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Using Blockchain to Improve Collaborative Business Process Management: Systematic Literature Review

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ABSTRACT BlockChain Technology (BCT) has appeared with strength and promises an authentic revolution on business, management, and organizational strategies related to utilization of advanced software systems. In fact, BCT promotes a decentralized architecture to process management and the collaborative work between entities when these ones are working together in a business process. This paper aims to know what proposals exist to improve any stage of business process management using BCT because this technology could provide benefits in this management. For this purpose, this paper presents a systematic literature review in area of Collaborative Business Processes (CBP) in BCT domain to identify opportunities and gaps for further research. This paper concludes there is a rapid and growing interest of public bodies, scientific community and software industries to know opportunities that BCT offers to improve CBP management in a decentralized manner. However, although the topic is in early stages, there are very promising lines of research and relevant open issues, but there also is lack of scientific rigor in validation process into the different studies.

INDEX TERMS Systematic literature review, collaborative business processes, blockchain technology, business process management, inter-organizational process management, BPM.

I. INTRODUCTION

Over last decade, the use of process engineering principles on numerous environments is worldwide accepted as mechanism to increase the excellence, productivity and quality of any kind of organization [69], [70]. In fact, there are standards [1] and management guidelines [2], [3], [71], as well as important techniques and methods for ICT (Information Communications Technology) business environments [4], [5] that recommend to manage main business processes as mechanism for increasing efficiency and effectiveness within organizations associated with the utilization of advanced information systems [72].

In this context, BPM (Business Process Management) [6] is a well-known business strategy to achieve these goals what allows to obtain different advantages [7] (e.g., higher productivity, competitiveness, efficiency and reduced cost, among others). In addition, the business process definition is traditionally oriented to be executed centrally for a single company. In fact, there are many technologies (known as BPM Suites [8]) to manage, implement and execute these processes and, although this technology allows to assign specific tasks of the process to external actors, all those tasks are orchestrated in a centralized way at process level.

This centralized architecture is appropriate for single companies, but it is not efficient when it is necessary to collaboratively involve multiple entities or companies into the same process. Some reasons for this situation are that each company usually has its interests and software systems, and they are usually reluctant to share business data of the process [9], [10], among others. In addition, each entity must also meet certain conditions or legal clauses with remaining entities participating when the process is executed by each entity. This aspect is very relevant in some Collaborative

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Business Processes (CBP) (e.g., supply chain or logistics processes, among others [9]).

Moreover, over the last decade, new technology has emerged that could provide a technological solution to execute and manage CBP. We refer to BlockChain Technology (BCT) [11]. This technology offers valued cost reductions by enabling transactions to be run in a peer-to-peer (P2P) way (i.e., as P2P processes) directly between entities or individual users. This execution can be carried out without requiring mutual trust between each party. The distributed blockchain was contextualized in 2008 by Satoshi Nakamato. The goal of this proposal was to establish a secure history to exchange data using a timestamp to verify each exchange. This architecture was designed to work without central authority. In fact, this solution was the technological base that caused the birth of cryptocurrencies such as Bitcoin [12].

These features have led to a rapid and growing attention on Blockchain since it was applied in the financial field with the development of cryptocurrencies. Since 2008, many applications of BCT have been and are been studied and researched in numerous real field and service [13] around the word (electronic health records [14], ownership management, financial market [15], energy supply [16], supply chain [17] and Internet of Things [18], among others) to build decentralized software applications whose architecture is based on shared agreements on decentralized data through a network of unknown participants [19].

Taking this context into account, it is possible to see the interest of public bodies and software industries to know the feasibility and opportunities that BCT offers to improve the process management (from the broad perspective of the word) in a decentralized manner. This collaborative management could become to offer better services to citizens and companies.

This study addresses the need to know the state-of-the-art of research papers offered by the literature where techniques, approaches or methods are proposed to improve collaborative BPM using blockchain technology. More precisely, this paper presents a systematic review and it deals with collaborative BPM and BCT when focusing on two parallel (but complementary) work lines: (*i*) supporting each activity of the BPM lifecycle with blockchain approach, and (*ii*) executing collaborative processes using supporting tools based on BCT.

Therefore, main contribution of this paper is to provide complete knowledge and review of research papers that propose techniques, approaches or methods are proposed to improve collaborative BPM using BCT. In the scientific literature, we found only a few review papers that target specific areas, instead of a complete overview of blockchain-related research within topic of collaborative BPM. In addition, our review covers the most updated papers in the aforementioned areas. In this sense, the systematic review has been carried out without filtering by publication date what allows to know all research production that has been published on this subject.

Similarly, this systematic review analyzes and discusses what activities (related to the BPM lifecycle) are supported by each primary study. This analysis has also allowed to: (1) identify the business contexts (healthcare, manufacturing, supply chains, etc.) where each primary study has been applied; (2) know specific applications in the industry about business process improvement using BCT; and (3) identify most popular used blockchain technologies in domain of collaborative business process management.

This analysis provides knowledge that is relevant, useful and valuable to decision-makers because it identifies trends and not-covered challenges that can be addressed by the research community. In fact, new research lines have been opened in our research group after considering the results of this systematic review. These research lines are related to software testing process and traceability process of biological samples within laboratories 4.0. Both research lines are mentioned as future works in conclusion section of this paper.

In short, this paper presents a comprehensive review of blockchain technology and its applications in domain of collaborative process management, which we perceive to be the strength of this paper.

Finally, it is important to mention that this systematic review has been carried out following the formal Kitchenham's methodology [24] to identify existing gaps and offer future guidelines of research on issues related to BPM in a collaborative context in BCT domain. This methodology is chosen because it has been successfully applied in many fields (e.g., software engineering). In addition, Kitchenham's methodology has been extended with the ≪snowball≫ technique [30] in order to improve the review protocol. This technique consists of analyzing reference and related works, among other aspects, of each primary study to be analyzed.

The rest of this paper is structured as follows. Related works are briefly presented in Section 2. This section also presents differences from our systematic review with all previous works that are identified in Section 2. Subsequently, Section 3 describes the planning of our systematic review process and, once search systematic protocol has been executed, results are described in Section 4. Later, discussions on these results are offered in Section 5, and, Section 6 finally establishes future works and conclusions.

II. COMPARISON WITH RELATED WORKS

Although blockchain technology is related to financial services and the implementation of bitcoin cryptocurrency [20], both the international research community and private corporations are trying to apply this technology in different areas. For example, blockchain is being very considered in recent years to improve the design of inter-organizational processes and their management. This growing interest has led to the publication in the scientific literature of several SLRs and reviews on this subject. Their main conclusions are briefly described below.

Konstantinidis *et al.* [21] have carried out SLR to identify business areas (applications and services) where blockchain technology has been used or is being applied in recent years. Authors also identify some of the possible challenges of this technology to improve its applicability in a greater number of business areas. Although authors identify challenges related to technological aspects (privacy, security, latency, and computational cost) of blockchain, it is not focused on the application of this technology in BPM domain what hinders to address and know BPM challenges that could be supported by BCT. These limitations are resolved in our paper, which identifies gaps and open issues of the state-of-the-art on research approaches that propose techniques, tools or methods to improve the collaborative process management using BCT.

Mendling *et al.* [19] study challenges of BCT in BPM context. Authors do not describe a systematic review itself, but we consider their paper is interesting because it summarizes seven research trends on the use of BCT in the BPM domain. These trends are related to: execution and monitoring systems on BC; methods of engineering process based on BC; redesigning processes; evolution and adaptation of business process; techniques which allow to identify, discover, and analyze relevant processes for the application of BC; knowing what is the impact associated with the implementation of BC in new business models; and understanding the cultural change that involves the use of this technology in business process execution as well as the contracting of services.

Lu [22] presents a survey which identifies future researches and highlighting open issues on blockchain. Author does not follow any systematic review method, and it just focuses on a paper published by IEEE. However, it is interesting to know how features of the blockchain (decentralization, openness and transparency, independence, safety, etc.) are supported by different researchers.

As mentioned above, authors summarize research trends [19] and open issues [22] on the use of blockchain technology, but they have not identified the state-of-the-art on existing specific where techniques, tools or methods to improve collaborative BPM using BCT are presented.

Regarding weaknesses, Lu's paper does not follow any methodology (which hinders its reproducibility) and is only focused on papers published by IEEE. Both weaknesses are mitigated by our systematic review. On the one hand, our paper follows Kitchenham's methodology [24] which improves the objectivity of the results that have been obtained, as well as the reproducibility of our search protocol. On the other hand, our systematic review is applied on four digital libraries, which increases the probability of locating a significant sample of primary studies to be evaluated. In this sense, after performing our systematic review, our paper increases scientific knowledge of BCT applied to improve collaborative BPM.

Casino *et al.* [88] present a survey with the current state of the technological application of blockchain to different application domains. Specially, authors consider the economic application of BCT as an immovable aspect (cryptomoney and its management). For this purpose, authors review how the application of BCT produces an unprecedented B2C (Business to Consumer) and B2B (Business to Business) shift in online business processes. However, authors do not address or analyze implications, limitations or weaknesses of BCT when it is used to improve the management of these specific types of business processes. In addition, authors just focus on business processes related to economic applications.

Something similar happens in [89] and [90]. On the one hand, Hawlitschek *et al.* [89] conduct a systematic review of the existing literature on blockchain technology, but authors lack a broad perspective in the field of computer science. Authors consider only one topic for their study (i.e., ≪*blockchain technology as a means of decentralized trust management in the business and social economy*≫), but authors do not address the application of BCT to improve collaborative BPM. On the other hand, Seebacher and Schüritz [90] present a systematic review on BCT applied to software systems based on web services and processes. It does include the concept of supporting processes based on BCT as a possible aspect of BPM improvement into service-oriented architectures. However, authors indicate this possibility as a lesson learned after reviewing some previous works within following any methodological review process itself.

After analyzing previous related works, it is possible to conclude and summary that these papers are focused on topics related to BCT and some specific kind of business processes, but they do not provide an overview of the state-of-the-art on this technology and collaborative process management. In fact, these related works have not addressed the specific challenges and gaps of this topic. In this sense, therefore, our systematic review provides a general point of view to analyze research papers that propose techniques, methods or tools to improve the inter-organizational process management using BCT. This analysis allows to identify gaps and open issues in this topic which has emerged repeatedly in recent years in the related works, but that none has explored in depth as a research objective.

III. PLANNING THE SYSTEMATIC REVIEW

One of most important possible aspects of any systematic review is to ensure its reproducibility and, for this purpose, it is necessary to define and plan its review process. This process includes the definition of the motivation to conduct this review, what are the research questions to be answered and the search protocol to perform, as well as quality assurance search criteria to apply. The planning stage also presents exclusion and inclusion criteria that are used to locate the most relevant primary studies. In this sense, it is also important to mention that filters on publication date have not been applied what allows to know all research production that has been published on our research subject. Next subsections describe in detail these aspects.

A. IDENTIFYING THE NECESSITY OF THE REVIEW

Over the last decade, many investigations are being carried out around the world to evaluate and identify challenges and obstacles to apply BCT on the field of Collaborative Business Processes (CBP). These researches have presented and evaluated blockchain technology in multiple processes and services of different business areas (logistics, supply chain, health, financial sector, etc.) what could have identified possible challenges and barriers of this technology to manage collaborative processes.

In this context, this paper systematically reviews the field of CBP in BCT domain in order to characterize and present opportunities and gaps for further research, as well as identify the nature of each primary study (i.e., academic prototype, application in industry, etc.).

B. FORMULATING RESEARCH QUESTIONS

According to Kitchenham's methodology, Research Questions (RQ) are a mechanism that allows to focus any systematic review on specific topics. The objective is to improve scientific knowledge after analyzing research paper that are related to this topic. In this context, the systematic review described in this paper is guided by the following main research question: ≪*What is the state-of-the-art about the use of blockchain technology (BCT) to improve collaborative process management (CPM)?*≫. This main RQ has been divided into more specific RQ in order to offer more specific analysis and characterization of primary studies about BCT and CPM. These specific RQs and their motivations are described in Table 1.

TABLE 1. Research questions.

Research Questions	Description
RQ1. What are the re existing approaches in the literature that use BCT in the domain of collaborative process management?	The objective of this RQ is to locate research papers that have published proposals to improve CPM using BCT. The motivation of this RQ is also to identify objectives and motivations of each primary study.
RQ2. What activities of BPM lifecycle are supported by each primary study and main contributions of each proposal? What is the nature of each primary study?	The objective of this RQ is to: (i) discover what activities (related to the BPM lifecycle) are supported by each primary study; and (ii) classify each primary study within the BPM lifecycle and describe main contributions of each proposal. The answer to this question must take account of clear pieces of evidence that are provided in each primary study considered in this SLR. This research question also aims to classify each primary study according to its own nature.
RQ3. What is research method applied to validate each primary study?	This research question determines the type of research method that is applied to validate each primary study.
RQ4. What are the business or industrial contexts where BCT is used to improve CBP management?	This RQ aims is to: (*i*) know main business and industrial contexts (such as, healthcare, manufacturing, supply Chains processes, etc.) where BCT is used to improve CBP management; and (*ii*) discuss specific industry applications.
RQ5. What are technical characteristics of each primary study?	The objective of this RQ is to identify technical characteristics of each primary study.

C. DEFINING THE REVIEW PROTOCOL

After establishing background and research questions to be answered, it is necessary to specify the review protocol to be carried out. For this purpose, this protocol defines aspects such as search strategy to find primary studies, what are selection criteria to select primary studies and what quality criteria will be applied on each primary study. These aspects are described in following subsections.

1) SEARCH STRATEGY

This section aims to describe the search procedure which are going to allow to locate relevant research papers related to the improvement of CPM using BCT. For this purpose, research papers published in journal and relevant conferences are going to be searched in various digital libraries following a two-stage strategy.

On the one hand, pre-searches are firstly performed to confirm the keywords to be used. These keywords improve the quality of the systematic review because these ones focus the location of research papers under study. Finally, Table 2 shows all keywords that have been used in this systematic review (some synonyms have been also considered to guarantee the inclusion of relevant papers).

On the other hand, after carrying out preliminary searches, and once keywords have been established, these keywords are combined to build search expressions, which are used to search primary studies in each digital library. The construction of these expressions is mathematically formalized in Equation 1.

TABLE 2. Keywords.

A	B	C
Collaborative Inter-Organizational	Business Process Process Management BPM Process Workflow	Blockchain

Mathematical expression to build search expressions using keywords.

$$E_1 = [(V_{i=1}^{2} A_i) \wedge (V_{j=1}^{4} B_j)] \wedge (V_{k=1}^{1} C_k) \quad (1)$$

Moreover, some authors have established methodological criteria to select relevant digital libraries on which execute systematic reviews. For example, Ngai *et al.* [31] considers it relevant to use the following digital libraries: ABI Database, ScienceDirect, Academic Search Premier, Business Source Premier, ACM Digital Library, IEEE Xplore Digital Library, Science Direct, Springer, World Scientific Net and Web of Knowledge.

However, after carrying out preliminary searches, it is possible to observe that many papers are simultaneously

TABLE 3. Search expressions used on each digital library.

Digital Library		Query (Q)
ACM Digital Library	Q1	[[[Publication Title: "business process"] OR [Publication Title: "bpm"] OR [Publication Title: "process management"] OR [Publication Title: "collaborative business process"] OR [Publication Title: "collaborative process"] OR [Publication Title: "process"] OR [Publication Title: "collaborative bpm"] OR [Publication Title: "collaborative process management"] OR [Publication Title: "inter-organizational process"] OR [Publication Title: "inter-organizational bpm"] OR [Publication Title: "inter-organizational process management"] OR [Publication Title: "inter-organizational business process"] OR [Publication Title: "workflow"] OR [Publication Title: "collaborative workflow"] OR [Publication Title: "inter-organizational workflow"]] AND [All: "blockchain"]]
	Q2	[[[Abstract: "business process"] OR [Abstract: "bpm"] OR [Abstract: "process management"] OR [Abstract: "collaborative process"] OR [Abstract: "process"] OR [Abstract: "collaborative business process"] OR [Abstract: "collaborative bpm"] OR [Abstract: "collaborative process management"] OR [Abstract: "inter-organizational process"] OR [Abstract: "inter-organizational bpm"] OR [Abstract: "inter-organizational process management"] OR [Abstract: "inter-organizational business process"] OR [Abstract: "workflow"] OR [Abstract: "collaborative workflow"] OR [Abstract: "inter-organizational workflow"]] AND [All: "blockchain"]] OR [All:)) and] OR [[[Abstract: "business process"] OR [Abstract: "bpm"] OR [Abstract: "process management"] OR [Abstract: "collaborative process"] OR [Abstract: "process"] OR [Abstract: "collaborative business process"] OR [Abstract: "collaborative bpm"] OR [Abstract: "collaborative process management"] OR [Abstract: "inter-organizational process"] OR [Abstract: "inter-organizational bpm"] OR [Abstract: "inter-organizational process management"] OR [Abstract: "inter-organizational business process"] OR [Abstract: "workflow"] OR [Abstract: "collaborative workflow"] OR [Abstract: "inter-organizational workflow"]] AND [Abstract: "blockchain"]]
	Q3	[[Keywords: "business process"] OR [Keywords: "bpm"] OR [Keywords: "process management"] OR [Keywords: "collaborative business process"] OR [Keywords: "collaborative process"] OR [Keywords: "process"] OR [Keywords: "collaborative bpm"] OR [Keywords: "collaborative process management"] OR [Keywords: "inter-organizational process"] OR [Keywords: "inter-organizational bpm"] OR [Keywords: "inter-organizational process management"] OR [Keywords: "inter-organizational business process"] OR [Keywords: "workflow"] OR [Keywords: "collaborative workflow"] OR [Keywords: "inter-organizational workflow"]] AND [Keywords: "blockchain"]
IEEE Xplore	Q4	(((((((((((((((("Document Title":collaborative process) OR "Document Title":process) OR "Document Title":BPM) OR "Document Title":collaborative BPM) OR "Document Title":process management) OR "Document Title":collaborative process management) OR "Document Title":collaborative business process) OR "Document Title":business process) OR "Document Title":Inter-Organizational process) OR "Document Title":Inter-Organizational BPM) OR "Document Title":Inter-Organizational process management) OR "Document Title":Inter-Organizational business process) OR "Document Title":Workflow) OR "Document Title":collaborative Workflow) OR "Document Title":Inter-Organizational Workflow)AND "Document Title":blockchain))
	Q5	(((((((((((((((("Abstract":collaborative process) OR "Abstract":process) OR "Abstract":BPM) OR "Abstract":collaborative BPM) OR "Abstract":process management) OR "Abstract":collaborative process management) OR "Abstract":collaborative business process) OR "Abstract":business process) OR "Abstract":Inter-Organizational process) OR "Abstract":Inter-Organizational BPM) OR "Abstract":Inter-Organizational process management) OR "Abstract":Inter-Organizational business process) OR "Abstract":Workflow) OR "Abstract":collaborative Workflow) OR "Abstract":Inter-Organizational Workflow) AND "Abstract":blockchain))
	Q6	(((((((((((((((("Author Keywords":collaborative process) OR "Author Keywords":process) OR "Author Keywords":BPM) OR "Author Keywords":collaborative BPM) OR "Author Keywords":process management) OR "Author Keywords":collaborative process management) OR "Author Keywords":collaborative business process) OR "Author Keywords":business process) OR "Author Keywords":Inter-Organizational process) OR "Author Keywords":Inter-Organizational BPM) OR "Author Keywords":Inter-Organizational process management) OR "Author Keywords":Inter-Organizational business process) OR "Author Keywords":Workflow) OR "Author Keywords":collaborative Workflow) OR "Author Keywords":Inter-Organizational Workflow) AND "Author Keywords":blockchain))
Science Direct	Q7	Title, abstract, keywords: ("business process" OR "BPM" OR "process management" OR "collaborative business process" OR "collaborative process" OR "process" OR "collaborative BPM" OR "collaborative process management" OR "Inter-Organizational process" OR "Inter-Organizational BPM" OR "Inter-Organizational process management" OR "Inter-Organizational business process" "Workflow" OR "collaborative Workflow" OR "Inter-Organizational Workflow") AND ("blockchain")
Springer Link	Q8	("business process" OR "BPM" OR "process management" OR "collaborative business process" OR "collaborative process" OR "process" OR "collaborative BPM" OR "collaborative process management" OR "Inter-Organizational process" OR "Inter-Organizational BPM" OR "Inter-Organizational process management" OR "Inter-Organizational business process" OR "Workflow" OR "collaborative Workflow" OR "Inter-Organizational Workflow") AND "blockchain"

located in numerous of these libraries, what does not add new value to any systematic review but rather complicates the execution because it is necessary to discriminate more duplicate papers. This fact has been corroborated after executing the preliminary searches mentioned above.

In this context and considering these conclusions, following digital libraries have been selected to execute and manage[1] our systematic review: IEEE Xplore Library, ACM Library, Springer Link and ScienceDirect. It is also necessary to clarify that search expressions (formalized in Equation 1) are going to be applied on title-abstract-keyword metadata of each primary study according to the mathematical formula expressed in Equation 2.

Mathematical expression to identify primary studies according to their metadata.

$$E_2 = title\ (E_1) \vee abstract\ (E_1) \vee keyword\ (E_1) \qquad (2)$$

Table 3 presents each search expression (Equation 2) that has been used on each digital library. It is important to clarify that some search expressions have been divided into several

[1] Jabref [32] and Microsoft Excel spreadsheet have been used to systematize the management of papers under study.

TABLE 4. Description of exclusion and inclusion criteria.

Phase	Description of each inclusion and exclusion criteria
P1	This phase does not have exclusion criteria in themselves because its objective is to execute each search expression described in Table III. Therefore, all papers returned after executing these searches are considered in this phase.
P2	At this stage, different inclusion and exclusion criteria are applied. On the one hand, inclusion criteria are: (*i*) papers written in English and whose full content can be obtained; (*ii*) papers published in relevant forums, such as journals indexed in JCR (Journal Citation Reports) [33] or prestigious conferences categorized in CORE Conference Ranking [34]. Regarding CORE, conferences with A *, A and B level will be considered. On the other hand, papers not related to BCT and CPM are excluded.
P3	In this phase, duplicated papers are excluded, but the most comprehensive and recent paper always has priority. In addition, abstract, discussion, panel, surveys, tutorial, reviews or opinion papers are also excluded. This phase of exclusion considers the reading of full content of each paper. Any questions about any paper will cause the preliminary inclusion of this paper. The final decision will be considered and evaluated in the fourth phase.
P4	In this first meeting, relevant papers could be included, but there are no new exclusion/inclusion criteria are applied. In this phase also, all the doubtful papers are studied in detail, considering full content.
P5	Researchers apply the «snowball» technique in this phase using P2 criteria, as mentioned above.
P6	In this second meeting, all the doubtful papers (obtained from P5) are in detail studied to include relevant papers, but there are no new exclusion/inclusion criteria are applied.

sub-expressions because of their excessive size (number of logical clauses). Some digital libraries do not support the use of long logical expressions to perform searches. For example, IEEE Xplore does not allow to indicate logical expressions with more than 15 logical clauses.

Finally, after automatically executing the search expressions (see Table 3) and, once papers under study are identified, the ≪snowball≫ technique is applied to extend the search process. In this sense, each reference used by each paper has been analyzed to identify other relevant papers related to our topic. The results of this strategy are in detail described in Section V.A.

2) SELECTION PROCESS OF PRIMARY STUDIES

The selection process allows to standardize the identification of primary studies and it has been defined to integrate the participation of several different researchers who are jointly working on this systematic review. Specifically, this systematic review is carried out by two senior researchers and one junior researcher. In this context, six phases are proposed to uniformly and homogeneously execute this selection process. In addition, exclusion and inclusion criteria have been defined to be applied in each phase of the selection process. Table 4 summarizes these criteria.

Firstly, the objective of first phase (P1) is to execute all search expressions described in Table 3. As mentioned above, these searches allow to select candidate papers considering their metadata (title, abstract and keywords). Once the first phase is completed, inclusion and exclusion criteria are applied by all researchers in the second phase (P2).

TABLE 5. Quality questions.

#	Question & Scores
QQ1	Does the primary study describe what are the benefits and limitations of applying BCT technology to improve CPM? The possible answers are: Yes (+1); No (+0).
QQ2	Has the primary study been published in relevant conference (indexed in CORE Ranking [34]) or relevant journal (indexed in JCR index [33])? The possible answers are: A* or Q1 (+2); A or Q2 (+1.5); B or Q3 (+1); C or Q4 (+0.5); Unranked (+0).
QQ3	Does the paper describe which phase of BPM lifecycle it is supported and applied? The possible answers are: Yes (+1); No (+0).
QQ4	Is the paper validated with the scientific method? The possible answers are: Empirical validation applying experiment, survey or case study methods (+1); Unvalidated (+0).

Subsequently, after applying inclusion and exclusion criteria, each primary study is analyzed in detail to determine if its topic is related to the topic of this review. This analysis process is executed in the third phase (P3). After executing this stage, it is possible that some doubts appear about the adequacy of some primary studies. In this situation, the selection process proposes to conduct face-to-face meetings (fourth phase; P4) between researchers in order to minimize bias of each researcher and avoid subjective decisions, as well as establish consensual agreements on which primary studies are relevant.

At the ending, once fourth phase is finished, semifinal primary studies are obtained. These are preliminary because it is still necessary to apply the ≪snowball technique≫ (fifth phase; P5) on these semifinal studies to find new relevant studies. During the execution of this stage, it is also possible that some doubts arise when these new studies are considered by all researchers. In this sense, a second face-to-face meeting (sixth phase; P6) among all researchers is proposed to reach consensus on relevant papers and avoid subjective decisions.

3) QUALITY QUESTIONS

Quality Questions (QQ) allows to establish objective criteria to determine the quality of each primary study that is reviewed. Table 5 summarizes each quality question, which has associated scoring criteria (final quality score is going to be the cumulative score per quality question). It is important to mention that this quality score is not used to exclude primary studies, but to establish the relevance and representativeness of each primary study in future researches.

4) CHARACTERIZATION SCHEME

Each primary study that is analyzed in this systematic review may contain a wide variety of information, so, the analysis of this information could become a very tedious task. Table 6 defines a characterization scheme to reduce the effort required to carry out this task. The process for

TABLE 6. Characterization scheme.

Feature	Description
Kind of publication	This feature means the forum where the approach has been published (i.e., journal, conference, or workshop).
Business area	It refers to the business area in which the approach has been applied.
Motivation and Description	This feature collects brief description of each primary study and its motivation.
Phase of BPM lifecycle	It means what is the phase in process management in which the proposal is focused.

completing this scheme is based on two stages. Firstly, each researcher analyzes each primary study and complete the characterization scheme. Later, all researchers establish ordered discussions to agree on final data of this evaluation.

5) EXTERNAL VALIDATION OF THE REVIEW PROTOCOL

Kitchenham's methodology recommends establishing mechanisms to refine the search protocol of any systematic literature review. The objective is to maximize the adequacy of this protocol with the objectives of the systematic review. In this sense, a couple of mechanisms have been proposed to carry out this review of the review protocol itself. Firstly, preliminary searches have been set up to adjust keywords, exclusion criteria and search expressions of this systematic review (as mentioned above; Section III.C.1). Secondly, an expert in conducting SLRs has been consulted to refine our review protocol. This person, who is Full professor in Software Engineering at University of Seville (Spain), proposed some changes, which have allowed to improve our review protocol.

IV. CONDUCTING AND QUALITY RESULTS

This section describes the execution of the review protocol that has been described in previous section. In this sense, on the one hand, Section IV.A presents the results of the selection process and statistical studies of these results. On the other hand, final primary studies that are considered in this systematic review are indicated in Section IV.B. This last section also includes the quality score of each primary study after applying the characterization scheme on each one (see Table 5). Finally, some threats may have occurred during the review process. These aspects are also discussed in Section IV.C.

A. EXTRACTION AND DETECTION OF PRIMARY STUDIES

After applying search queries described above, our selection process and inclusion/exclusion criteria have been applied. Figure 1 illustrates the complete process of selecting the primary studies and Table 7 summarizes the distribution of research papers that have been analyzed in this selection process.

Regarding Figure 1, each phase of the selection process has been named using the abbreviations described in previous sections. Furthermore, it is important to mention that the third phase has been represented by two different steps in Figure 1 in order to show the evolution of primary studies when some exclusion criteria have been applied. Specifically, these steps represent two exclusion criteria: duplicate articles (C1) and reviews/discussions/opinions/etc. (C2).

Table 7 summarizes for each research database, the number of papers that are the result of each stage of the review protocol. This table also includes a record of papers obtained after applying the snowball technique (these papers have not been classified by database to facilitate the management of results). In addition, Figure 2 shows how the evaluation of the search protocol has been along three main milestones.

TABLE 7. Characterization scheme.

Database	P1	P2	P3	P4	P5	P6
ACM	94	14	6	1	-	-
IEEE Xplore	649	65	23	8	-	-
ScienceDirect	91	21	12	5	-	-
SpringerLink	300	31	15	10	-	-
Snowball technique	0	0	0	0	56	10
Subtotals	1134	131	56	24	56	10
TOTAL	**34**					

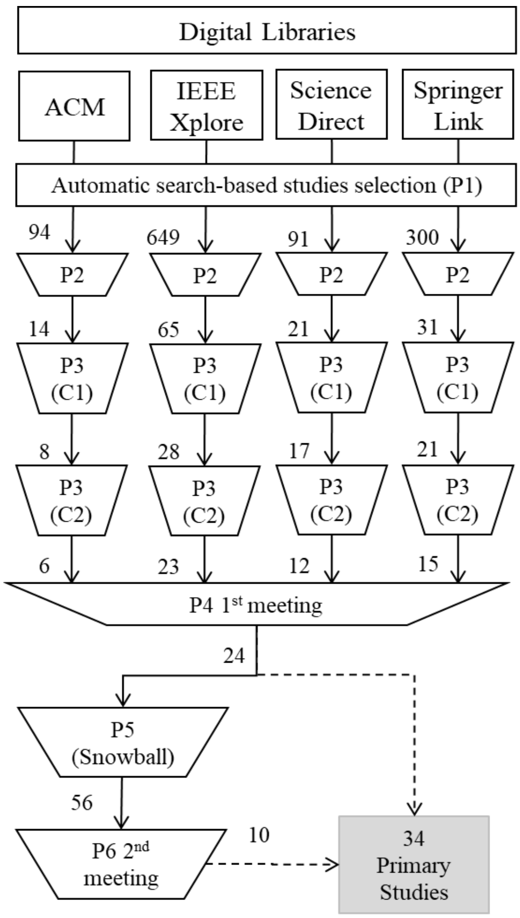


FIGURE 1. Summary diagram of the selection process of primary studies.

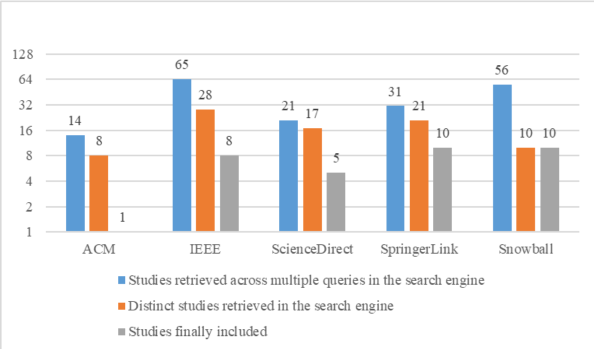


FIGURE 2. Studies retrieved through search engines.

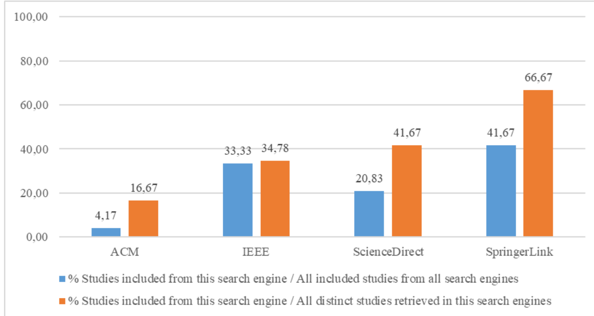


FIGURE 3. Analysis of retrieved results from digital libraries respect to total final primary studies.

Firstly, after finishing the first phase of the selection process, 1134 candidate papers have been found (see Table 7). These candidate papers have been returned after executing each search expression (Table 3) on each digital library. Secondly, exclusion criteria have been applied in the second phase (P2), which returns 131 candidate research papers and is considered the first milestone of our review protocol. Figure 2 shows this milestone in the first data series of the histogram. Specifically, this series represents papers that are retrieved from each digital library after executing all search expressions.

Subsequently, the next executed phase (P3; third phase) returns 56 candidate research papers when this one has finished. These results are the second milestone of the search protocol and are associated with the second data series of the histogram (Figure 2). This series means the number of primary studies that are obtained from each digital library after deleting duplicate papers. Furthermore, these results also exclude research papers related to comparative studies, systematic mapping studies, surveys, systematic literature reviews, and opinion articles, among others.

At this moment, the fourth phase (P4) of the selection process is carried out and consists in carrying out the first face-to-face meeting to establish consensus when there are doubts. Some candidate papers could be doubtful because their subject is on the border with respect to our subject. At the ending of this phase, 24 candidate primary studies have been selected (see Table 7) and ≪snowball≫ technique is applied to these ones (fifth phase; P5). In addition, the second face-to-face meeting is also performed (sixth phase; P6) to decide the adequacy of each candidate papers found after applying this technique. The application of this ≪snowball≫ technique has allowed to find 10 new primary studies that are related to our subject.

Finally, the third milestone in our search process corresponds to the total number of primary studies (i.e., 34 primary studies), which is the result of adding the number of primary studies obtained when P4 and P6 are completed. This milestone is related to the third data series of the histogram shown in Figure 2.

Moreover, Figure 3 shows the distribution of primary studies that are retrieved in each digital library with respect to the total of selected studies of all the search engines. It is interesting to note that Springer provides 42 % (approx.) of primary studies and most digital libraries include 10% (approx.) of the studies. This fact can be observed of the second value of the series shown in Figure 3. This value presents primary studies that are finally considered in the analysis and retrieved from the digital library divided by all the different primary studies that are been retrieved from the same digital library.

B. THREATS IN THE VALIDATION

The existence of threats is an inherent fact when any task has been carried out by people. In this sense, it is possible to identify some threats associated with the selection process and the validation process that have been executed in this paper. For instance, some mistakes could have appeared during selection of primary studies or data extraction. However, our selection process (Section III.C.2) has been planned in well-controlled phases to minimize this risk. Furthermore, several reviews and meetings between researchers have also been carried out to reduce this risk.

Moreover, it is important to consider that it is not possible to guarantee full coverage of each research paper on a specific topic because some papers are not indexed and there is gray literature that could not be included in our review [35]. This threat has been mitigated using a significant sample of digital libraries. These libraries publish papers on a wide range of scientific topics, which could be reasonable enough to locate the largest number of relevant papers related to the topic of this systematic review.

V. ANALYSIS

This section answers and discusses in detail each research question (Table 1) to detect strengths and weaknesses of each primary study.

A. RQ1. WHAT ARE THE EXISTING APPROACHES IN THE LITERATURE THAT USE BCT IN THE DOMAIN OF COLLABORATIVE PROCESS MANAGEMENT?

Table 8 presents a summary of the primary studies which have been found and, finally, considered in this SLR, as well as the application of all quality criteria on each paper

TABLE 8. Primary studies and their quality assessment score.

Primary studies	Authors and title	Scores (max.6)	Ref.
[P1]	C.Yuanyuan; W. Hui; L. Xuefeng: Improving Business Process Interoperability by Shared Ledgers.	0,00	[36]
[P2]	S. Chen; R. Shi; Z. Ren; J. Yan; Y. Shi; J. Zhang: A Blockchain-Based Supply Chain Quality Management Framework.	0,75	[37]
[P3]	A. Kapitonov; I. Berman; S. Lonshakov; A. Krupenkin: Blockchain Based Protocol for Economical Communication in Industry 4.0.	1,00	[38]
[P4]	O. López-Pintado; L. García-Banuelos; N. Dumas; I. Weber: Caterpillar: a blockchain-based business process management system.	4,50	[39]
[P5]	W. Viriyasitavat; D. Hoonsopon: Blockchain characteristics and consensus in modern business processes.	2,00	[40]
[P6]	C. Prybila; S. Schulte; C. Hochreiner; I. Weber: Runtime verification for business processes utilizing the Bitcoin blockchain.	3,50	[41]
[P7]	C. Shuchih; C. Yi-Chian; L. Ming-Fang: Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process.	1,00	[42]
[P8]	W. Viriyasitavat; L. XuZhuming; B. Assadaporn: Blockchain-based business process management (BPM) framework for service composition in industry 4.0.	2,00	[43]
[P9]	D. Silva; S. Guerreiro; P. Sousa: Decentralized Enforcement of Business Process Control Using Blockchain.	2,00	[44]
[P10]	M.F. Madsen; M.Gaub; T. Hgnason; M.E. Kirkbro; T. Slaats; S. Debois: Collaboration among adversaries: distributed workflow execution on a blockchain.	2,00	[45]
[P11]	I. Weber; X. Xu; R. Riveret; G. Governatori; A. Ponomarev; J. Mendling: Untrusted Business Process Monitoring and Execution Using Blockchain.	4,50	[46]
[P12]	D. Karastoyanova; L. Stage: Towards Collaborative and Reproducible Scientific Experiments on Blockchain.	1,50	[47]
[P13]	L. García-Bañuelos; A. Ponomarev; M. Dumas; I. Weber: Optimized Execution of Business Processes on Blockchain.	4,50	[48]
[P14]	C. Sturm; J. Szalanczi; St. Schonig; S. Jablonski: A Lean Architecture for Blockchain Based Decentralized Process Execution.	4,50	[49]
[P15]	G. Falazi; M. Hahn; U. Breitenbcher; F. Leymann: Modeling and execution of blockchain-aware business processes.	3,00	[50]
[P16]	X. Liang: Blockchain Based Provenance Sharing of Scientific Workflows.	2,00	[51]
[P17]	H. Nakamura; K. Miyamoto; M. Kudo: Inter-organizational Business Processes Managed by Blockchain.	4,00	[52]
[P18]	C. Di Ciccio; A. Cecconi; J. Mendling; D. Felix; D. Haas; D. Lilek; F. Riel; A. Rumpl; P. Uhlig: Blockchain-based traceability of inter-organisational business processes.	2,00	[53]
[P19]	O. López-Pintado; M. Dumas; L. García-Bañuelos; I. Weber: Interpreted Execution of Business Process Models on Blockchain	4,00	[25]
[P20]	D. Fernando; S. Kulshrestha; J. D. Herath; N. Mahadik; Y. Ma; C. Bai; P. Yang; G. Yan; S. Lu: SciBlock: A Blockchain-Based Tamper-Proof Non-Repudiable Storage for Scientific Workflow Provenance	1,00	[26]
[P21]	M. Li; G. Q. Huang: Blockchain-enabled workflow management system for fine-grained resource sharing in E-commerce logistics	2,00	[27]
[P22]	N. Bore; A. Kinai; J. Mutahi; D. Kaguma; F. Otieno; S. L. Remy; K. Weldemariam: On Using Blockchain Based Workflows	1,00	[28]
[P23]	F. Panduwinata; P. Yugopuspito: BPMN Approach in Blockchain with Hyperledger Composer and Smart Contract: Reservation-Based Parking System	1,00	[29]
[P24]	G. Fridgen; S. Radszuwill; N. Urbach; L. Utz: Cross-organizational workflow management using blockchain technology - towards applicability; auditability; and automation	3,50	[74]
[P25]	Y. Fang; X. Tang; M. PanYang Yu: A Workflow Interoperability Approach Based on Blockchain	3,00	[75]
[P26]	J. Ladleif; M. Weske; I . Weber: Modeling and Enforcing Blockchain-Based Choreographies	4,50	[76]
[P27]	A. Abid; S. Cheikhrouhou; M. Jmaiel: Modelling and Executing Time-Aware Processes in Trustless Blockchain Environment	2,50	[77]
[P28]	A. B. Tran; Q. Lu; I. Weber: Lorikeet: A model-driven engineering tool for blockchain-based business process execution and asset management	2,50	[78]
[P29]	C. Sturm; J. Scalanczi; S. Schönig; S. Jablonski: A Blockchain-based and resource-aware process execution engine	3,00	[79]
[P30]	M . Li; L. Shen; Q. Huang: Blockchain-enabled workflow operating system for logistics resources sharing in E-commerce logistics real estate service	3,50	[80]
[P31]	Mercenne; L.; Brousmiche; K. L.; Hamida; E. B.: Blockchain studio: A role-based business work	3,00	[81]
[P32]	O. López-Pintado; L. García-Bañuelos; M. Dumas; I. Weber; A. Ponomarev: Caterpillar: A business process execution engine on the Ethereum blockchain	4,50	[82]
[P33]	P. Klinger; F. Bodendorf: Blockchain-based Cross-Organizational Execution Framework for Dynamic Integration of Process Collaborations	2,00	[83]
[P34]	O. López-Pintado; M. Dumas; L. García-Bañuelos; I. Weber: Dynamic role binding in blockchain-based collaborative business processes	4,50	[84]

(Section III.C.3). Anyway, it is relevant to mention that these quality criteria have not been used to reduce the number of primary studies, but rather to identify the most important ones for future research.

TABLE 9. **Distribution of primary studies related to activities of BPM lifecycle (Dumas *et al.* [63]) and types of proposals.**

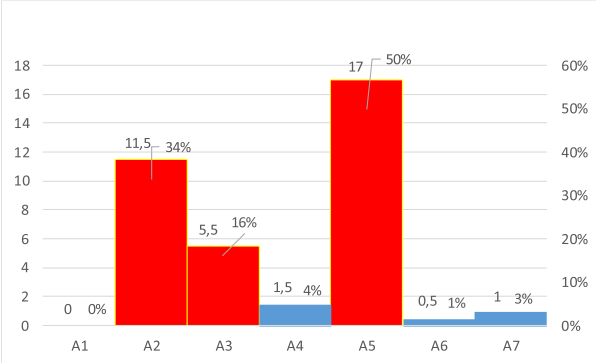
Primary studies	Activities of BPM lifecycle							Types of Proposals						
	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**
[P1]		○		○	○	○		☒	☒					
[P2]					○			☒	☒					
[P3]					○				☒					
[P4]		⊙			⊙									☒
[P5]		⊙			⊙			☒	☒					
[P6]			⊙					☒		☒				☒
[P7]			○						☒			☒		
[P8]			⊙					☒	☒	☒				
[P9]		⊙			⊙			☒				☒		☒
[P10]			⊙		○			☒						☒
[P11]		⊙			⊙			☒		☒				☒
[P12]					○			☒						
[P13]		⊙								☒				
[P14]					⊙			☒						☒
[P15]		⊙						☒		☒				☒
[P16]		⊙						☒						
[P17]		⊙						☒		☒				
[P18]			⊙		○			☒						☒
[P19]				⊙			⊙							☒
[P20]			⊙		○									☒
[P21]					○									☒
[P22]					○			☒						☒
[P23]		○						☒		☒				
[P24]					○			☒						☒
[P25]		○						☒	☒	☒				
[P26]		⊙						☒	☒			☒		☒
[P27]		⊙			⊙			☒		☒		☒		☒
[P28]		⊙			○									☒
[P29]					⊙			☒	☒	☒				
[P30]					⊙			☒						☒
[P31]					○									☒
[P32]					⊙									☒
[P33]					⊙				☒					☒
[P34]					⊙			☒	☒			☒		☒

Acronyms and Abbreviations - A1: Identification, A2: Discovery & modeling, A3: Analysis, A4: Redesign, A5: Implementation & execution, A6: Monitoring, A7: Adaptation; T1: Approach, T2: Framework, T3: Method, T4: Methodology, T5: Model or metamodel, T6: Measures and T7: Tool; Symbols: ○ (supported without evidence), ⊙ (supported with evidence), ☒ (applicable type)

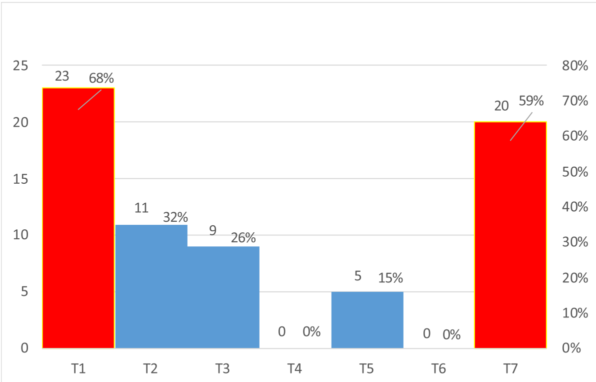
B. RQ2. WHAT ACTIVITIES OF BPM LIFECYCLE ARE SUPPORTED BY EACH PRIMARY STUDY AND MAIN CONTRIBUTIONS OF EACH PROPOSAL? WHAT IS THE NATURE OF EACH PRIMARY STUDY?

Process management is a strategy that can be implemented on different business contexts and applied by numerous user roles [58], [59], what has caused the publication of different perspectives of lifecycles [60]–[62]. However, we have considered the traditional BPM lifecycle proposed by Dumas *et al.* [63] to answer this research question and normalize our discussion and analysis. This lifecycle includes these activities: identification, discovery, analysis, redesign, implementation & execution, monitoring, and adaptation. In this sense, Figure 4 shows the distribution of primary studies in terms of each activity of BPM lifecycle. In addition, Table 9 analysis in detail which activities of BPM lifecycle are supported by each study, as well as its classification or type that has been given by authors to their proposal (e.g. methodology, approach, framework, method, etc.).

Moreover, it is also relevant to mention that Figure 4 shows the total amount of the distribution is greater than the number of studies because a primary study may support more than one activity. As may be observed in Table 9 and Figure 4, activities of greatest interest in BPM lifecycle are implementation & execution, modeling, and analysis. Table 9 also identifies the primary studies that do not provide enough evidence to verify the level of support. Figure 4.A reflects this fact considering that a primary study has value 0.5 points



A. Distribution activities of BPM lifecycle and primary studies.



B. Distribution types of proposals and primary studies.

FIGURE 4. A. Distribution activities of BPM lifecycle and primary studies. B. Distribution types of proposals and primary studies.

when it supports an BPM activity without presenting enough evidence (otherwise, the proposal has 1 value point).

The traditional BPM lifecycle is based on the following activities and, considering results shown in Table 9, it is possible to draw some conclusions about the support of each primary study on these activities. Following sections contain these conclusions for each activity of BPM lifecycle.

1) DISCUSSION FOR ≪IDENTIFICATION≫ ACTIVITY

This BPM activity aims to provide a high-level description of an organization from a perspective based on processes in order to link its business strategy with the improvement of its processes [63]. This activity could be reinforced from the point of view of BCT if techniques or mechanisms are investigated and proposed to systematically identify the most appropriate processes of an organization to be implemented on blockchains [19]. After studying analyzing each primary study shown in Table 9, it has not been possible to find any primary study that supports this activity of BPM lifecycle.

2) DISCUSSION FOR ≪DISCOVERY & MODELING≫ ACTIVITY

This BPM activity means capturing information about how a business process should work. It is possible to find some methods and techniques (interviews, process mining, walkthroughs, and documentation analysis, among others) in the scientific literature to capture this information [64]. This activity also considers the definition of the process model which contains a description of the process from perspectives of data flows, control flows, and resources, among other aspects. Some authors also identify challenges in process discovery techniques when BCT is used as technique to describe inter-organizational processes [19] (for example, business data need to be fragmented, encrypted or fully/partly stored on BC Network (BCN), obtaining process models from smart contracts using reverse engineering techniques, definition of design patterns, definition of anti-patterns and BPMN [23] (Business Process Model and Notation) extensions to design blockchain-based processes, among others.

After studying each primary study shown in Table 9, it has not been possible to find any primary study that provides techniques to capture information from users to know how a business process should work. However, there are some primary studies that provide mechanisms to define the process model.

Yuanyuan *et al.* [P1] propose a framework to intercommunicate multiple participants and systems on a mutual agreed shared ledger (i.e., BCN). This framework provides mechanisms to model process transitions between participants (among other functionalities related to other activities of the BPM lifecycle). Specifically, authors propose a language to define the sequence of states which are connected by transitions. However, this framework is in working-progress, and no evidence is provided to know this modeling language.

Viriyasitavat *et al.* [P5] propose a process-based architecture in BC to offer persistence, validity, auditability, and intermediary on Business Processes Management Suites (BPMS) [8]. This general architecture includes mechanisms to model business processes using its own modeling language, which has artifacts to describe the integration of the process with BCT. However, at present, this paper only describes this architecture proposal, but authors plan as future works to implement a software prototype to support this architecture.

Shuchih *et al.* [P7] aim to research an alternative private-chain design to improve the transparency and distributed collaboration processes of supply chain contexts. Authors propose to blockchain-based business process re-engineering framework based on blockchain and smart contracts to design chain supply processes and business activities across various organizations. However, this framework is conceptually and theoretically described, and it does not provide evidence on how this framework is used in practice.

Other authors have oriented their proposals to solve the lack of traceability and control in CBPs. In this sense, Silva *et al.* [P9] integrate their DEMO tool [55] (which allows to model business transactions and human interactions) and Hyperledger Composer [56] to model and execute business transactions between different participants of a collaborative process. Regarding the process modeling, authors have proposed a metamodel (based on UML), which defines concepts to relate transactions and Hyperledger Composer.

In this sense, Panduwinata *et al.* [P23] also use Hyperledger Composer technology. These authors present mechanisms to define BPMN process models on Hyperledger Composer. Especially, authors establish briefly a method to map Hyperledger Composer concepts from BPMN models and smart contracts from BPMN activities. However, this last mapping has not been implemented in technological solutions. Furthermore, this proposal is highly focused on a specific case study and authors do not provide general mechanisms or formal evidence of these mechanisms or methods.

Moreover, a relevant aspect to decide if BCT is suitable in BPM context is the cost of its use. García-Bañuelos *et al.* [P13] argue that ≪the cost required for blockchain is highly dependent on the volume of data recorded and the frequency of data updates by smart contracts≫. In this context, they present an optimization mechanism to execute and compile BPMN process model into Solidity smart contract, that are executed on Ethereum [57], as well as be used for the execution of process instances.

Falazi *et al.* [P15] identify usual BPM languages do not address particularities of BCT (e.g., the necessary management of mining, insertion, verification, replication of nodes, etc.) what could save costs and gain flexibility. So, they present an extension in BPMN notation to be able to deal with all these particularities. Authors have also developed a prototype using Java 8 and RESTful HTTP APIs on Ethereum. However, it does not justify a great gain in cost or structural or temporal flexibility compared to existing solutions in state of the art.

Liang [P16] describes a proposal to store formal processes (linked to experimental research projects) in BC, in order to facilitate the verification, replication, and refutation of such works through the collaboration of other research groups with access to that chain of blocks. To tell the truth, the proposed solution is not specially adapted to the BPM domain, and the block format allows to save fragments of BPMN coding, business processes or really any other type of data or research result that has no relation with the BPM domain.

Nakamura *et al.* [P17] propose a method to address two common problems present in the BPM field: trust and consistency of operations and processes. This method takes business process models (specially, BPMN models) as input and converts them into state charts adapted to the usual block typology of blockchain technologies: these state charts are the inputs they use to create smart contracts to be stored in the chain.

Fang *et al.* [P25] propose a theoretical framework and method for modeling interoperability between work process models and workflow enactment services, using blockchain networks. Furthermore, communication and movements between workflows is synchronized using smart contracts. This proposal could make modeling interorganizational collaborative processes more flexible, but it does not provide detail on how authors' method is generally applied on any type of process model.

Ladleif *et al.* [P26] propose an extension of BPMN to incorporate new concepts (such as, shared data, observability constraints, embedded logic, transaction semantics, etc.) related to the choreography of organizational business processes. Authors also describe the operational semantics of these concepts and propose a proof of concept based on their previous proposal [46].

Abid *et al.* [P27] have detected limitations of blockchain when this one is used to execute collaborative business processes. Specifically, this limitation is related to the definition and management of temporary restrictions of tasks (such as, start as soon as possible, finish as late as possible, must finish on, start no earlier than, etc.). In this sense, authors propose an extension of BPMN to include these temporary restrictions in BPMN process models. Furthermore, authors describe translation mechanisms for obtaining smart contracts from these temporary restrictions.

3) DISCUSSION FOR ≪ANALYSIS≫ ACTIVITY

This activity refers to obtain information on issues related to processing performance (e.g., number and frequency of instances, actors involved, durations, etc.) to detect deviations [64] and verify the trustiness of businesses and partners. This analysis is often based on studying performance data of these processes, which can be usually found within the organization [63]. However, obtaining this information can become a complex task if the process is implemented on BCT because it is necessary to compose and transform transaction data (which are stored on BC blocks) in an appropriate format [19]. In this sense, some primary studies provide support to this BPM activity.

Viriyasitavat *et al.* [P8] propose mechanisms to evaluate the trust of businesses and partners in Industrial 4.0 context. Authors identify that the most critical aspect (when BPM systems are used) is evaluation, and verification of trustworthiness in assets. Authors propose to use BCT and smart contracts to verify the trustiness of inter-organizational processes selecting and composing services. This solution improves the management and quality of business workflows between organizations through the composition of services. As future work, these authors plan to automate this verification in BPMSs.

Prybila *et al.* [P6] describe a mere proof of concept to deal with the business process runtime verification of choreography using BCT. Authors demonstrate that the process choreography management system based on blockchain is at least as powerful as the existing BPMS but adding two key aspects: the anonymity of the parties involved in the process and the independence of those parties. The transactions stored in BC are not in this case smart contract to use, but simplified abstractions created by authors, focused above all on the choreography of services and processes, rather than on an authenticated workflow as in other works studied.

Di Ciccio *et al.* [P19] study the application of BCT as an infrastructure to store, in a traceable, verifiable, and reliable way, a supply chain formalized through BPM notation.

Authors retrieve information to trace process instances execution solely from the transactions written on BCN. This goal is achieved through the inverse engineering of smart contracts encoded with Solidity. Authors validate its implementation through a case of real use based on the pharmaceutical domain, through a supply chain so common in that domain.

Madsen *et al.* [P10] present proof by reduction to the absurd where the mistrust in a system of distributed declarative workflow execution implemented with smart contracts is refuted. This paper shows that, although the parties do not trust each other or in the transactions related to each other, the system itself ends up overturning those doubts since it guarantees: a) the semantics of workflows, and b) the incontrovertible record of workflow execution history. authors also propose a method to define process models in a declarative way (using DCR Graph[2]) and improve trust between participants of collaborate processes. In addition, authors have developed a software prototype to validate this method using smart contracts (Solidity) on Ethereum.

Dinuni *et al.* [P20] present the SciBlock platform to analyze and verify the provenance and veracity of data that are returned by scientific workflows. The main objective of this proposal is to protect this type of data and control that these ones cannot be modified. This proposal also proposes mechanisms to analyze data and the trace of collaborative workflows within scientific contexts. However, authors do not provide details of this platform, nor information on future works or roadmaps to improve this proposal.

4) DISCUSSION FOR ≪REDESIGN≫ ACTIVITY

This BPM activity refers to systematically improving the process model using design patterns as an optimization method [19]. In this context, the primary studies have been analyzed to know if they propose appropriate techniques and heuristics for Blockchain. After analyzing the primary studies shown in Table 9, some primary studies support this activity. In this sense, some primary studies provide support for this activity.

Yuanyuan *et al.* [P1] propose a framework that external business processes can be managed on BCN as mentioned above. They mention that their framework also includes a set of process templates (which allows modeling common business processes) and mechanisms to include new templates, but this paper does not provide any evidence of this support either.

5) DISCUSSION FOR ≪IMPLEMENTATION & EXECUTION≫ ACTIVITY

This BPM activity aims to automate the process model as well as the generation of its executable version. Specifically, this aspect refers to how the executable version is implemented on process-oriented information systems or BPMS that are capable of executing processes [63]. Today, these software systems are traditionally used to execute processes in a single organization, but when BCT is used in this context, there are some important differences with respect to the traditional way in which these software systems operate. Some relevant differences are related to the way of exchanging messages between participants through blockchain transactions to the smart contracts, guaranteeing the correctness and security of data or how the data are shared and used collaboratively, among other aspects [19]. In this sense, some primary studies provide support for this activity.

Yuanyuan *et al.* [P1] propose a framework that external business processes can be managed on BCN, as mentioned above. This framework also includes a service layer to execute the sequence of transactions and process states. The execution of these states is carried out through a stack of messages sent between participants. This stack is suspended in the database using a serialization framework and is also managed by schedulers or triggers. As mentioned above, this paper provides a very general description of the authors' proposal, and it does not present any evidence of this execution support.

Chen *et al.* [P2] propose a blockchain-based framework to support the execution and monitoring of business processes. However, this proposal is oriented to a very specific business context: processes related to Supply Chain Quality Management (SCQM). Regarding the execution activity, this one is based on IoT (Internet of Things) devices and smart contracts on a BCN. Smart contracts are used in this proposal to: (i) control the quality of data captured from IoT devices and improve the efficiency of the supply chain; and (ii) plan automatically activities (executed by manufacturers and customers) of the logistics process and control data transactions between process participants. Despite these characteristics, this paper provides a very general description of the authors' proposal, and it does not present any evidence of the execution support of the process.

In supply chain context, Shuchih *et al.* [P7] propose a blockchain-based framework (which also uses smart contracts and shared information ledger) to execute and operationally control the supply chain process for multilateral collaboration among supply chain participants. This proposal aims to reduce the execution time of supply chain processes and, especially, reduction of time during the exchange of information between participants of this kind of processes.

Kapitonov *et al.* [P3] have oriented their BPM-Blockchain proposals towards the context of Industry 4.0 to reduce the number of intermediaries in any industrial process and improve decision making, as well as improve the exchange of information between cyber-physical agents (i.e., autonomous robots, assembly chains, sensors, etc.) and stakeholders. For this purpose, authors use P2P network based on Ethereum network and smart contracts to organize interaction between cyber-physical agents, stakeholders, and industrial processes,

[2]DCR Graph [85] is a language that allows you to model workflow using events (graph nodes) as activities and flows (graph edges) as relationships between tasks, which establish the executability of each event according to previous events.

but this proposal just supports the phase of execution of these processes.

López-Pintado *et al.* [P4] [P32] present Caterpilla, which is a process engine where states and tasks are stored and executed in Etherium. To do this, BPMN models are translated into Solidity Smart Contracts using an external BPMN - Solidity compiler, which has a very promising operation. However, the translation method or code of this compiler is not described in this paper. The rest of the paper demonstrates how Caterpillar works, without affecting technical or low-level aspects of the system itself, except for a very general diagram of its architecture. Nor does it include enough related bibliography to be able to investigate the technology used by the authors, beyond the GitHub where they store Caterpillar.

López-Pintado *et al.* [P34] present an extension of Caterpillar to control the permissions that each role has on task instances running. In this sense, authors propose a model to dynamically relate actors with collaborative business processes, as well as a language which allows specifying the policies and restrictions associated with actor-task relationships. Furthermore, authors propose transformation rules to automatically obtain smart contracts that verify these restrictions and security policies on Caterpillar.

Other authors have also performed improvements to Caterpillar. Mercenne *et al.* [P31] introduce Blockchain Studio, which is an extension of Caterpillar. Blockchain Studio allows to automate business processes on Ethereum, but authors are focused on BPMN process models based on human tasks to introduce mechanisms that allow incorporating role restrictions on these human tasks. Once these restrictions are modeled, authors generate Solidity code. Some limitations are identified: unfriendly user interface because restrictions are encrypted; there are not security mechanisms to verify the status of each smart contract; there are not mechanisms of automatic synchronization between the BPMN process model and role restrictions when any changes are performed. However, technical, theoretical or practical evidence that are provided in this paper are is not enough to use the proposal.

Tran *et al.* [P28] also propose to obtain Solidity code from BPMN models. In this case, these authors briefly present an overview of the architecture of Lorikeet tool. This tool implements model driven mechanisms to automatically obtain Solidity executable code of smart contracts from BPMN business process models. However, this paper does not provide evidence on these model-to-text transformation mechanisms or how this code is executed.

Viriyasitavat *et al.* [P5] present an architecture which provides support to manage business processes in BC. This support is focused on the phase of discovery and definition of the BPM lifecycle as mentioned above, but this architecture also supports the process execution on BCN. Business processes are encoded into smart contracts in this architecture. However, at present, this paper only proposes this architecture, but authors plan as future works to implement software prototype to support this architecture.

Another proposal to execute CBPs on BCN is the proposal presented in [P9] by Silva *et al.* (as mentioned previously). They integrate, in a theoretical way, DEMO and HC tools in order to model and execute business transactions between different participants of a CBP. In addition, they have designed and developed a software prototype to apply their proposal in real environments on BCT. Specifically, they validate their proposal on BCN in a real case study related with food supply chain.

Weber *et al.* [P11] propose to combine BCT for the definition of the choreography of processes using smart contracts. For this purpose, authors have designed: (i) a method to translate process models (specifically, BPMN) into smart contracts, which are executed on a BCT; and (ii) triggers, which transforms calls to blockchain transactions at a smart contract, and receives status updates from the smart contract that converts to calls (i.e., triggers relate BCN and organization's process implementations). Authors have also developed proof-of-concept prototypes based on different technologies: Java, BPMN2.0 XML files, JBoss BPMN2 Modeller, Solidity scripting language on Ethereum, and JavaScript.

Moreover, Karastoyanova *et al.* [P12] also propose an approach to execute flexible choreography of collaborative processes, but they focus on eScience context. However, authors discuss, in a preliminary and theoretical way, their proposal which is based on two lines of action for future research: (i) using BCT only to store relevant data for the reproducibility of collaborative experiments; and (ii) using BCT to execute research choreographies and processes using adaptive smart contracts. However, as mentioned above, authors only present a roadmap to design and develop their proposal in future work.

Sturm *et al.* [P14] facilitate the decentralized collaboration within choreography processes between organizations. They provide a detailed definition of both lean architecture and smart contracts and blocks to be stored in Ethereum. The most interesting part is the collaboration manager of their software prototype which is integrated with Camunda [54]. Collaboration manager is based on transformations of process models (which encodes the collaboration with BPMN) to transactions (which operate on the same generic smart contract for every instance of the process) which are executed in Camunda.

Falazi *et al.* [P15] present an extension in BPMN notation to be able to deal with all particularities of BCT, as mentioned above. Authors have also validated this proposal by developing an integration middleware (prototype) that allows to execute external applications with public blockchain networks. As mentioned above, this prototype has been developed using Java 8 and RESTful HTTP APIs on Ethereum.

Li *et al.* [P21] also present a blockchain-based workflow system (named BCWMS) to allow the integration of logistics processes and resources between different providers and allow the modeling of heterogeneous requirements between services from different providers. However, authors do not provide technical details of this platform, nor information on future works or roadmaps to improve this proposal.

Bore *et al.* [P22] propose a workflow management platform that automates the creation of workflows on blockchain-based solutions. This platform provides web editors, workflow engine and abstract connectors (which allow to connect blockchain solutions within this platform). In addition, this proposal automatically allows to generate user interfaces, but authors do not provide evidence on this feature. The current version of this platform is very basic, but authors plan to improve the automation of the process with smart contracts and provide evaluation and performance mechanisms of processes.

Fridgen *et al.* [P24] briefly present an experience to automate a collaborative manual workflow (related to document management between banks) using Ethereum. Authors have developed a software prototype to automate and execute this workflow on Ethereum, but evidences are not provided by authors on how this process has been modeled or is being executed, or on what platform is deployed.

Moreover, as mentioned Section V.B.2, Abid *et al.* [P27] propose an extension of BPMN to include temporary restrictions in BPMN process models and translation mechanisms for obtaining smart contracts from these temporary restrictions. In addition, authors propose an extension of Caterpillar to execute these models BPMN with temporal constraints.

Sturm *et al.* [P29] propose a theoretical framework to improve the trust when several organizations collaborate in the same business process. For this purpose, authors present a blockchain-based process engine and mechanisms to model the organizational perspective of BPMN process models. Later, this BPMN model is transformed into smart contracts, which are deployed on Ethereum networks. Although authors do not provide technical evidences about their process engine, this framework and theoretical mechanisms are theoretically described in detail. This proposal is focused on human collaborative tasks, but authors plan to extend their proposal for integration with non-human tasks (IoT devices, external systems, etc.).

Lia *et al.* [P30] also propose a software prototype that is blockchain-enabled workflow operating system (Bc-WfOS). It is focused within field of industrial logistics and its main characteristics are: (*i*) it provides Universal Plug and Play mechanisms to interconnect heterogeneous logistics resources within Bc-WfOS; and (*ii*) it allows to coordinate workflow models between organizations, which have different business logics. This paper describes the architecture of Bc-WfOS platform and its use from a theoretical and technological perspective; it also describes a case study to validate the proposal. Authors plan to include new features on their prototype; features such as security tool, automatic deployment tools on blockchains, user management, monitoring of shared data, etc.

Klinger *et al.* [P33] propose a software platform to execute Cross-organizational business processes. For this purpose, authors focus on orchestration diagrams which are defined with BPMN and, later, these ones are transformed into Solidity contracts. This platform also includes voting and deployment mechanisms on Ethereum.

6) DISCUSSION FOR ≪MONITORING≫ ACTIVITY

Process monitoring refers to collect execution data of processes and show them in a suitable format to facilitate decision making and control the compliance with service level agreements between participants of the business process. During process monitoring, business intelligence techniques with dashboards are usually used. These techniques and tools also tend to be integrated into traditional process management systems such as BPMS [63]. However, there are differences and technological challenges in the way in which these performance data are collected and displayed when BCT is used. Some of these challenges are identified in [19], but the main one is related to the fragmentation and encryption of data because it is probable that data stored in BC are not enough to extract metrics or indicators. It is possible that this data must be made integrated with local data stored out of the chain. In this context, some primary studies provide a different level of support.

Yuanyuan *et al.* [P1] propose a framework that external business processes can be managed on BCN, as mentioned above. Authors mention that their framework provides mechanisms of monitoring and performance of the process to monitor the status and performance of the execution of the process for some specific metrics (which are not indicated). Authors also fail to provide evidence on how process monitoring is carried out in practice.

7) DISCUSSION FOR ≪ADAPTATION≫ ACTIVITY

This activity means providing flexibility at runtime in order to allow changing the process model when this one is being executed. This property has been addressed in some traditional approaches [65]. However, adaptation is a more complex property in blockchain context and should be avoided [19] because if any participant changes the process model at runtime (or change even the smart contract that enforces the process), this participant could obtain an advantage over other participants. In this context, some primary studies provide a different level of support.

López-Pintado *et al.* [P19] propose a BPMN model interpreter that is integrated with dynamic data structures on blockchain networks. This proposal provides flexibility when an inter-organizational process needs to be redesigned and it tries to ensure that running instances of this process will not end up in an inconsistent state after changing the process model. The authors' interpreter has been also integrated into Caterpillar tool [39] (process execution engine).

C. RQ3: WHAT IS RESEARCH METHOD APPLIED TO VALIDATE EACH PRIMARY STUDY?

Once primary studies (Table 8) have been analyzed, more than half of primary studies (58,33%) have applied some research method to validate each proposal. The distribution of primary studies and research validation methods is described in Table 10. Most popular methods are experiments (8 primary studies), proof-of-concept (9 primary studies) and case studies (5 primary studies).

It is possible to observe a relevant threat in these studies: few papers (e.g., [P6] [P11] [P13], among others) describe comprehensive validation plans. This situation could hinder the reproducibility of these validations. However, this situation would be solved if a rigorous validation plan is performed to verify the contribution of each primary study.

TABLE 10. Research validation methods and primary studies.

Research Validation Method	Primary Studies	Total	%
Proof-of-concept	[P3] [P6] [P10] [P11] [P18] [P19] [P26] [P28] [P29]	9	25,00
Experiment	[P13] [P14] [P16] [P17] [P20] [P25] [P32] [P34]	8	22,22
Case studies	[P2] [P9] [P30] [P31] [P33]	5	14,71
No evaluation	[P1] [P4] [P5] [P7] [P8] [P12] [P15] [P21] [P22] [P23] [P24] [P27]	12	35,29

D. RQ4. WHAT ARE THE BUSINESS OR INDUSTRIAL CONTEXTS WHERE BCT IS USED TO IMPROVE CBP MANAGEMENT?

After analyzing and discussing previous RQs, it has been possible to verify that BCT is becoming increasingly popular by the research and industrial communities to solve use cases in many fields related to CBP management. Although there are systematic reviews that are focused on identifying applications of this technology in industrial contexts [21], [22], it is interesting to include a brief analysis of industrial applications that are described by primary studies (Table 8) in this paper.

In this sense, Table 11 shows the distribution of primary studies per business environments where the results of these primary studies have been applied.

TABLE 11. Business sectors and primary studies.

Business Sectors	Primary Studies	Total	%
Supply Chain & Logistic	[P2] [P7] [P9] [P18] [P21] [P30] [P23]	4	20,58
Industry 4.0	[P3] [P8]	2	5,88
Banking	[P24]	1	2,94
Scientific	[P5] [P12] [P16] [P20]	4	11,76
General Sector	[P1] [P4] [P6] [P10] [P11] [P13] [P14] [P15] [P17] [P19] [P22] [P25] [P26] [P27] [P28] [P29] [P31] [P32] [P33] [P34]	20	58,84

According to the primary studies that have been analyzed in this paper, five specific business domains have been identified, in which BCT is been used to improve collaborative process management.

These domains mainly are supply chain, industry 4.0, logistic, banking, and scientific context. It is also possible to highlight a relevant fact: 58.84% of primary studies present general-purpose proposals what reinforces the commitment of the research community to propose transversal solutions that can be applied in different business contexts instead of proposing ad hoc solutions in specific business sectors.

Although the application of each primary study in its business context has been described in previous sections, below, A summary of how BCT can improve CPM is presented by each business sector mentioned in Table 11.

Regarding ***supply chain & logistic sector***, BCT ensures identification of product provenance and facilitates tracking of processes. This sector implies complicated process that frequently involve different and independent actors and stakeholders which have to work together assuring the compliance between them. It is one of the main sectors where BCT is being successfully applied. Its own characteristic with the constraints and collaborative requirements can be improved with blockchain principles [100].

Regarding ***industry 4.0 sector***, BCT in industrial applications is having immense potential to improve numerous aspects (security aspects, shared data collection, efficiency, effectiveness, etc.) in the inter-organizational process management [87]. In this sector, the assurance that each step of the collaborative process is executed following time, resources and quality requirements is critical for the good results. Besides, some of these steps are executed by robots or machines which requires an obligatory collaboration between them. The use of smart contract and blockchain to define these collaborative processes offers successful cases and very interesting results as some authors argue [101].

Regarding ***banking sector***, some authors have proposed techniques to improve the collaborative process execution between financial institutions using BCT. The banking sector is probably the first sector that got benefits from blockchain. In this sector, the security of collaborative processes and the independence between them is crucial to guarantee good results and banks around the world are applying blockchain technology in their IT solutions [102].

Moreover, it is possible to find also another set of applications and successful examples in the application of BCT on CBP within ***scientific sector***. As this paper presents, the research community are interested in this technology, both for researching and for sharing knowledge between researcher jointly. Thus, we can find a high number of examples in research sectors like medicine, educational among other, that are assuming blockchain to improve their processes [103].

Finally, the application of blockchain principles is so huge that we have to consider other sectors, entitled in this paper like ***general sectors***. In this sense, it is important to highlight

TABLE 12. Technical features by primary study.

Primary studies	Blockchain Platform or Architecture				Process Modeling Language					Smart Contract Technology			Process Execution Platform or Process Engine			
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
[P1]				⊠		⊠										⊠
[P2]				⊠								⊠				
[P3]		⊠										⊠				⊠
[P4]		⊠			⊠					⊠					⊠	
[P5]				⊠								⊠				
[P6]			⊠													⊠
[P7]				⊠												
[P8]				⊠												
[P9]	⊠							⊠								
[P10]		⊠					⊠			⊠						⊠
[P11]		⊠			⊠						⊠					⊠
[P12]				⊠								⊠				⊠
[P13]		⊠			⊠						⊠					
[P14]		⊠			⊠					⊠						
[P15]				⊠	⊠						⊠					
[P16]				⊠												
[P17]	⊠				⊠						⊠					⊠
[P18]		⊠			⊠					⊠					⊠	
[P19]		⊠			⊠					⊠					⊠	
[P20]		⊠						⊠								⊠
[P21]				⊠									⊠			
[P22]	⊠										⊠					⊠
[P23]	⊠				⊠											⊠
[P24]		⊠														⊠
[P25]	⊠							⊠						⊠		
[P26]		⊠			⊠					⊠						
[P27]		⊠			⊠					⊠					⊠	
[P28]		⊠			⊠					⊠						⊠
[P29]		⊠			⊠							⊠				⊠
[P30]				⊠									⊠			
[P31]		⊠			⊠					⊠					⊠	
[P32]		⊠			⊠					⊠					⊠	
[P33]		⊠			⊠					⊠						⊠
[P34]		⊠							⊠						⊠	

Acronyms and Abbreviations – F1: Hyperledger, F2: Ethereum, F3: Bitcoin, F4: other shared ledger or unspecified platform, F5: BPMN (base or extension), F6: languages based on state-machine, F7: graph-based notations, F8: metamodel-based notations, F9: languages based on Petri-nets, F10: Solidity, F11: Go, F12: unspecified programming language, F13: BCWMS, F14: Zeebe (base or extension), F15: Caterpillar (base or extension), F16: other process execution platform or unspecified platform; Symbols: ⊠ (applicable technical characteristic)

that many primary studies propose general-purpose techniques or tools, which allow their application in numerous business contexts. However, it is also relevant to mention there are other business sectors where BCT can be used to improve the collaborative process management such as public sector and public governance [104] or social and industrial sector [105].

E. RQ5. WHAT ARE THE MOST RELEVANT TECHNICAL CHARACTERISTICS OF EACH PRIMARY STUDY?

Once primary studies have been presented and discussed in previous sections, it is possible to identify the most used technologies that are used by authors to support their proposals. Table 12 summarizes technical characteristics of each primary study. These characteristics have been grouped into four technical categories: (1) blockchain platforms or architectures, (2) process modeling languages, (3) smart contract technologies, and (4) process execution platform or process engine with blockchain support. Above, next subsections discuss these technical categories for all primary studies.

1) BLOCKCHAIN PLATFORM OR ARCHITECTURE

Today, there are many open-source or proprietary blockchain platforms to support blockchain features (transaction validation, shared data and consensus and identity management mechanisms, among other features) [92]. Table 12 identifies most popular platforms that have been used to develop each proposal. These platforms are: Hyperledger (F1), Ethereum (F2) and Bitcoin (F3) blockchains. Nevertheless, some authors have used other shared ledger, or they even mention the use of blockchain platforms, but they do not indicate in their paper what specific platform is. This category includes this possibility using the value ≪other shared ledger or unspecified platform≫ (F4). Figure 5 also reveals the degree to which the blockchain platforms or architectures are covered.

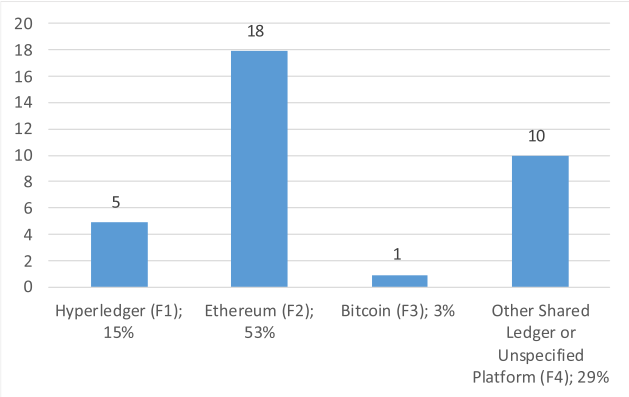


FIGURE 5. Reporting - detail of blockchain platforms or architectures covered by the primary studies.

The most commonly used blockchain platform is the platform offered by Ethereum [57], which is an open source, public, blockchain-based distributed computing platform that also supports programming languages (e.g., Solidity and Serpent) to encode smart contracts. It is possible to observe Ethereum is applied in 18 primary studies (representing 53 % of total) as shown Figure 5.

The next two platforms used to support each proposal are Hyperledger [93] and Bitcoin blockchain [41].

On the one hand, Hyperledger is an open-source project of blockchains that was created by the Linux Foundation. It includes own consensus protocols and storage mechanisms, as well as services for identity and access control. It also supports programming languages (such as, Java, or Solidity, among others) to encode smart contracts. In this case, Hyperledger is observed in 5 primary studies (Figure 5), which represents 15 % of the proposals.

On the other hand, Bitcoin blockchain is well-known first generation blockchain and public ledger, which stores all transactions of the Bitcoin network. It has been implemented to support use cases of financial processes associated with cryptocurrencies. This platform is observed in a single total proposal (representing 3% of primary studies) as shown Figure 5.

Finally, after analyzing each primary study, it is possible to observe that the three previously mentioned platforms are very popular (especially Ethereum) to implement each proposal. However, a significant number of authors mention the use of blockchain platforms to develop their proposals, but these platforms are not identified. Other authors also decide to implement their own blockchain architectures, protocols and algorithms; although this option is not significant. Figure 5 shows this situation with the value ≪other shared ledger or unspecified platform≫ (F4). In this sense, this situation is observed in 10 primary studies, which represents 29% of the proposals.

2) PROCESS MODELING LANGUAGES

Since 1980s, many notations and languages have been proposed by research community to model processes, each of which with a concrete purpose. In this context, some authors have established taxonomies to group these Process Modeling Languages (PMLs) [94], [95], and these taxonomies have been used in this paper to group each primary study. Figure 6 reveals the degree to which PMLs are covered by the primary studies.

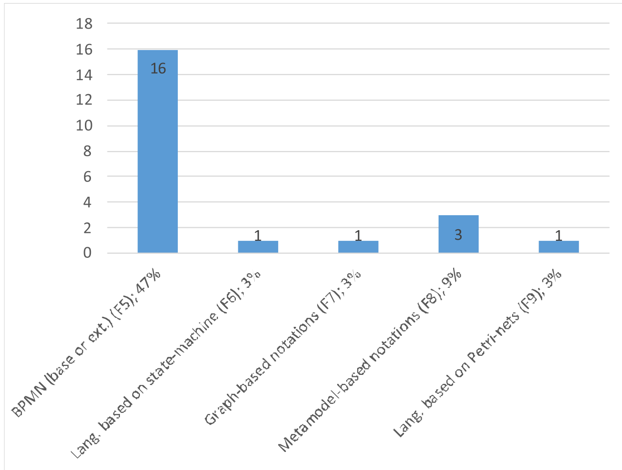


FIGURE 6. Reporting - detail of process modeling languages covered by the primary studies.

As observed in Figure 6, not all primary studies support some process modeling language. In fact, there are only 22 primary studies (64% of total of the primary studies) that include some mechanisms to model blockchain features into process models. This fact may be justified because not all primary studies support ≪Discovery & modeling≫ activity of the BPM lifecycle (see Table 9). Nevertheless, after considering previous taxonomies and analyzing each primary study, some PMLs have been identified as the most widely used paradigms to define or model blockchain features into process models (see Table 12): BPMN (Business Process Model and Notation) or BPMN extensions (F5), languages based on state machines (F6), graph-based notations (F7), metamodel-based notations (F8), and languages based on Petri-nets (F9).

As mention above, Figure 6 shows the distribution of type of PMLs that are supported by the primary studies. The lowest ones are graph-based languages (1 primary study), languages based on state machines (1 primary study) or based on Petri-nets (1 primary studies). The percentage associated with these types is 9% of primary studies.

Moreover, the most popular choice for defining blockchain features within process models is to use BPMN (or extensions of BPMN) and metamodel-based languages; although the former is more widely used than the latter. In this sense, BPMN is observed in 16 primary studies (representing 47% of primary studies) while metamodel-based languages are only used by 3 proposals (representing 9% of primary studies). Preferred notation by authors for process modeling with BC features seems BPMN. This situation could be justified because BPMN is an international standard for business process modeling and is the most supported notation by many process execution engines what facilitates its deployment in real environments [8].

3) SMART CONTRACT TECHNOLOGIES

Before mentioning the degree of coverage of these technologies by the primary studies of this review, it is important to know the meaning of smart contract. Some authors briefly define the concept of smart contract as a Turing-complete program that encodes a digital protocol predefined by parties who proceed to an agreement [99]. This protocol checks and executes a set of rules (clauses of the agreement) over a blockchain network.

In this context, the combination of BPM and blockchain technology can improve efficiency and effectiveness of the execution of inter-organizational processes between several organizations. These entities can agree on business rules, contractual conditions, etc., associated with transactions that occur during the execution of these collaborative processes. Before the existence of blockchain technology, these entities usually collaborated with other external entities, which verified the contractual conditions of collaborate processes. This situation usually caused extra cost and uncertainty for the companies that were collaborating. Today, smart contracts allow to automatically verify these business rules and contractual conditions of inter-organizational processes when the smart contract is deployed and executed on a blockchain network. In addition, these contractual conditions are also automatically verified at runtime without the need for an intermediary or auditor to verify compliance. This advantage increases confidence and reduces costs for all organizations when these ones jointly collaborate in inter-organizational processes.

Today, there are two types of smart contracts [96]: deterministic and non-deterministic smart contracts. The first one is a smart contract that when it is run, it does not require any information from an external party (i.e., from outside the blockchain network), whereas the second one is a smart contract that depends on information (called oracles or data feeds) from an external party. Nowadays, there are technologies (based on Turing-complete programming languages) to encode both kind of smart contracts. For example, Turing-complete programming languages such as Solidity and Serpent allow to develop deterministic and non-deterministic smart contracts, while other programming languages (such as Java, Go, and Fabric, among others) allow only to develop deterministic smart contracts [91].

Figure 7 also reveals the degree to which the smart contract technologies are covered by the primary studies. It is possible to observe that not all primary studies support smart contract technologies. In fact, 21 proposals only use these technologies.

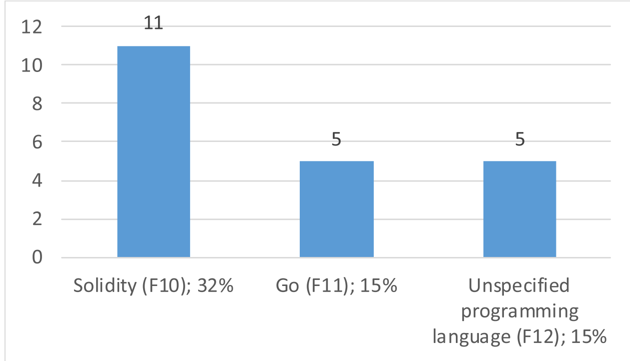


FIGURE 7. Reporting - detail of smart contract technologies covered by the primary studies.

The programming languages most used by authors to encode smart contracts are Solidity (F10) and Go (F11); although the former is more widely used than the latter as is shown in Table 12. Specially, Solidity is observed in 11 primary studies (representing 32 % of primary studies), whereas Go programming language is used by 5 authors (representing 15 % of all primary studies).

Finally, it is possible to observe some authors mention the use of programming language to encode smart contracts, but they do not specify in their paper what programming language is used. This fact is included within this category using the ≪unspecified programming language≫ (F12) value, and it is possible to note this situation in 5 primary studies (see Table 12) what represents 15% of all primary studies (see Figure 7).

4) PROCESS EXECUTION PLATFORM OR PROCESS ENGINE

Business process engines (named usually Business Process Management Systems; BPMS) are software solutions that enables the execution and maintenance of process workflows. It provides business process interaction and communication between different data/process sources spread across one or more IT (information technology) applications and services [97].

These software tools include different functionalities to support each phase of BPM lifecycle, but these engines are usually general-purpose tools [97], and their core features do not provide usually specific mechanisms to integrate BCT. This reason has promoted research community designs and develops specific process engine to support features of BCT.

In this context, after analyzing the primary studies, it is possible to observe three main technological solutions that have been used or proposed to support and improve the execution of collaborative process using BCT. These platforms are: BCWMS (F13), Zeebe process engine (F14) and Caterpillar (F15). In addition, it is possible to observe two facts. Firstly, some authors propose their own execution platform, but they do not provide detailed technical information about this platform. This category includes this situation using this value: ≪other execution platform or unspecified platform≫ (F16). Secondly, it is also possible to note that not all authors provide mechanisms to execute their proposals with some execution platform. In this sense, only 24 primary studies include the development of some process execution platform with BCT support. The rest of papers have been theoretically presented and do not provide evidence on the use of this kind of execution platform.

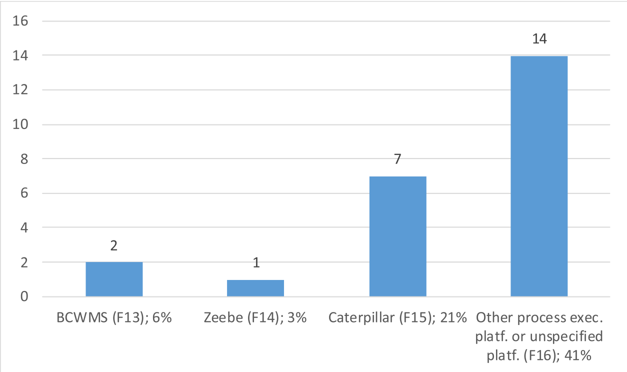


FIGURE 8. Reporting - detail of process execution platform or process engine covered by the primary studies.

Table 12 identifies these technological solutions and Figure 8 also reveals the degree to which the process engines are covered by the primary studies. Below, data on process engines or execution technology platforms that are used by the primary studies are analyzed.

On the one hand, the lower covered execution platforms are BCWMS and Zeebe process engine, which has been proposed and used to support the execution of two and one primary studies, respectively (see Table 12). Both technological solutions cover 9% of all primary studies. Firstly, BCWMS is a blockchain-enabled workflow management system to specially support logistic workflow models with different customers. From a technological perspective, this platform is offered as an IaaS (infrastructure-as-a-service) platform and has been developed with Java technology, as well as Spring, SpringMVC and MyBatis frameworks [97]. Secondly, Zeebe [98] is a workflow engine for microservices orchestration that is integrated with Camunda and it provides workflow orchestration, metrics associated with these workflows, and monitoring of process instance. In this specific case, authors [P25] have used Zeebe to execute their proposal, but this process engine has not been extended with new functionalities.

On the other hand, the second most used process engine is Caterpillar [39]. Caterpillar is an open-source BPMS with the tamper-profess of a blockchain platform, and it provides a REST API that exposes three types of components: BPMN models; set of running process instances; and API services, i.e. references to smart contracts used for communicating with external services. Caterpillar also provides extension mechanisms what allows to evolve and increase its features and functionalities. In this sense, some authors have used these mechanisms to develop and integrate their proposals on Caterpillar. Specifically, 7 authors use (or extend) Caterpillar to support the execution of their proposals (representing 21% of primary studies). Main contributions of these 7 primary studies are described in Section V.B.

Finally, regarding the other proposals, these ones have been categorized as ≪other process execution platform or unspecified platform≫ following two criteria: (*i*) when authors do not provide technical evidences or detailed technical information about their process execution platform with BCT support; or (*ii*) when authors describe their execution platform, and this one is not a general-purpose platform, but it is an ad-hoc execution platform. In this context, 15 primary studies (representing 41% of total) have been included in this category (see Figure 8). The most popular main technologies to develop these ad-hoc execution platforms are: (*i*) Java, Spring framework and RESTful HTTP APIs (which are used in [P6] [P11] [P15] [P28], among others); and (*ii*) Python (which are used in [P20]). Other primary studies also use web technologies such as JavaScript and Node.js (e.g., [P11] [P17] [P33]).

VI. CONCLUSION AND OPEN ISSUES

BlockChain Technology (BCT) has emerged as new technology and offers valued cost reductions by enabling transactions to be executed in a peer-to-peer manner directly between entities or individual users, without delegating trust to central official authorities nor requiring mutual trust between each couple of parties. These features have led to a rapid and growing attention on BCT within different contexts; for instance, BPM [73]. In fact, it is possible to see the interest of public bodies, scientific community and software industries to know the feasibility and opportunities that BCT offers to improve collaborative process management in a decentralized manner.

In this context, a systematic review is presented in this paper, which identifies and analyses the state-of-the-art of research papers about collaborative BPM in BCT domain. For this purpose, Kitchenham's method has been followed, what allows to locate different types of proposals that address the CBP management using BCT. Specifically, 34 primary studies have been identified once the search protocol described in this paper has been executed.

These studies have been also classified according to the activities of the BPM lifecycle to which they offer support. For this purpose, Dumas' BPM lifecycle has been used to perform this classification. After carrying out this review, open issues have been identified.

As mentioned above, the BPM activities that are mainly supported by the primary studies are, respectively, (Figure 4.A): (*i*) process implementation & execution (47%), (*ii*) process modeling (37%), and (*iii*) process analysis (16%). However, it is important to mention that some primary studies (such as, [P1], [P2], [P3], [P7] or [P12], among others) have not provided enough evidence to verify this support. However, it is possible to conclude that the current efforts by the scientific community in integrating BCT into

BPM are at a very early stage. In addition, there are also important challenges that have to be addressed to provide effective and adequate support in each activity of the BPM lifecycle.

On the one hand, there is a lack of proposals that provide support for the first and last activity of the Dumas' lifecycle, that is, ≪A1 - Identification≫ and ≪A7 - Adaptation≫ activities (these ones are supported by 0 and 1 proposals, respectively). This situation is an opportunity for innovation for the research community to be pioneers in this field. This also occurs in ≪A4 - Redesign≫ and ≪A6 - Monitoring≫ activities (both ones are supported by 4% and 1% of primary studies, respectively). Although it has been possible to find one primary study ([P1]) with support for these activities, authors only describe good intentions of their proposal, and it does not provide any evidence of this support either. In this sense, it is also a relevant opportunity to be investigated to improve the modeling of processes using patterns.

On the other hand, it is possible to establish some conclusions and identify some trends in process modeling. After carrying out this review, 37 % of primary studies provide support for ≪A2 - Discovery & modeling≫ activity. Specifically, two main trends have been identified. The first one is based on its own languages; for example, [P1] [P5] [P7] support this activity through their own modeling language, but very little evidence is presented about this language. The second one ([P13], [P15], [P16] or [P17], among others) is based on extensions of BPMN (standard notation) what could be considered the most appropriate option to guarantee the compatibility and integration of these proposals with commercial process engines (the vast majority of which supports BPMN).

Finally, it is possible to observe that ≪A3 - Analysis≫ and ≪A5 - Implementation & execution≫ activities are also well-supported BPM activities with 16% and 47%, respectively. Regarding the first one, we conclude that six primary studies support this Analysis activity, but these studies are just focused on verifying the veracity of the process during its execution (specifically, the verification of the transactions carried out between inter-organizational activities). However, there is a lack of proposals that provide performance analysis and data transformation when a process is executed. This aspect is relevant in ≪A3 - Analysis≫ activity. As an opposite situation, we have observed that the execution activity is the most activity supported by the primary studies. After performing this review, it is possible to infer two current trends in this field. The first one is to develop ad-hoc tools to implement the authors' frameworks whereas the second trend consists of integrating the proposals with commercial BPMS (e.g., [P4], [P11], [P14], among others). This last trend could be considered the most appropriate option to guarantee practical application in real environments since it provides compatibility and integration with commercial process engines. However, we have observed a relevant fact. Many proposals with execution support are oriented towards specific domains (supply chain processes and industrial processes, mainly). It could be, therefore, interesting and important to propose solutions that allow executing any type of process of any business scope.

Moreover, regarding the type of proposal of primary studies, it is possible to observe that the vast majority are conceptual and theoretical proposals (71%; Figure 4.B) on how BCT could be applied, but a lot of them are framed into specific contexts of process management (mainly industrial processes and supply chain processes). Furthermore, there are no methodologies and measures that support the definition and practical development of these proposals. In fact, it might be convenient to propose an ontology or glossary to define each of these elements, because we have identified that these concepts are indiscriminately used by many authors (for example, some authors may identify their proposal an approach, while in the glossary of their paper are mentioned as model, or a framework, or something else). Anyway, this situation shows more weak points concerning the methodological types (approaches, model, frameworks and methods), that is, there is no authors who describes what methodological features is proposing. This weak description without a clear roadmap (beyond theoretical and scientific content) could end up hindering the transfer of knowledge to the productive fabric of society, as well as the design and development of technological solutions that provide practical support in real environments.

Despite this situation, this systematic review shows that the international scientific community has an important and growing interest to address the improvement of process management using BCT. In addition, more than half of primary studies use some type of research validation method (experiment, case studies or proofs-of-concept are the most popular methods), but it is possible to observe mistakes when these methods are named in research papers related to software engineering. In other words, some authors mistakenly use the concept "case study" since they are really describing practical application experiences. In any case, this fact is not a bad practice since it is something that also occurs in other research fields. It is also possible to observe that there are no primary studies with understandable validation plans, which hinders the reproducibility of the results of each study. In this context, it could be interesting to promote formal guidelines within scientific community to validate results of each research proposal that is published. The purpose is to improve contributions and quality of international scientific production.

Finally, it is possible to observe a fact related to the support tools for the application of each proposal in practice. After carrying out this systematic review, we have observed that most of the support tools are initial prototypes. However, we have been able to identify a prototype (called Caterpillar [P4] [P32]) that stands out from the rest and is emerging strongly because it is integrated with Camunda (a commercial BPMS). Anyway, this fact is not a disadvantage itself, but quite the opposite because it allows opening new research lines to design and develop robust technological solutions soon.

Once this review has been completed, some research lines are going to be explored as future work. Specially, we will research model-driven mechanisms to facilitate the integration between blockchain technology and collaborative process management. The use of model-driven engineering paradigm has obtained satisfactory results in other areas [66]–[68] and it could be interesting its application in this topic to reduce costs and improve quality. For example, we are exploring model-driven early testing techniques to approve and validate smart contracts that are tied to business rules on critical processes. In this sense, we are applying and evaluating first results on a case study related to the collaborative execution of software processes between software organizations. Furthermore, we plan to explore how to improve the definition of traceability requirements on collaborative process within SoS (System of Systems) context. Once this definition has been completed, we plan to verify and audit these traceability requirements (using blockchain technology) when these artifacts are manipulated. These techniques are being verified in the context of laboratories 4.0 and ART (Assisted Reproductive Treatment) process [86].

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REFERENCES

[1] E. Psomas and D. Kafetzopoulos, ''Performance measures of ISO 9001 certified and non-certified manufacturing companies,'' *Benchmarking, Int. J.*, vol. 21, no. 5, pp. 756–774, Jul. 2014.

[2] *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*, Project Manage. Inst., Newtown Square, PA, USA, 2000, vol. 2.

[3] C. Bentley, *PRINCE2: A Practical Handbook*. Evanston, IL, USA: Routledge, 2009.

[4] CMMI Product Team, ''CMMI for systems engineering/software engineering/integrated product and process development/supplier sourcing, version 1.1, staged representation (CMMI-SE/SW/IPPD/SS, V1.1, Staged),'' Softw. Eng. Inst., Carnegie Mellon Univ., Pittsburgh, PA, USA, Tech. Rep. CMU/SEI-2002-TR-012, 2002. [Online]. Available: http://resources.sei.cmu.edu/library/asset-view.cfm?AssetID=6109

[5] A. Hochstein, R. Zarnekow, and W. Brenner, ''ITIL as common practice reference model for IT service management: Formal assessment and implications for practice,'' in *Proc. IEEE Int. Conf. e-Technol., e-Commerce e-Service*, Mar. 2005, pp. 704–710.

[6] W. M. P. Van Der Aalst, ''Business process management demystified: A tutorial on models, systems and standards for workflow management,'' in *Advanced Course on Petri Nets*. Springer, 2003, pp. 1–65.

[7] J. Stark, ''Product lifecycle management,'' in *Product Lifecycle Management*, vol. 2. Springer, 2016, pp. 1–35.

[8] A. Meidan, J. A. García-García, M. J. Escalona, and I. Ramos, ''A survey on business processes management suites,'' *Comput. Standards Interfaces*, vol. 51, pp. 71–86, Mar. 2017.

[9] F. Milani, L. García-Bañuelos, and M. Dumas, ''Blockchain and business process improvement,'' BPTrends Newsletter, 2016.

[10] Q. Chen and M. Hsu, ''Inter-enterprise collaborative business process management,'' in *Proc. 17th Int. Conf. Data Eng.*, 2001, pp. 253–260.

[11] Z. Zheng, S. Xie, H. Dai, X. Chen, and H. Wang, ''An overview of blockchain technology: Architecture, consensus, and future trends,'' in *Proc. IEEE Int. Congr. Big Data (BigData Congress)*, Jun. 2017, pp. 557–564.

[12] S. Nakamoto. (2009). *Bitcoin: A Peer-to-Peer Electronic Cash System*. Accessed: May 2009. [Online]. Available: http://www.bitcoin.org/bitcoin.pdf

[13] M. Pilkington, ''Blockchain technology: Principles and applications,'' in *Research Handbook on Digital Transformations*. Edward Elgar Publishing, 2016.

[14] A. Dubovitskaya, Z. Xu, S. Ryu, M. Schumacher, and F. Wang, ''Secure and trustable electronic medical records sharing using blockchain,'' in *Proc. AMIA Annu. Symp.* Bethesda, MD, USA: American Medical Informatics Association, 2017, p. 650.

[15] Y. Guo and C. Liang, ''Blockchain application and outlook in the banking industry,'' *Financial Innov.*, vol. 2, no. 1, p. 24, Dec. 2016.

[16] E. Mengelkamp, B. Notheisen, C. Beer, D. Dauer, and C. Weinhardt, ''A blockchain-based smart grid: Towards sustainable local energy markets,'' *Comput. Sci.-Res. Develop.*, vol. 33, nos. 1–2, pp. 207–214, Feb. 2018.

[17] F. Tian, ''An agri-food supply chain traceability system for China based on RFID & blockchain technology,'' in *Proc. 13th Int. Conf. Service Syst. Service Manage.*, 2016, pp. 1–6.

[18] A. Bahga and V. K. Madisetti, ''Blockchain platform for industrial Internet of Things,'' *J. Softw. Eng. Appl.*, vol. 9, no. 10, pp. 533–546, 2016.

[19] J. Mendling *et al.*, ''Blockchains for business process management-challenges and opportunities,'' *ACM Trans. Manage. Inf. Syst.*, vol. 9, no. 1, 2018, Art. no. 4.

[20] A. M. Antonopoulos, *Mastering Bitcoin: Unlocking Digital Cryptocurrencies*. Sebastopol, CA, USA: O'Reilly Media, 2014.

[21] I. Konstantinidis, G. Siaminos, C. Timplalexis, P. Zervas, V. Peristeras, and S. Decker, ''Blockchain for business applications: A systematic literature review,'' in *Proc. Int. Conf. Bus. Inf. Syst.* Cham, Switzerland: Springer, 2018, pp. 384–399.

[22] Y. Lu, ''Blockchain: A survey on functions, applications and open issues,'' *J. Ind. Integr. Manage.*, vol. 3, no. 4, Dec. 2018, Art. no. 1850015.

[23] B. Silver, *BPMN Method and Style, With BPMN Implementer's Guide: A Structured Approach for Business Process Modeling and Implementation Using BPMN 2.0*. Aptos, CA, USA: Cody-Cassidy Press, 2011, p. 23.

[24] B. Kitchenham and P. Brereton, ''A systematic review of systematic review process research in software engineering,'' *Inf. Softw. Technol.*, vol. 55, no. 12, pp. 2049–2075, Dec. 2013, doi: 10.1016/j.infsof.2013.07.010.

[25] O. López-Pintado, M. Dumas, L. García-Bañuelos, and I. Weber, ''Interpreted execution of business process models on blockchain,'' in *Proc. IEEE 23rd Int. Enterprise Distrib. Object Comput. Conf. (EDOC)*, Oct. 2019, pp. 206–215.

[26] D. Fernando, S. Kulshrestha, J. D. Herath, N. Mahadik, Y. Ma, C. Bai, P. Yang, G. Yan, and S. Lu, ''SciBlock: A blockchain-based tamper-proof non-repudiable storage for scientific workflow provenance,'' in *Proc. IEEE 5th Int. Conf. Collaboration Internet Comput. (CIC)*, Dec. 2019, pp. 81–90.

[27] M. Li and G. Q. Huang, ''Blockchain-enabled workflow management system for fine-grained resource sharing in E-commerce logistics,'' in *Proc. IEEE 15th Int. Conf. Automat. Sci. Eng. (CASE)*, Aug. 2019, pp. 751–755.

[28] N. Bore, A. Kinai, J. Mutahi, D. Kaguma, F. Otieno, S. L. Remy, and K. Weldemariam, ''On using blockchain based workflows,'' in *Proc. IEEE Int. Conf. Blockchain Cryptocurrency (ICBC)*, May 2019, pp. 112–116.

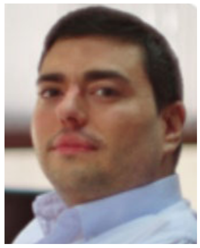
[29] F. Panduwinata and P. Yugopuspito, ''BPMN approach in blockchain with hyperledger composer and smart contract: Reservation-based parking system,'' in *Proc. 5th Int. Conf. New Media Stud. (CONMEDIA)*, Oct. 2019, pp. 89–93.

[30] C. Wohlin and R. Prikladnicki, ''Systematic literature reviews in software engineering,'' *Inf. Softw. Technol.*, vol. 55, no. 6, pp. 919–920, Jun. 2013, doi: 10.1016/j.infsof.2013.02.002.

[31] E. W. T. Ngai, Y. Hu, Y. H. Wong, Y. Chen, and X. Sun, ''The application of data mining techniques in financial fraud detection: A classification framework and an academic review of literature,'' *Decis. Support Syst.*, vol. 50, no. 3, pp. 559–569, Feb. 2011, doi: 10.1016/j.dss.2010.08.006.

[32] S. Feyer, S. Siebert, B. Gipp, A. Aizawa, and J. Beel, "Integration of the scientific recommender system Mr. DLib into the reference manager JabRef," in *Proc. Eur. Conf. Inf. Retr.*, in Lecture Notes in Computer Science, 2017, pp. 770–774, doi: 10.1007/978-3-319-56608-5_80.
[33] (2019). *JCR, Journal Citations Report*. [Online]. Available: https://goo.gl/8VZwFa
[34] (2019). *CORE, Computing Research & Education*. [Online]. Available: https://goo.gl/xqMzmg
[35] C. M. Schmucker, A. Blümle, L. K. Schell, G. Schwarzer, P. Oeller, L. Cabrera, E. von Elm, M. Briel, and J. J. Meerpohl, "Systematic review finds that study data not published in full text articles have unclear impact on meta-analyses results in medical research," *PLoS ONE*, vol. 12, no. 4, Apr. 2017, Art. no. e0176210, doi: 10.1371/journal.pone.0176210.
[36] Y. Cen, H. Wang, and X. Li, "Improving business process interoperability by shared ledgers," in *Proc. 6th Int. Conf. Informat., Environ., Energy Appl. (IEEA)*, 2017, pp. 89–93.
[37] S. Chen, R. Shi, Z. Ren, J. Yan, Y. Shi, and J. Zhang, "A blockchain-based supply chain quality management framework," in *Proc. IEEE 14th Int. Conf. e-Bus. Eng. (ICEBE)*, Nov. 2017, pp. 172–176.
[38] A. Kapitonov, I. Berman, S. Lonshakov, and A. Krupenkin, "Blockchain based protocol for economical communication in industry 4.0," in *Proc. Crypto Valley Conf. Blockchain Technol. (CVCBT)*, Jun. 2018, pp. 41–44.
[39] O. López-Pintado, L. García-Bañuelos, M. Dumas, and I. Weber, "Caterpillar: A blockchain-based business process management system," in *Proc. BPM Demos*, Sep. 2017, pp. 1–5.
[40] W. Viriyasitavat and D. Hoonsopon, "Blockchain characteristics and consensus in modern business processes," *J. Ind. Inf. Integr.*, vol. 13, pp. 32–39, Mar. 2019.
[41] C. Prybila, S. Schulte, C. Hochreiner, and I. Weber, "Runtime verification for business processes utilizing the bitcoin blockchain," *Future Gener. Comput. Syst.*, vol. 107, pp. 816–831, Jun. 2020.
[42] S. E. Chang, Y.-C. Chen, and M.-F. Lu, "Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process," *Technol. Forecasting Social Change*, vol. 144, pp. 1–11, Jul. 2019.
[43] W. Viriyasitavat, L. Da Xu, Z. Bi, and A. Sapsomboon, "Blockchain-based business process management (BPM) framework for service composition in industry 4.0," *J. Intell. Manuf.*, vol. 1, pp. 1–12, 2018.
[44] D. Silva, S. Guerreiro, and P. Sousa, "Decentralized enforcement of business process control using blockchain," in *Proc. Enterprise Eng. Work. Conf.* Cham, Switzerland: Springer, 2018, pp. 69–87.
[45] M. F. Madsen, M. Gaub, T. Høgnason, M. E. Kirkbro, T. Slaats, and S. Debois, "Collaboration among adversaries: Distributed workflow execution on a blockchain," in *Proc. Symp. Found. Appl. Blockchain*, Mar. 2018, p. 8.
[46] I. Weber, X. Xu, R. Riveret, G. Governatori, A. Ponomarev, and J. Mendling, "Untrusted business process monitoring and execution using blockchain," in *Proc. Int. Conf. Bus. Process Manage.* Cham, Switzerland: Springer, 2016, pp. 329–347.
[47] D. Karastoyanova and L. Stage, "Towards collaborative and reproducible scientific experiments on blockchain," in *Proc. Int. Conf. Adv. Inf. Syst. Eng.* Cham, Switzerland: Springer, 2018, pp. 144–149.
[48] L. García-Bañuelos, A. Ponomarev, M. Dumas, and I. Weber, "Optimized execution of business processes on blockchain," in *Proc. Int. Conf. Bus. Process Manage.* Cham, Switzerland: Springer, Sep. 2017, pp. 130–146.
[49] C. Sturm, J. Szalanczi, S. Schönig, and S. Jablonski, "A lean architecture for blockchain based decentralized process execution," in *Proc. Int. Conf. Bus. Process Manage.* Cham, Switzerland: Springer, Sep. 2018, pp. 361–373.
[50] G. Falazi, M. Hahn, U. Breitenbücher, and F. Leymann, "Modeling and execution of blockchain-aware business processes," *SICS Softw.-Intensive Cyber-Phys. Syst.*, vol. 34, pp. 105–116, Feb. 2018.
[51] W. Chen, X. Liang, J. Li, H. Qin, Y. Mu, and J. Wang, "Blockchain based provenance sharing of scientific workflows," in *Proc. IEEE Int. Conf. Big Data (Big Data)*, Dec. 2018, pp. 3814–3820.
[52] H. Nakamura, K. Miyamoto, and M. Kudo, "Inter-organizational business processes managed by blockchain," in *Proc. Int. Conf. Web Inf. Syst. Eng.* Cham, Switzerland: Springer, Nov. 2018, pp. 3–17.
[53] C. Di Ciccio, A. Cecconi, J. Mendling, D. Felix, D. Haas, D. Lilek, F. Riel, A. Rumpl, and P. Uhlig, "Blockchain-based traceability of inter-organisational business processes," in *Proc. Int. Symp. Bus. Modeling Softw. Design*. Cham, Switzerland: Springer, Jul. 2018, pp. 56–68.
[54] *Camunda: Workflow and Decision Automation Platform*. Accessed: Jul. 2019. [Online]. Available: https://camunda.com/
[55] J. L. Dietz, *Enterprise Ontology: Theory and Methodology*. Heidelberg, Germany: Springer, 2006, doi: 10.1007/3-540-33149-2.
[56] *Hyperledger Composer*. Accessed: Jul. 2019. [Online]. Available: https://hyperledger.github.io/composer
[57] V. Buterin. (2014). *Ethereum White Paper: A Next-Generation Smart Contract and Decentralized Application Platform First Version*. [Online]. Available: https://github.com/ethereum/wiki/wiki/White-Paper
[58] J. B. Hill, M. Cantara, E. Deitert, and M. Kerremans, "Magic quadrant for business process management suites," Gartner Res., Stamford, CT, USA, Tech. Rep. G001252906, 2007.
[59] J. B. Hill, J. Sinur, D. Flint, and M. J. Melenovsky, "Gartner's position on business process management," *Gartner Res. G*, vol. 136533, 2006.
[60] W. M. P. Van Der Aalst, "Business process management demystified: A tutorial on models, systems and standards for workflow management," in *Advanced Course on Petri Nets*. Springer, 2003, pp. 1–65.
[61] M. Havey, *Essential Business Process Modeling*. Sebastopol, CA, USA: O'Reilly Media, 2005.
[62] J. B. Hill, J. Sinur, D. Flint, and M. J. Melenovsky, "Gartner's position on business process management," Bus. Issues Gartner, Stamford, CT, USA, Tech. Rep. G00136533, 2006. [Online]. Available: https://www.gartner.com/en/documents/489533/gartner-s-position-on-business-process-management-2006
[63] M. Dumas, M. La Rosa, J. Mendling, and H. A. Reijers, *Business Process Management*. Springer, 2013.
[64] W. Van Der Aalst, "Data science in action," in *Process Mining*. Springer, 2016, pp. 3–23.
[65] M. Reichert and B. Weber, *Enabling Flexibility in Process-Aware Information Systems: Challenges, Methods, Technologies*. Springer, 2012.
[66] J. G. Enríquez, R. Blanco, F. J. Domínguez-Mayo, J. Tuya, and M. J. Escalona, "Towards an MDE-based approach to test entity reconciliation applications," in *Proc. 7th Int. Workshop Automating Test Case Design, Selection, Eval. (A-TEST)*, 2016, pp. 74–77.
[67] R. Blanco, J. G. Enriquez, F. J. Dominguez-Mayo, M. J. Escalona, and J. Tuya, "Early integration testing for entity reconciliation in the context of heterogeneous data sources," *IEEE Trans. Rel.*, vol. 67, no. 2, pp. 538–556, Jun. 2018.
[68] J. Chacón-Montero, A. Jiménez-Ramírez, and J. G. Enríquez, "Towards a method for automated testing in robotic process automation projects," in *Proc. IEEE/ACM 14th Int. Workshop Automat. Softw. Test (AST)*, Piscataway, NJ, USA, May 2019, pp. 42–47, doi: 10.1109/AST.2019.00012.
[69] F. J. Domínguez-Mayo, M. J. Escalona, M. Mejías, M. Ross, and G. Staples, "A quality management based on the quality model life cycle," *Comput. Standards Interfaces*, vol. 34, no. 4, pp. 396–412, Jun. 2012.
[70] F. J. Domínguez-Mayo, M. J. Escalona, M. Mejías, M. Ross, and G. Staples, "Quality evaluation for model-driven Web engineering methodologies," *Inf. Softw. Technol.*, vol. 54, no. 11, pp. 1265–1282, Nov. 2012.
[71] C. Arevalo, M. J. Escalona, I. Ramos, and M. Domínguez-Muñoz, "A metamodel to integrate business processes time perspective in BPMN 2.0," *Inf. Softw. Technol.*, vol. 77, pp. 17–33, Sep. 2016.
[72] T. Srivardhana and S. D. Pawlowski, "ERP systems as an enabler of sustained business process innovation: A knowledge-based view," *J. Strategic Inf. Syst.*, vol. 16, no. 1, pp. 51–69, Mar. 2007.
[73] F. Enríquez, J. A. Troyano, and L. M. Romero-Moreno, "Using a business process management system to model dynamic teaching methods," *J. Strategic Inf. Syst.*, vol. 28, no. 3, pp. 275–291, Sep. 2019.
[74] G. Fridgen, S. Radszuwill, N. Urbach, and L. Utz, "Cross-organizational workflow management using blockchain technology-towards applicability, auditability, and automation," in *Proc. 51st Hawaii Int. Conf. Syst. Sci.*, 2018.
[75] Y. Fang, X. Tang, M. Pan, and Y. Yu, "A workflow interoperability approach based on blockchain," in *Proc. Int. Conf. Internet Vehicles*. Cham, Switzerland: Springer, 2019, pp. 303–317.
[76] J. Ladleif, M. Weske, and I. Weber, "Modeling and enforcing blockchain-based choreographies," in *Proc. Int. Conf. Bus. Process Manage.* Cham, Switzerland: Springer, 2019, pp. 69–85.
[77] A. Abid, S. Cheikhrouhou, and M. Jmaiel, "Modelling and executing time-aware processes in trustless blockchain environment," in *Proc. Int. Conf. Risks Secur. Internet Syst.* Cham, Switzerland: Springer, 2019, pp. 325–341.

[78] A. B. Tran, Q. Lu, and I. Weber, "Lorikeet: A model-driven engineering tool for blockchain-based business process execution and asset management," in *Proc. BPM Dissertation/Demos/Industry*, 2018, pp. 56–60.
[79] C. Sturm, J. Scalanczi, S. Schönig, and S. Jablonski, "A blockchain-based and resource-aware process execution engine," *Future Gener. Comput. Syst.*, vol. 100, pp. 19–34, Nov. 2019.
[80] M. Li, L. Shen, and G. Q. Huang, "Blockchain-enabled workflow operating system for logistics resources sharing in E-commerce logistics real estate service," *Comput. Ind. Eng.*, vol. 135, pp. 950–969, Sep. 2019.
[81] L. Mercenne, K.-L. Brousmiche, and E. B. Hamida, "Blockchain studio: A role-based business workflows management system," in *Proc. IEEE 9th Annu. Inf. Technol., Electron. Mobile Commun. Conf. (IEMCON)*, Nov. 2018, pp. 1215–1220.
[82] O. López-Pintado, L. García-Bañuelos, M. Dumas, I. Weber, and A. Ponomarev, "Caterpillar: A business process execution engine on the ethereum blockchain," *Softw., Pract. Exper.*, vol. 49, no. 7, pp. 1162–1193, May 2019.
[83] P. Klinger and F. Bodendorf, "Blockchain-based cross-organizational execution framework for dynamic integration of process collaborations," in *Proc. 15th Int. Conf. Wirtschaftsinformatik*, Potsdam, Germany, 2020, pp. 1–16.
[84] O. López-Pintado, M. Dumas, L. García-Bañuelos, and I. Weber, "Dynamic role binding in blockchain-based collaborative business processes," in *Proc. Int. Conf. Adv. Inf. Syst. Eng.* Cham, Switzerland: Springer, 2019, pp. 399–414
[85] S. Debois and T. Hildebrand, "The DCR workbench: Declarative choreographies for collaborative processes," in *Behavioural Types: From Theory to Tools* (River Publishers Series in Automation, Control and Robotics). Pensacola, FL, USA: River Publishers, 2017, pp. 99–124.
[86] L. M. Trujillo, J. A. Garcia-Garcia, L. Lizcano, and M. Mejías, "Traceability management of systems of systems: A systematic review in the assisted reproduction domain," *J. Web Eng.*, vol. 18, no. 4, pp. 409–446, 2019.
[87] T. Alladi, V. Chamola, R. M. Parizi, and K.-K. R. Choo, "Blockchain applications for industry 4.0 and industrial IoT: A review," *IEEE Access*, vol. 7, pp. 176935–176951, 2019.
[88] F. Casino, T. K. Dasaklis, and C. Patsakis, "A systematic literature review of blockchain-based applications: Current status, classification and open issues," *Telematics Informat.*, vol. 36, pp. 55–81, Mar. 2019.
[89] F. Hawlitschek, B. Notheisen, and T. Teubner, "The limits of trust-free systems: A literature review on blockchain technology and trust in the sharing economy," *Electron. Commerce Res. Appl.*, vol. 29, pp. 50–63, May 2018.
[90] S. Seebacher and R. Schüritz, "Blockchain technology as an enabler of service systems: A structured literature review," in *Proc. Int. Conf. Exploring Services Sci.* Cham, Switzerland: Springer, 2017, pp. 12–23.
[91] N. Ul Hassan, C. Yuen, and D. Niyato, "Blockchain technologies for smart energy systems: Fundamentals, challenges, and solutions," *IEEE Ind. Electron. Mag.*, vol. 13, no. 4, pp. 106–118, Dec. 2019.
[92] T. Ali Syed, A. Alzahrani, S. Jan, M. S. Siddiqui, A. Nadeem, and T. Alghamdi, "A comparative analysis of blockchain architecture and its applications: Problems and recommendations," *IEEE Access*, vol. 7, pp. 176838–176869, 2019.
[93] C. Cachin, "Architecture of the hyperledger blockchain fabric," in *Proc. Workshop Distrib. Cryptocurrencies Consensus Ledgers*, vol. 310, 2016, p. 4.
[94] K. Z. Zamli and P. A. Lee, "Taxonomy of process modeling languages," in *Proc. ACS/IEEE Int. Conf. Comput. Syst. Appl.*, Jun. 2001, pp. 435–437.
[95] L. García-Borgñón, M. A. Barcelona, J. A. García-García, M. Alba, and M. J. Escalona, "Software process modeling languages: A systematic literature review," *Inf. Softw. Technol.*, vol. 56, no. 2, pp. 103–116, 2014.
[96] M. Alharby and A. van Moorsel, "Blockchain-based smart contracts: A systematic mapping study," 2017, *arXiv:1710.06372*. [Online]. Available: http://arxiv.org/abs/1710.06372
[97] X. Wen and G. Jianhua, "Research of Web application framework based on Spring MVC and MyBatis," *Microcomput. Appl.*, vol. 7, pp. 1–4, Jul. 2012.
[98] *Zeebe. Workflow Engine for Microservices Orchestration*. Accessed: Jun. 2020. [Online]. Available: https://zeebe.io/
[99] G. Wood, "Ethereum: A secure decentralised generalised transaction ledger," *Ethereum Project Yellow Paper*, vol. 151, pp. 1–32, Apr. 2014.
[100] M. A. Barcelona, L. García-Borgoñón, M. J. Escalona, and I. Ramos, "CBG-framework: A bottom-up model-based approach for collaborative business process management," *Comput. Ind.*, vol. 102, pp. 1–13, Nov. 2018.
[101] T. M. Fernandez-Carames and P. Fraga-Lamas, "A review on the application of blockchain to the next generation of cybersecure industry 4.0 smart factories," *IEEE Access*, vol. 7, pp. 45201–45218, 2019.
[102] K. Ikeda and M.-N. Hamid, "Applications of blockchain in the financial sector and a peer-to-peer global barter Web," *Adv. Comput.*, vol. 111, pp. 99–120, Jan. 2018.
[103] M. Holmen, "Blockchain and scholarly publishing could be best friends," *Inf. Services Use*, vol. 38, no. 3, pp. 131–140, Oct. 2018.
[104] M. Atzori, "Blockchain technology and decentralized governance: Is the state still necessary?" 2015.
[105] T. Aste, P. Tasca, and T. Di Matteo, "Blockchain technologies: The foreseeable impact on society and industry," *Computer*, vol. 50, no. 9, pp. 18–28, 2017.



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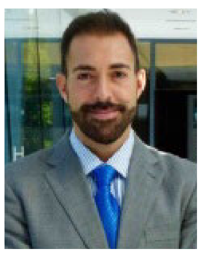

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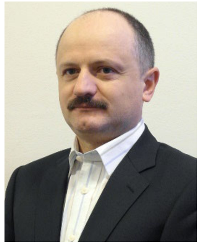

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