase the added value they deliver to their customers, the value they are able to capture and to make coordination with partners more efficient. This remains valid regardless of whether customers are consumers or other organizations.

To innovate and/or improve their BPs, organizations need to use certain tools. Information Technology (IT) is one of them and was considered by many as the most powerful one, already in the 90s [7, Ch. 1]. Nowadays, IT can be used for a variety of BPM activities, including the execution of existing BPs and their reengineering in the light of the new capabilities offered by IT. Different types of IT systems can be used to do so, including Workflow Management Systems (WfMSs), Business Process Management Systems (BPMSs) and Process-Aware Information Systems (PAISs). More details on the distinctions between these are available in [8]. Such systems have been well adopted by organizations in order to effectively and efficiently support the execution of their BPs, but they are often confined within organizational boundaries [9]. In order to go beyond such boundaries, there is a need for organizations to integrate the IT systems they use to support their BPs. Doing so can yield a number of benefits including more transparency, increased integration, faster communication and higher throughput [10]. Although not all processes rely on IT to support them, only such processes are considered in the scope of this paper. Furthermore, we focus on the integration of IT systems to foster the development of cross-organizational business processes but it is important to underline that other (complementary) solutions can be considered to achieve this goal.

A central requirement to be met for organizations to collaborate together and integrate their processes revolves around trust. For instance, collaborating organizations integrating their systems need to have a solution that provides trustworthy monitoring information about the execution of the process. In this context, trustworthy means that it has to reflect reality and ensure that this history has not been tampered with. Further details on such matters are discussed in the next sections of this paper. Such a trust requirement is particularly critical considering that the lack of trust between organizations can hamper the innovation and development of cross-organizational BPs [11].

In this context, blockchain technology is argued to be a potential solution to solve the issue of trust between organizations, and thereby facilitate the development and innovation of cross-organizational BPs. However, as it is still considered as a new technology, research on the use of blockchain for BPM activities is still scarce and many related questions remain unanswered [8].

The remainder of this paper is organized as follows. First, section II provides a generic introduction to blockchain technology. After that, section III discusses the role of blockchain as a software connector and suggests the use of Model-Driven Engineering (MDE) approaches for the development of blockchain-based artefacts. Then, section IV presents opportunities and challenges of blockchain technology to support BPM activities with a focus on IT systems supporting these. After that, section V discusses existing work with regards to these challenges and opportunities. Furthermore, it motivates the interest of a software connector view in order to design blockchain-based systems aiming at facilitating the integration of IT systems supporting cross-organizational BPs. In the same section, the need for a methodology helping to build blockchain-based software connectors using a MDE approach is underlined. Finally, section VI closes this paper with a conclusion.

II. Introduction to Blockchain

A. *Origin and potential impact*

In 2008, a person or group under the pseudonym of Satoshi Nakamoto published a white paper describing an alternative, digital and distributed currency called Bitcoin [12]. This currency relies on a distributed ledger technology that is used to record transactions and is referred to as blockchain technology (or simply blockchain in the rest of this paper). With the developments of this underlying technology, a much broader range of applications was made possible. Blockchain is argued to have the potential to disrupt many industries, and may have brought us at the dawn of a new revolution [13]. The industries and activities that can potentially be impacted by this technology include but are not limited to financial services [14, Ch. 3], healthcare [15], governmental services [13, pp. 44–52], energy [16], insurance [17] and supply chain management [18], attracting the attention of both researchers and practitioners.

The expectations and promises related to this technology are numerous. They range from more efficient operations for organizations to the possibility for entities to interact directly with one another without the need of a Trusted Third Party (TTP) or other intermediary. In turn, blockchain can help reduce costs and delays while giving entities more control over whatever is managed using this technology (money, creative content, data, etc.).

B. *Characteristics*

Blockchain can first be described as being a distributed database (or ledger, since it records transactions) that is shared among and agreed upon a peer-to-peer network [19]. In a blockchain network, the peers (also called nodes) are maintaining a copy of the ledger and validating the transactions that are to be recorded. This is managed by the network of peers, and not by a central authority having the possibility to accept, reject or even modify transactions.

In order to be recorded in the ledger, the transactions (which are timestamped) are grouped into blocks. Whenever a new block is added on a blockchain network, it includes a hash of the previous block that was added. In doing so, blocks are linked together and form a chain of blocks, hence the name of blockchain. Whenever a new block is created, it has to be verified and added to the blockchain. In order to do so, particular nodes are selected to validate the block and then publish their version of the blockchain which contains the new block for the rest of the network. The fact that blocks are linked together using hashes of previous blocks makes it easy for a participant to verify whether or not the history of transactions as published by a given node has been tampered with. Indeed, changing the details of a transaction changes the content of a block. Changing the content of a block in turn changes its hash and therefore breaks the chain of blocks, which means that past transactions have been tampered with. Assuming that a transaction has been validated by the relevant nodes, it will get propagated to all the other nodes (as part of a block) and cannot be deleted or changed.

Finally, transactions need to be cryptographically signed by their initiator (e.g. a person willing to make a payment on the Bitcoin blockchain), preventing entities to write transactions on behalf of others without having their cryptographic keys.

As a result of these characteristics, blockchain can be defined as "[…] a distributed database, which is shared among and agreed upon a peer-to-peer network. It consists of a linked sequence of blocks, holding timestamped transactions that are secured by public-key cryptography and verified by the network community. Once an element is appended to the blockchain, it cannot be altered, turning a blockchain into an immutable record of past activity" [19, p. 3].

Since the development of the Bitcoin blockchain, other blockchains started to appear, offering different characteristic and being more (or less) suitable for different types of use. The Bitcoin (initial) blockchain is focused on currencies and payments [13, Ch. 1]. Although such a blockchain is capable of handling transactions of various types (including non-financial), more recent implementations such as Ethereum [20] added an additional layer focusing on the development of programming code that can be deployed and executed on a blockchain [13, Ch. 2]. Such a code is referred to as a smart contract and their development makes blockchain not only a shared database but also a shared execution environment.

C. *Challenges*

As a new technology, blockchain faces many challenges anchored in various disciplines. In [21], a research framework around blockchain is proposed, and identifies a number of questions that still need to be answered. Among these are included the following:

- *Q1*: How can interfaces between smart contracts and existing [IT] systems be designed to increase interoperability?
- *Q2*: How can firms utilize blockchain features for their own business processes?
- *Q3*: How does blockchain provide added value for companies to conduct transactions […] with customers, other companies [and] stakeholders […]?

As this paper focuses on the use of blockchain to support BPM activities, such questions are addressed in the different sections that follow. The reader can refer to [21] for more details about the broader challenges faced by blockchain.

III. Blockchain as a software connector and model-driven engineering approach

A. Blockchain as a software connector

As discussed in the previous section (c.f. *Q1*), one of the challenges of blockchain is to integrate smart contracts with existing IT systems. As suggested by [22], this can be achieved by having dedicated integration components on top of a blockchain. Indeed, a blockchain by default only has access to what is on the blockchain. However, smart contracts can emit events that can be captured by external systems, and the different functions that they provide can be called from these. This can happen in a direct way (i.e. by adapting existing systems to make use of blockchain) or using dedicated integration components, as suggested by [22]. With such possibilities and considering blockchain as a shared database and execution environment, it can be used to integrate different systems. In the light of its distinctive characteristics, [23] suggests that blockchain can be seen as a type of software connector.

According to [23], software connectors offer a number of interaction services, defined as:

- *Communication services* focused on transferring data among different components.
- *Coordination services* managing the transfer of control towards different components.
- *Conversion services* adjusting interactions between components and ensuring that each component can process the received information even though it was not initially in the expected format.
- *Facilitation services* support and optimize interactions between the different components (e.g. clearing payments, transactions validation and permissions management).

Seeing blockchain as a software connector provides a number of advantages. First, it helps making explicit the necessity to make a number of architectural choices impacting performance and quality attributes of the systems such as security, privacy, scalability and sustainability [23]. Although such attributes are not deeply discussed in this paper, they are very important to consider when designing blockchain-based solutions. A second advantage claimed by the authors of [23] after applying this view on a number of cases is that it helps improve information transparency and traceability. Both of these are important in the context of cross-organizational BPs. Although not explicitly mentioned, some organizations involved in the development of blockchain technologies also share (at least partly) this view [24]. On top of that, it can be argued that the software connector terminology fits well with the needs of blockchain-based solutions supporting cross-organizational BPs. Such a fit is discussed in more details in section IV.

The proposition of the present paper is to adopt the view of blockchain as a software connector in a context where this technology is used to facilitate the integration of IT systems supporting a number of BPM activities across organizations.

B. Model-driven engineering approach

Other challenges related to the use of blockchain include the development and implementation of blockchain-based artefacts. Assuming that blockchain is used as a software connector, the question to know how to develop these remains open. As with any technology, an organization willing to investigate, experiment or implement blockchain-based solutions requires people with knowledge and skills around it. However, people meeting such requirements are still scarce and the development of blockchain-based solutions remains difficult due to the steep learning curve [25] and lack of adequate tooling for developers [8]. This difficulty to find appropriate people is a challenge that organizations investigating blockchain currently have to face. Another challenge involved in the development of smart contracts results from their immutable character. Once a contract is deployed, it is not possible to change it or to remove it. Therefore, programming or logic errors in their code can have costly consequences. In addition to that, executing smart contracts on certain platforms induces costs based on the computing resources that are required for the execution. Therefore, producing optimized and high-quality smart contracts is a critical issue that has to be considered. Finally, there are a lot of different blockchain implementations that are available, and it is an ecosystem evolving quite rapidly. Therefore, it would be valuable for organizations to have the ability to implement blockchain-based solutions on different implementations without having to re-develop their artefacts for each platform.

One of the solutions that can facilitate the development of blockchain-based artefacts in such a context is the use of MDE approaches [25]. Such approaches consist in transforming a (set of) model(s) into code that can be executed. The code that is generated is typically based on best practices, is expected to be of high quality and is generated consistently. This helps mitigating the issues mentioned in the previous paragraph. MDE approaches also allow domain experts to be more closely involved in the development of the software, potentially allowing them to generate working prototypes on their own, and without the (direct) need of computer scientists or more technical people.

Our suggestion in the present paper is to make use of MDE to design and implement blockchain-based solutions as software connectors. Such connectors could then be actually implemented on different blockchains using the same models as initial input while providing more flexibility to domain specialists, reducing the need of blockchain specialists and providing high-quality smart contracts.

In the section that follows, opportunities and challenges of using blockchain for BPM activities across organizations are summarized, using [8] as a framework to structure the discussion. While discussing this, the present paper highlights the implications of adopting a software connector view of blockchain in this particular context and the implications of the use of MDE to design and implement such connectors.

IV. Blockchain and business process management

As stated before, blockchain represents a number of opportunities and challenges for BPM. In [8], a review of these is proposed and structured along two dimensions. The first one is made of the stages of the traditional BPM lifecycle: process identification, discovery, analysis, redesign, implementation, execution, monitoring and adaptation and evolution. The present paper focuses on IT-related aspects of the implementation, execution and monitoring phases of BPs that are supported by IT. The second dimension used to structure the review of [8] is made of BPM capability areas: strategy, information technology and people. In this paper, only human and strategic aspects are discussed. The first one is only briefly discussed in section III.B while the second is further developed in the present section. Through the discussions in this section, partial answers to questions *Q1, Q2* and *Q3* (c.f. section II.C) are provided.

A. Cross-organizational business process monitoring

When organizations integrate their processes, there is typically an underlying contract specifying the terms of the collaboration with regards to the different participants (obligations, rights, rules, etc.) [26]. As part of such contracts, rules may specify Service Level Agreements (SLAs) and compensation mechanisms to be applied in case SLAs are not met or in case of non-compliance with the agreed upon process. Considering this, records about the execution of the process represent the basis information to verify whether or not the terms of the contract are respected, and to support the enforcement of the contract (e.g. enforce a compensation mechanism) [26]. Therefore, this information needs to be indisputable and recognized by all the participants [26].

When different organizations integrate their IT systems supporting the execution of BPs, different options can be considered. One of them is to implement a Service-Oriented Architecture (SOA). In such an architecture, different system components interact through messages that can be captured and that represent monitoring information about the execution of BPs. Although such a history of messages could be stored and managed in many different ways, the characteristics of blockchain make it a particularly interesting candidate. Indeed, message exchanges can be stored on a blockchain and inherit its characteristics (a.o. the immutable and tamper-proof character), ensuring that records cannot be tampered with and are not under the control of a given participant or TTP [8], [22], thanks to the distributed and peer-to-peer nature of the technology. This contributes to the creation of an indisputable basis of information to enforce the contract underlying the collaboration. Assuming that a given entity has access to that history of messages, independent monitoring of the BP is possible [8].

Having a history of message exchanges that can be trusted and accessed to prove the (non-)compliance with agreed upon aspects of a collaboration contract can reduce the risk faced by organizations involved in such collaborations. Thereby, it can facilitate the development and innovation of cross-organizational BPs. With such ideas in mind, a number of platforms (including [25], [22], [26] and [27]) relying on blockchain to (among others) monitor the execution of BPs have been developed.

Although not initially classified in the monitoring stage of the BPM lifecycle, having access to trustworthy records about the execution of BPs can also yield interesting opportunities related to process discovery. Indeed, it could be analyzed by an organization (e.g. using process mining techniques) to establish trust in the way a (prospective) partner operates [8]. Although this can be qualified as an opportunity, it can equally be qualified as being a risk since other organizations could apply the same idea and reverse-engineer internal BPs [8].

Assuming that blockchain is used to create a shared repository of trusted records about the execution of BPs, it can be considered as providing communication and conversion services, as defined in section III.A. The communication service here would be used to send data about process execution from the systems used within one organization towards the blockchain. It can then be reused by a given software component whose goal is to display or manage monitoring information about the BP. The data that are transferred can be converted into a format different from the one in which they are initially sent. Doing so using smart contracts consists in building a conversion service.

B. Business process implementation and execution

While some existing platforms supporting BPM activities and relying on blockchain focus on monitoring aspects (e.g. [26]), others (e.g. [22], [25] and [27]) propose to include the actual implementation and execution of BP (choreographies) on blockchain. Indeed, smart contracts can be used to enforce a sequence of activities, require particular inputs for particular tasks, produce outputs, etc. and different instantiations of a given smart contract can be used to represent different instances of a BP.

While it is possible to implement fully-fledged BPMSs relying on blockchain, another possibility is to integrate smart contracts with existing IT systems used by organizations to support their BPs.

Considering that blockchain is used to manage the implementation and execution of BPs, it can be considered as providing communication and coordination services as defined in section III.A. The communication service is here mainly about communicating the state of the process execution along with data that are required for the execution itself. Depending upon the state of the process and the process itself, blockchain could define what activity needs to be executed next and by which participant. Assuming that only certain participants can conduct certain activities, the blockchain would be responsible for managing the control of the process. It can therefore be seen as a coordination service in a software connector terminology.

When implementing and executing BPs on a blockchain, the advantage of using smart contracts also lies in their immutable character. For instance, if the sequence of activities defined in a process is implemented as a smart contract, participants can be sure that it won't be possible not to follow the agreed upon sequence [22]. In a similar idea, particular activities can be executed directly using a smart contract and without the need of additional systems. Doing so, blockchain provides a number of facilitation services. For more details about the challenges and opportunities of blockchain for BP improvement and reengineering, the reader can refer to [8].

C. Strategic considerations

After having summarized the challenges and opportunities of blockchain for BPM based on the different stages of the traditional BPM lifecycle, this section continues with strategic considerations. Strategic alignment consists in actively managing connections between organizational priorities and BPs, and is typically conducted in a top-down manner [8]. As blockchain represents a potential threat (but also opportunity) for a number of (core) BPs, there is a need for certain organizations to work the other way around. Indeed, they should investigate how they should define/adapt their strategy in the light of the implications of blockchain [8]. It is therefore crucial for organizations to understand the strategic value that they can derive from this technology.

Although blockchain has the potential to enable new types of business models, its initial impact is considered as being an increase in operational efficiency through the removal of intermediaries and/or efforts related to record keeping and transaction reconciliation [28]. For organizations to reap benefits out of blockchain, [29] suggests a four-step process which includes a prototyping phase. That phase will include a number of adjustments to the prototypes that can later on be validated and scaled appropriately. Starting from the perspective of an organization's business model, [30] identifies two groups of drivers for innovation in business models: internal and external drivers. While external drivers include technological changes (such as the availability of blockchain), internal drivers include the outcomes of the organizational learning process [30]. This process implies conducting and evaluating small experiments (in this context) with blockchain [30].

In order to launch experiments with blockchain, it will be required to create a team or set of teams working on this, potentially with help from external companies [29]. In a context where people having sufficient knowledge and skills are scarce and where development follows a steep learning curve, using MDE can yield a number of benefits. Indeed, it can help create prototypes faster, prototypes of higher quality than what humans would do when developing smart contract code manually, and targeting multiple platforms using a pre-defined set of models. Regardless of the speed and quality of prototyping, it remains important for organizations to select well-appropriated use cases since blockchain is not expected to provide benefits for all types of processes, but this question is not in the scope of the present paper.

D. Research directions

In the previous sub-sections, a review of the challenges and opportunities of blockchain for BPM was presented. It was based on the review suggested in [8], focused on particular aspects, complemented with additional research and analyzed adopting a software connector view. In their review, authors of [8] propose a number of directions for future research, including:

- *FRD1*: The development of a set of blockchain-based solutions for the execution and monitoring of business processes.
- *FRD2*: The development of methods for the analysis and engineering of business processes relying on blockchain technology. The underlying goal is to find ways to efficiently specify and deploy such business processes.

The sub-section that follows provides an overview of the work that has already been conducted and that can be considered as an answer to the future research directions suggested by [8]. Such answers are then analyzed in the light of the suggestions of this paper i.e. to use blockchain as a software connector to support cross-organizational BPs implemented as workflows and to develop these using MDE.

V. Discussion

A. Blockchain-based platforms supporting business process monitoring, implementation and execution

Following the research direction *FRD1*, a number of platforms already propose to support the monitoring and/or implementation and execution of BPs on a blockchain ([22], [25], [26] and [27]). Although they have distinctive characteristics, a common element to three of these solutions ([22], [25] and [27]) is that they use MDE to generate smart contracts based on Business Process Model and Notation (BPMN) models. They also typically make use of dedicated integration components (e.g. [22]) that are used to integrate smart contracts with existing systems, as discussed in section III.A. Other authors also propose to use MDE to manage decisions on blockchain, transforming Decision Model and Notation (DMN) models into smart contracts [31].

Most of the platforms discussed above seem to adopt a BPMSs vision. Although such platforms can be very useful and do provide interesting insights, we believe that an alternative vision of the use of blockchain for BPM can yield different advantages. Instead of seeing blockchain as a platform on top of which fully-fledged BPMSs can be implemented, we believe that seeing blockchain explicitly as a software connector (as suggested by [23]) can be a good way of facilitating the development of cross-organizational BPs. One of the reasons behind this idea is that organizations having invested significant efforts and amounts of money into the development of PAISs (e.g. Enterprise Resource Planning (ERP) systems) are unlikely to replace these by systems relying entirely on blockchain. Indeed, integrating such software so that they can interact with blockchain for different purposes seems to be a more realistic approach. However, the solutions discussed above would make more sense for organizations already using BPMSs instead of PAISs to support their processes.

B. Analysis and engineering of business processes relying on blockchain

After briefly presenting existing platforms supporting the monitoring and/or implementation and execution of BPs using blockchain, the focus is now on research direction *FRD2*.

As stated before, MDE approaches offer a promising avenue for the engineering of systems relying on blockchain to support cross-organizational BPs. In order to use MDE, there is a need to define what needs to be modeled (e.g. roles, access rights, SLAs, activity sequence, data structures, etc.) and what types of models should be used to represent different complementary aspects of the system which is being designed. Existing work so far has mainly relied on BPMN and focuses on the control-flow perspective of BPs, with one of the contributions suggesting to manage decisions on the blockchain based on smart contracts generated from DMN models. Hence, there is a need to further investigate the other perspectives and elements to be incorporated in the system to be designed.

Existing solutions focusing on BPMN and on a control-flow perspective provide useful insights to answer such questions. In addition to that, other work has for instance suggested to adopt an artefact-centric perspective for the modeling of BPs relying on blockchain [32]. Another example of existing work that can provide useful insights is the WSLA framework [33] that can be used to formalize and operationalize SLAs monitoring and compensation mechanisms in SOAs.

Although existing work can provide insights to answer the questions discussed in this sub-section, to the best of our knowledge there are no methodology proposing an integrated and consistent set of models that can be combined together to design and implement software connectors relying on blockchain to support the integration of IT systems used for cross-organizational BPs.

VI. CONCLUSION

In this paper, we review existing work on the use of blockchain technology to support BPM activities, with a focus on IT-related aspects. One of the prominent interests of this technology in that context is to be used as a platform for monitoring and/or implementing and executing cross-organizational BPs. Existing platforms doing so seem to have the vision of blockchain as a technology underlying new kinds of BPMSs. We suggest to adopt a different view and to consider blockchain as a software connector, as argued by other authors, as it can yield a number of benefits and fits well in the context of cross-organizational BPs to integrate across organizations. In the light of the difficulties to face when designing and developing blockchain-based solutions, relying on MDE techniques offers a promising avenue. In this context, we call for the definition of a methodology allowing to design complementary models that together would offer a complete and consistent picture of the system to be developed, and that could be transformed into code executed on blockchain technology. Such an approach could then be used to implement either production-ready or, at least, experiments using blockchain in the context of cross-organizational BPs. As suggested by different reports, such an activity is crucial in order for organizations to clearly identify and capture the strategic value that blockchain has to offer.

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