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Towards an integrated framework for developing blockchain systems

Mahdi Fahmideh, University of Southern Queensland, Australia
Babak Abedin, Macquarie University, Australia
Jun Shen, University of Wollongong, Australia

Abstract. Although the expanding applications of blockchain technologies have been widely explored in the IS literature, a noticeable gap exists in understanding information systems development methods (ISDMs) that facilitate the implementation of systems leveraging these technologies. A conceptual foundation that cohesively organizes an ISDM along with its facets associated with the development lifecycle for this class of systems is lacking. Applying a Design Science Research approach and borrowing ideas from method engineering, we describe a comprehensive framework for the development of blockchain systems. A series of qualitative in-depth applicability checks with domain experts and case studies lend credence to the core framework fragments. The evaluation results demonstrate the utility of the proposed framework as a conceptual anchor to simplify the understanding of the complex nature of developing blockchain systems and lead researchers to suggest future research agendas in their quests using our framework. The framework can aid practitioners in comparing or designing new ISDMs to satisfy the requirements of blockchain development.

Keywords: Information system development, blockchain, design science, method engineering

1. Introduction

Organizations are still concerned about the intricate complexities and uncertainties involved in implementing systems that leverage blockchain technology [1],[2]. For example, numerous transactions stored on Ethereum have been attacked, with high severity in multiple incidents. For instance, the DAO and Parity Wallet hacks caused a total loss of USD $150 M. Failures have extended beyond Ethereum, with USD $58,000 and USD $600 million stolen from the EOS and Axie Infinity [3] platforms, respectively, using fake tokens. To alleviate these issues, there is a long-standing acknowledgment that the adoption of information systems development methods (ISDMs), among other factors, plays a crucial role in the successful implementation and effective maintenance of systems coupled with emerging technologies [4],[5],[6]. Research and practice in the IS field have largely benefited from ISDMs as the centerpiece of quality management initiatives to build sustainable ISs in a cost-effective manner [7],[8].

Although practitioners believe that conventional system development practices can be applied to implement blockchain systems, as characterized by the phrase *old wine in new bottles* [9], opponents vehemently argue that the shift to blockchain results in unique complexities and requirements to address within the system development lifecycle [10],[11],[12]. Many aspects of blockchain systems appear to contradict the development of conventional systems. For example, blockchain platforms enable multiple individuals, organizations, and devices to execute a cross-chain business workflow concurrently in a decentralized manner, resulting in new ways of data validation, transaction integrity, and interactions. While some of these complexities are rooted in the immaturity of current blockchain platforms and the relatively nascent nature of their application domains, others are inherent to the fundamental concept of the distributed ledger architecture upon which blockchain systems are developed and run. Therefore, the development of ISs that use blockchain is considerably more complicated than that of non-blockchain systems [2],[13].

However, a theoretical framework underpinning ISDMs pertinent to this class of systems is nonexistent in the literature, and *a disciplined, organized, and mature development process is lacking* [14]. Despite its significance, mounting evidence in the literature reveals that the concept of blockchain-specific ISDMs has not been aptly sharpened as an individual unit of analysis; rather, the concept is murky at best and often combined with purely technical, narrowly scoped trial and error techniques for programming smart contracts and researcher intuitions [15].

Blockchain research is one of the most vibrant areas in the IS field, and extensive work is still required to redress the suggestion of Rossi et al. [2] that *novel theories are needed or existing theories should be revisited in light of blockchain*. The availability of an integrated blockchain-specific ISDM is critical to advance the understanding of this salient area of blockchain research [16]. As with any emerging technology in the IS field, the development of blockchain systems requires the availability of advanced tools and implementation techniques as well as a nuanced understanding of their holistic development lifecycle. The lack of a theoretical framework underpinning blockchain-specific ISDMs hinders research that aims to establish the sequence of its underlying mechanisms; that is, *analysis and engineering business processes based on blockchain* [17]. The availability of such a conceptual framework would offer a complementary viewpoint to existing knowledge in IS blockchain research and elucidate the development lifecycle of these systems.

To address this knowledge gap, the current research extends the concept of ISDMs to emerging IS research in the blockchain domain by providing an integrated framework constituting an expanded array of conventional IS development lifecycles. The framework, which is based on the concepts of *method engineering* [18] in the IS field, aims to take an wholistic view of the scattered literature on blockchain development to unify different perspectives and abstract away from technical concentration (e.g., Bitcoin scripting languages, smart contract programming models, and cryptography algorithms). The framework serves as a means of establishing a shared understanding and standardized terminology to facilitate effective communication and utilization, and to evaluate existing or new blockchain-specific ISDMs.

We illustrate the utility of our framework, which is rigorously designed and validated based on the guidelines of the Design Science Research (DSR) approach [19], through a series of qualitative interviews with selected blockchain experts and real-world scenarios of blockchain implementation in the supply chain and finance industries. Based on these findings, this study provides a useful yardstick for IS researchers and practitioners to guide the design of entirely new blockchain ISDMs and to evaluate existing ones (a.k.a., in-house) analytically, so as to identify their deficiencies in supporting blockchain system development. Among the two dominant perceptions regarding the principal outcomes of a DSR project; that is, *design artifact camp vs. design theory camp* [20], the proposed framework tends towards the *artifact school of thought* leading to the provision of *new levels of customer service and convenience* [21]. From this perspective, the contribution of our work is an instance of *exaptation* [22]; that is, the adoption of solutions from the IS field to a new problem domain, which is a conceptual shortcoming associated with ISDMs pertinent to the blockchain domain. To the best of our knowledge, this is the first study to extend the application of design science to ISDMs in the blockchain context.

The remainder of this paper is organized as follows. Section 2 discusses the guiding theories for constructing our framework, unique requirements for developing blockchain systems, and the studies most relevant to this research. Our research approach is presented in Section 3, followed by a presentation of the proposed framework in Section 4. In Section 5, we demonstrate the utility and application of our framework in analyzing real-world scenarios of blockchain system development, before discussing the theoretical and practical implications of the study in Section 6. Finally, we discuss the limitations of our work and provide concluding remarks in Section 7.

2. Background

2.1. Theoretical foundations

A search of the IS literature reveals multiple definitions of ISDM, which vary significantly in direction and detail. More recently according to Sabine et al. [4], ISDM refers to the *entire suite of system development lifecycle activities, e.g., planning, analysis, design, building, testing, and maintenance, undertaken by humans individually/collectively to create a working information system*. This definition underscores at least three core aspects, namely *development processes (means of working)*, *roles (means of controlling)*, and *modeling (means of modeling)*, underlying typical ISDM constituents (Figure 1). These aspects organize the coordination of IS teams, specifications of certain activities/tasks, sequences, necessary input/outputs, and tools for a system implementation endeavor. That is, regardless of the application domains for which they are defined, ISDMs are commonly grounded in these fundamental aspects at the macro level, although they may vary at the micro level and in domain-specific operationalizations [7]. Retrospectively, this view is consistent with the studies conceptualizing ISDMs for systems relying on emerging technologies (e.g., business analytics [23], Internet of Things (IoT) [24], and cloud computing [25]) under the same aspects. This study complements these aspects by capturing the essence of ISDMs in implementing blockchain systems. This implies that it is necessary to rethink whether ISDMs require an extension or wholesale change in the development mindset attuned to blockchain development [2],[4],[16]. It is conceivable that the forthcoming generation of ISDMs can assist IS teams in effectively implementing blockchain systems. These ISDMs would fully or partially encompass the development process, modeling techniques, and relevant roles specifically prescribed for blockchain system development.

Several approaches subsumed under the notion of *method engineering* [26],[18],[27] are available, suggesting the construction and adaptation of ISDMs as a means of achieving flexible and well-situated information system development. We borrow ideas from method engineering, through which a set of *method fragments*; that is, individual and reusable building blocks of different ISDMs [18], are assembled to create a new integrated ISDM framework. In this study, the method fragments, which are labeled under three aspects (Figure 1), are derived from research data in the literature but are iteratively refined and complemented by the opinions of domain experts and real-world blockchain project case studies.

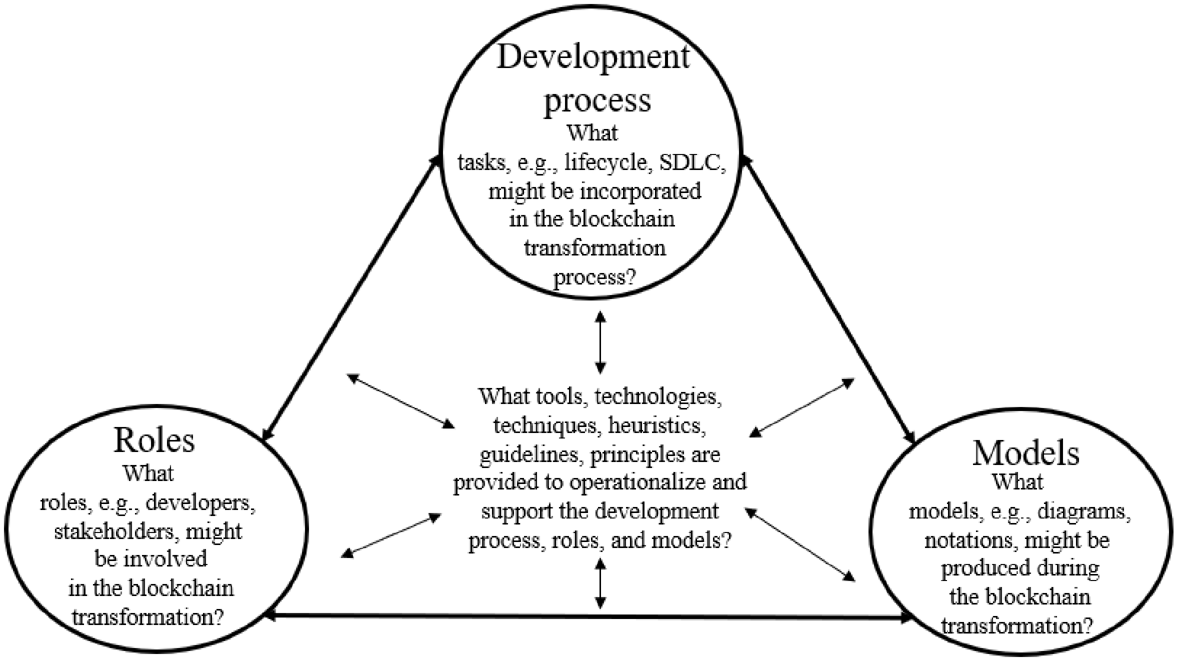

Figure 1. Core aspects of a typical ISDM used in this research, adapted from Sabine et al. [4]

2.2. Unique requirements in developing blockchain systems

Blockchain technology can be described as a distributed ledger technology (DLT), underpinned by five fundamental assumptions: decentralization, peer-to-peer (P2P) transmission, transparency with pseudonymity, irreversibility of records, and computational logic. These assumptions raise a set of essential requirements for a typical ISDM, which is applied to build blockchain systems. Drawing on the IS blockchain literature [28],[16],[29], the following requirements offer insight into the design of blockchain-specific ISDMs.

Security and privacy. Although blockchain technology holds promise for various industries, its credibility has been challenged by apprehensions regarding security and privacy. In particular, the legitimacy of public blockchains has faced scrutiny because of concerns such as smart contract vulnerabilities, consensus attacks, and privacy breaches. For example, in DLT protocols, where multiple network participant nodes execute smart contract code, the underlying logic of the smart contract becomes accessible to all entities operating these nodes. It is imperative to fortify the system against such vulnerabilities by implementing robust security measures and conducting comprehensive testing and auditing. To address these security concerns, an ISDM should incorporate method fragments guiding the selection of an appropriate blockchain type, whether permissioned or permissionless, with access restricted to authorized users only, thereby safeguarding the data and integrity of the platform.

Scalability and performance. Scalability pertains to the capacity of the system to maintain optimal performance as it undergoes expansion, such as increasing the number of network participant nodes, storage demands, and transaction response times in tandem as the network grows. Blockchain platforms often face scalability limitations, particularly in public and permissionless networks. The blockchain system performance may be degraded as the number of transactions and participant nodes increases. Hence, an ISDM must provide techniques to address scalability requirements. For example, the adoption of privately permissioned blockchains can be recommended by the ISDM because it involves a smaller number of nodes that add blocks to the chain, resulting in improved performance and scalability.

Interoperability. Systems may differ in their capabilities to exchange and utilize information effectively. Blockchain platforms may use different protocols, consensus algorithms, and data formats that may not be supported by existing infrastructure and legacy systems. Integrating different system components that run on/off blockchain platforms requires careful readiness analysis and interaction design standards to enable seamless cross-chain communication, interaction, and data transfer.

Energy consumption. Each smart contract transaction (in Ethereum, for instance) incurs a gas fee, which is determined by the computational intensity of the transaction. Higher computational requirements result in higher gas fees. The execution of the smart contract may fail if a transaction consumes an excessive amount of gas. Accurately estimating the gas consumption of a smart contract can be a complex task. Furthermore, proof-of-work consensus algorithms that are employed to validate transactions require significant computational resources and energy consumption. ISDMs should offer guidelines or techniques for designing energy-aware smart contracts and selecting appropriate consensus algorithms.

Maintenance. Once a blockchain system is in operation, challenges relating to maintainability negatively affect the ease of updating the deployed smart contract codes, such as incorporating new features, addressing flaws, and enhancing the code efficiency of smart contracts. An ISDM is expected to provide the necessary support for smart contract maintainability to enable seamless updates, flaw corrections, and code improvements throughout the smart contract lifecycle.

Programming languages. The choice of the smart contract programming language and execution platform may result in complexities in the development of blockchain systems. Not all programming languages provide built-in support for smart contract development. Some blockchain platforms (e.g., Hyperledger Fabric and Ethereum) may support only specific languages, restricting developers to a limited set of options. An ISDM may need to be tailored to align with the preferred programming paradigm of the selected platform. Thus, an ISDM focused on the development of smart contracts on Ethereum platforms may be suitable for a project using a language such as Solidity, which is a statistically typed contract-oriented programming language specifically designed for Ethereum.

2.3. Prior literature

Although ISDMs are applied frequently in the IS field, they are remarkably less prevalent in the blockchain literature. We found that the knowledge on ISDMs is spread out over the literature, where each study provides a partial view of the entire development lifecycle at different levels of abstraction, varying from a high level to purely technical. Apart from promising studies unveiling the challenges of blockchain adoption in IT-enabled organizations (e.g., [30],[31],[11],[2]), we deemed the cumulative body of literature most relevant to the current study to be organized within five interrelated streams.

The first stream of research addresses the need for governance frameworks to ensure that the development of blockchain systems in organizations is coordinated and compliant with legal regulations and ethical responsibilities. Very few studies have enhanced conventional IT governance models to oversee blockchain development projects. For example, Liu et al. [32] highlighted the lack of guidance on the governance of the decision-making process during the use and evolution of blockchain in organizations. They presented a new governance model synthesizing the six principles of the degree of decentralization, decision rights, incentives, accountability, ecosystem, and legal and ethical responsibilities. Werner et al. [33] defined a set of governance mechanisms and archetypes for blockchain adoption. The main difference between our framework and the aforementioned studies, as well as others (e.g., [34],[33],[35]), is that we narrow our focus to ISDMs as the unit of analysis and explore how they are defined to build a blockchain system. When developing a blockchain ecosystem governance is carried out as an umbrella process throughout the lifecycle of all development projects and technology adoption in organizations. Existing studies are neither sufficiently narrow nor precise in terms of the components of ISDMs in their proposed governance models. However, our framework is a complementary component to embed into these governance models to fill the gap in the development of blockchain systems.

The second stream examines blockchain adoption in different contexts but according to a specific IS theory. The work by Wenyu et al. [36] used the affordance-actualization theoretical lens to conduct a case study of blockchain implementation in a conglomerate organization and suggested a process model. The process model extended the affordance-actualization theory by adding an experimentation phase in which blockchain use cases within the organization are identified, implemented, and tested. Similarly, Wang et al. [37] used service-dominant logic and social exchange theory to explore value creation using blockchain platforms that offer solutions for supply chain partners. The results were interpreted through a series of qualitative analyses showing the benefits emanating from the blockchain by determining customer categories, their target motives, and the practices of resource exchanges. These sample studies and others such as[38],[39] remain in the phenomenological exploration of blockchain, and aspects of ISD methods, such as development process tasks, roles, and modeling, remain unexplored.

Mirroring developments in the broader literature, the third research stream, which is probably the closest to the focus of the current study, is dominated by two groups. The first group, which is mainly associated with the software engineering community, addresses the purely technical, implementation-oriented, and platform-centric challenges faced by smart contracts. In general, the central claim of these studies is the proposal of techniques and tools to help developers with automatic smart contract code generation, detecting security defects, detrimental code flaws, testing, code execution efficiency on the Ethereum, EOSIO, and Hyperledger Fabric platforms, and updating smart contract codes. Although there are merits to adopting these techniques in the implementation phase of the development lifecycle, they are largely naïve and insufficiently grounded in the concept of ISDM. In this study, we raised the abstraction level of the development lifecycle and fed these studies as data sources for the creation of our framework. In practice, the techniques proposed in this research stream can be used to operationalize the proposed framework. However, the second group of work in this research stream, which mainly originates from IS literature, either accommodates the common system development lifecycle (e.g., [40],[41],[42]) or promotes agile practices (e.g., [43]) in the development of blockchain systems. These studies do not incorporate core method fragments specialized for blockchain throughout the blockchain development lifecycle or provide a full end-to-end model for such development. For example, the method in [41] is specifically designed for implementing industrial IoT systems running on blockchain platforms.

The final stream of work covers broader literature such as Internet blogs and white papers that often do not provide rigorous domain-independent validation and generalization but propose general ideas surrounding blockchain development. The literature in this stream offers a multitude of studies (e.g.,[44],[45],[46]) driven by the intuitions of bloggers. Similarly, big IT market players such as IBM [47], Amazon [47], and Deloitte [48] provide experience reports and case studies of the successful implementation of blockchain systems. Nevertheless, the development lifecycle is either uncovered, probably because of intellectual property, privacy, and regulatory issues in publishing internal work, or somewhat narrowly bound to a specific blockchain development scenario.

Despite the proliferation of blockchain research, there is a dearth of studies that address overlapping ISDM areas, and none of the reviewed streams exclusively aims to create an integrated framework underpinning ISDMs for this context. The availability of these conceptual clues is critical. Because ISDMs span all lifecycle stages of implementing blockchain systems and are relevant to many prescriptions for business transformation to blockchain, their influence on the high-quality development of target blockchain systems is profound and overarching in nature. This study aims to address this gap; accordingly, we turn our attention to building a theory-grounded IS model to guide our inquiry.

3. Research approach

This study seeks to design and validate an integrated framework that provides a cohesive understanding of blockchain system development, thereby providing a foundation for researchers and practitioners to use the ISDM concept in the context of blockchain development. Research that focuses on creating meaningful artifacts to support system development is a type of design science in the IS field [19],[22]. Thus, we follow the guidelines of the DSR approach to create artifacts. A DSR project is stimulated by identifying a justifiable research problem, followed by defining an objective solution to solve the research problem. ISDMs that aid blockchain development are largely unnoticed and the existing material is fragmented, imprecise, and incomplete in the unbounded and continuously growing body of IS blockchain literature. A corollary of this shortcoming is that researchers and practitioners are unprepared and make ad-hoc interpretations when implementing this new class of ISs. This research ameliorates the lack of understanding of ISDM for blockchain by proposing a unified framework that captures key aspects and method fragments for incorporation into the blockchain system development lifecycle to guide IS practitioners and researchers when defining a new ISDM or evaluating and extending an existing one in support of blockchain development. Drawing on the view of Gregor and Hevner [22] that kernel theories are justificatory input for artifact creation, the concepts of method engineering are employed, wherein individual pieces of method fragments are reused and assembled from different existing sources to create an integrated framework. This framework enables the characterization of ISDMs for implementing blockchain systems from the perspective of the development process, roles, and modeling [4].

3.1. Framework artifact quality criteria and design iterations

A DSR project is administered in a series of build-validate-refine iterations, resulting in one or more artifacts. The iterations are driven by the extent to which an artifact is expected to meet certain quality criteria (i.e., design principles or meta-requirements) as its construction progresses [20]; that is, *seeking usefulness not necessarily perfect solutions* [49]. These quality criteria are used for artifact design and validation [22] and indicate the ability of an artifact to satisfy its purist goals.

The creation of our framework artifact is indeed a classificatory effort; that is, *creating a set of assumptions, concepts, values, and practices that constitutes a means of understanding the research within a body of knowledge* [50]. In this vein, we leverage the criteria set adopted from the IS literature (e.g., [51],[52]), which informs the content and structure of a classificatory artifact creation effort, such as theoretical frameworks, taxonomies, and typologies. Applying these criteria during the creation cycles of the framework artifacts is essential to ensure that the resultant framework comprises aspects that each have mutually exclusive and collectively exhaustive method fragments relevant to the blockchain system development lifecycle. The criteria in Table 1 were fed into the artifact creation iterations.

Table 1. Quality criteria revisited for the context of this research and fed into the framework design iterations [51], [52]

Criterion	Definition
Comprehensiveness	The framework has sufficient coverage of critical method fragments related to process, modeling, and roles for incorporation into the development lifecycle of blockchain systems.
Generality	The framework is abstract and independent of specific blockchain platforms, protocols, standards, implementations, and other concrete technical details.
Soundness	The framework is meaningful and has a semantic link to real-world blockchain development

Our DSR approach was sustained in three consecutive iterations of conceptualization/deduction (1st iteration) and empiricism/induction (2nd and 3rd iterations), each leading to a cumulatively built framework in line with the quality criteria (Table 1). This meant a shift of focus between research data (i.e., existing literature in the 1st iteration) and empirical data (i.e., domain experts and case studies in the 2nd and 3rd iterations, respectively). The iterations along with their underlying logic, input sources, applied analysis technique, and transitional results are outlined in Table 1, but the internal working of the iterations is delineated in sections 3.2.1–3.2.3. For simplicity, noticeable refinements to the framework after each iteration are presented in section 3.2.4.

Table 2. Framework creation iterations

Iteration	Primary purpose	Targeting quality criteria	Data source	Technique	Transitive artifact
1st	Crafting an initial framework	All, except for soundness	Blockchain literature	Systematic literature review (63 studies – Appendix A) and thematic analysis	Preliminary framework composed of 45 method fragments for 23 tasks, 7 roles, and 6 modeling
2nd	Validating, refining, and extending framework	All	Domain experts' review	12 qualitative interviews	Updated framework with 3 new method fragments under development process and role aspects, changing the structure of the framework
3rd	Validating, refining, and extending framework	All	Real-world blockchain system implementation scenarios	2 case studies	Updated framework with 3 new method fragments under the development process and modeling aspects

3.2. Creation of framework

3.2.1. 1st iteration: framework derivation from the literature

The guidelines in the systematic literature review [53] were considered as a point of departure to collate a set of commonly occurring method fragments from the literature. This iteration assumed that the literature on blockchain research is rooted in similar notions and axiomatic commonalities, although they may vary in technical and operational details, such as the choice of blockchain platforms, smart contract scripting languages, and development tools. We used secondary data in the form of studies selected from the literature along with the research streams listed in section 2.2. Secondary research data have been recognized as an important source for conceptualization and theory generation efforts [54] and have been used extensively in previous ISD studies [25], [55], [56]. The research data in the context of the current research were studies delineating either the partial or full development lifecycle of blockchain systems published in the scientific digital libraries of AIS, SCOPUS, Google Scholar, ACM, and IEEE from 2016 onwards.

Given the nascent state of ISDM for blockchain, each piece of work in the literature could provide only a partial view of specific phases or areas within the development cycle. A paper was selected from the literature to feed into the framework creation upon satisfaction of four conditions: (i) presenting a clear business problem for which the implementation of a blockchain system had been proposed as a viable solution; (ii) adopting blockchain as a core technology, rather than a subsidiary, as the focus of the system implementation; (iii) explaining an actual system implementation rather than ideation; and (iv) providing good records of system implementation in the form of an in-depth case study, interview, prototype, or simulation so that we could identify instances of method fragments.

The framework was derived based on preconceived assumptions regarding the development process, role, and modeling aspects. More precisely, the method fragments were defined by abstracting, harmonizing, and labelling text segments in the selected studies into a set of method fragments to align with the framework. If an identified method fragment was meaningfully related to one or more aspects, it was classified as such. Table 3 presents an example of research data on five exploratory case studies of blockchain adoption reported in AIS-leading journals, excluding MISQ, ISR, and ISJ, in which the blockchain development undertaken was ancillary to the purpose of our analysis. These case studies provided in-depth insights into the real-life development of blockchain systems, leading to the integration of method fragments within the overarching framework. Statistically, of 63 selected studies, 78%, 39%, and 37.5% provided method fragments related to aspects of the development process, role, and model, respectively (Appendix A).

Table 3. Excerpt of coding research data into relevant method fragments

Study	Venue	Research data	Aspect(s)	Candidate method fragment
[S28]	Wang, Lu, et al. Value creation in blockchain-driven supply chain finance, Information & Management (I&M)	"our findings indicate three distinct roles during the blockchain-enabled value creation processes: core company, supplier, financial institution," p. 5	Role	Blockchain user
		"standardized norms and protocols are required to be applied to transactions to increase the efficiency of B2B interactions," p.7	Development process (design phase)	Consensus protocol design
		"transactions in a multitier SCF scenario require higher settlement speed and adequate security guarantees," p.8	Development process (design phase)	Security design
[S47]	Du, Wenyu Derek, et al. Affordances, experimentation and actualization of FinTech: A blockchain implementation study, The Journal	"not all use cases were feasible. For example, AirSouth's headquarters intended to integrate the loyalty programs of subsidiaries, such as airlines, hotels and tourism, but subsidiaries did not want to give up their customer information," p. 11	Development process (analysis phase)	Feasibility assessment
		"The development team developed a use case, whereby small suppliers could use blockchain records to prove their solvency and secure loans from financial institutions," p. 7	Development process (analysis phase)	Requirements analysis

	of Strategic Information Systems (JSIS)			
[S58]	Vaia, Giovanni, et al. Digital governance mechanisms and principles that enable agile responses in dynamic competitive environments, European Journal of Information Systems (EJIS)	"The suppliers had the responsibility to define the specific architecture and manage all of the implementation activities at the periphery," p. 9	Model	Architecture models
		"Spunta proof-of-concept project was powered by close collaboration and coinnovation between all participants, with each playing a key role," p. 9	Development process (analysis phase)	Actor identification
		"Spunta participants reached consensus on "Corda" as the blockchain platform to underpin the project. The collaborative solution resolved mismatches through performing checks and exchanges directly within banking applications," p. 9	Development process (design phase)	Consensus protocol design
[S59]	Zhang, Wenping, et al. Beyond the block: A novel blockchain technical model for long-term care insurance, Journal of Management Information Systems (JMIS)	"we only include four prominent stakeholders in LTCI: a person applying for LTCI (denoted as applicant), a nursing home (denoted as NHO), an LTCI distributing insurance company (denoted as DIO), and an LTCI leading insurance company (denoted as LIO)," p. 15	Role	Blockchain user
		Proposed InsurModel blockchain model (Figure 1 on p. 10)	Model	Architecture models
[S14]	Chong, Alain Yee Loong, et al. Business on chain: A comparative case study of five blockchain-inspired business models, Journal of the Association for Information Systems (JAIS)	"if trading partners are on separate blockchains, transactional data are inscribed on both subchains synchronously," p. 10	Development process (design phase)	Off/on blockchain identification
		"by developing its own blockchain architecture, ChainArchitect is able to offer an open innovation platform," p. 10	Model	Architecture model
		"we designed a scenario-based task and recorded the time spent on task completion across three different technical models. This task aims to identify the source of tampering and fraud… This experiment has two players: a fraudster and a detective. The task of the fraud is to select a business node randomly, tamper with the file at this node, and send the tampered file to the subsequent node(s)," p. 16	Development process (implementation phase)	Test

3.2.2. 2nd iteration: domain expert review

To extend and refine the framework, we conducted a domain expert review [57] to obtain affirmative or dissenting qualitative feedback on how well the framework was perceived regarding the quality criteria (Table 1). The purposive selection of experienced practitioners was strictly driven by three exclusive conditions: (i) actively involved in at least one real-world blockchain (on-going) project with explicit responsibilities in a development team; (ii) formally enacted an ISDM (e.g., agile or in-house) at the macro level within which a micro-level blockchain-specific development was performed at the individual project level, as an indication of the maturity of the host organization in systematic system development; and (iii) possessed some knowledge of ISDMs. We invited 36 randomly selected experts from our industry network, of whom 13 accepted our invitations (denoted as E1–E13 in Table 4). The selected experts were from six countries and had a combined experience of over seven years in blockchain system development. Of the 11 interviewees with different roles, which allowed us to gain different perspectives on the framework artifact, two were purely technical developers of the core blockchain infrastructures. Our research project objectives, relevant terminologies, and review procedures were explained to each participant to obtain a consistent understanding of our research project goal. This included an invitation letter, a three-page document detailing the method fragments of the framework, and a set of open-ended questions associated with the quality criteria (Table 1), which was sent as an electronic document to each expert via Google Forms. Without communicating, each research participant qualitatively assessed the framework to determine its soundness and deficiencies as per the quality criterion set. Wherever required, we conducted follow-up interviews with each participant to prevent the misinterpretation of their feedback or further open-ended questions. The feedback collected from the research participants, which spanned two months, from August to

October 2022, was treated anonymously and confidentially to refine the framework, resulting in the next version.

Table 4. Details of domain experts recruited for framework review

ID	Number of review sessions	Role of expert	Adopted ISDM	Application domain	Experience	Blockchain type	Country
E1	2	Blockchain developer	Scrum	Blockchain	1 yrs	Permissioned public	Australia
E2	3	Blockchain developer	Scrum	Blockchain	1.6 yrs	Permissioned public	Switzerland
E3	4	Blockchain consultant	Scrum	Supply chain	6 yrs	Permissioned private	Australia
E4	1	Blockchain developer	Scrum/ Kanban	Digital governance	5 yrs	Permissioned private	Germany
E5	1	Blockchain developer	In-house	Finance	4 yrs	Permissioned private	Australia
E6	1	Project leader	In-house	Supply chain	1 yrs	Public	Pakistan
E8	1	Technical advisor	Lean	Energy	5 yrs	Permissioned private	United States
E9	1	Systems architect	XP	Game	2 yrs	Permissioned public	Germany
E10	2	Blockchain developer	Scrum	IT	1 yrs	Permissioned private	Canada
E11	2	Researcher	Lean	Education	3 yrs	Permissioned private	Australia
E12	1	Project leader	In-house	Finance	5 yrs	Permissioned private	Australia
E13	2	Project leader	In-house	IT	6 yrs	Permissioned public & private	Australia

3.2.3. 3rd iteration: case study application

As discussed in Section 5, the dual purpose of the case studies was to examine how capable the framework artifact is in framing blockchain system development endeavors in case organizations and to identify areas for improvements in an enacted in-house ISDM, which may positively impact the cost, on-time delivery, and quality of blockchain system development. This approach involved conducting a series of *thought trials* [58] that have been applied in previous literature to evaluate theoretical IS frameworks [51]. We selected two completed projects [55] that, in addition to the first two conditions in the 2nd iteration, had a consistent and relatively stable context and sufficient availability of documents (e.g., logs, reports, diagrams, and smart contract source codes) to strengthen the triangulation and substantiation of the method fragments of the framework. After obtaining permission from the ethics authority of our academic institute and ensuring the privacy of the project data of the organizations, we conducted a post-hoc analysis through a series of interviews with each project leader, over four months from August to December 2022, to analyze the conformance of the enacted ISDM in their organizations to the framework qualitatively. The interviewees were first provided with a full list of the method fragments of the framework, accompanied by their definitions. To determine whether the method fragments had been enacted in the in-house ISDM of the organization (e.g., Agile Scrum, XP, and relevant sprints), we asked interviewees to indicate the perceived important method fragments in their project and to provide a rationale and illustrative examples to support their answers. We investigated the adopted in-house ISDMs as the units of analysis. Among them, we examined the conformance of significant events, decisions, and actions in the project logs to the corresponding method fragments in our framework. The iteration provided an opportunity to identify missing method fragments in the framework, thereby yielding a refined framework.

3.2.4. Iterative refinements to framework and quality criteria

In relation to the DSR guidelines asking for *design as a search process* [49], ensuring the adherence of the framework to the quality criteria was related to both the conceptualization and empiricism iterations. Each iteration provided an opportunity to extend and refine the framework based on the quality criteria. The following provides exemplary evidence for applying quality criteria to the iterations of the framework creation.

To address the criterion of comprehensiveness, the snowballing technique [59] was applied in the 1st iteration, through which forward and backward searches over the selected papers were fed into the iteration as resources for identifying new method fragments. However, the framework was deficient in terms of feedback from domain experts and case studies in the 2nd and 3rd iterations. Thus, to improve its comprehensiveness, we extended the framework to two and three new method fragments associated with the process and role aspects, respectively.

For the generality criterion, the recommendation by Nickerson et al. [51] for taxonomy design was followed by noting that the conceptual models should be explanatory, not descriptive; that is, not explaining a framework in complete detail, but rather, providing useful explanations of the nature of the framework. Therefore, in the derivation of method fragments during the iterations, we were inclined to include method fragments that were sufficiently representative, agnostic to blockchain platforms, and independent of implementation techniques and tools to make them as equally applicable as possible in different contexts of blockchain system development. For example, we discarded a come-out candidate method fragment known as *analyze device mobility* (a task for blockchain IoT systems) that was identified from study 61 (Appendix A) in the 2nd iteration and *fuzzing test* (a technique to identify bugs in blockchain smart contracts written in different programming languages) as suggested by E3 in the 3rd iteration. We deemed that the inclusion of these method fragments could skew the framework towards being too specific, whereas other iterations did not necessarily recommend them out of other options.

In addition to the domain expert review in the 2nd iteration, we used a frequency-based technique as a yardstick to determine the inclusion of a candidate method fragment in the framework to satisfy the soundness criterion. The technique, with its previous application in the IS literature

[55],[25], is based on the premise that a conceptual model for a given domain should be formed based on the most commonly referred to and agreed upon elements. Hence, during the 1st iteration, candidate method fragments with a lower frequency were revisited or omitted from the framework.

4. Framework of ISDM for blockchain

The framework depicted in Figure 2 maintains a balance between being sufficiently theoretical to capture the essence of the development lifecycle for blockchain systems and being sufficiently aligned with empirical data for validation purposes. Inevitably, in such an artifact creation exercise, technical details relating to framework instantiation and operationalization will be mentioned; however, we deemphasized these details to focus on the core ISDM aspects for the development of blockchain systems.

The framework captures important method fragments that are classified according to the development process, role, and modeling aspects [4]. Within this framework, the *development process* unfolds along a set of task method fragments, although their sequences are not fixed, and they are grouped into seven phases: analysis, preliminary design, detailed design, construction, transition, maintenance, and retirement. It is worth noting that, at the macro level, the development phases in the framework are reminiscent of the conventional ISD lifecycle, e.g., the model of Avison et al. [6], yet consistent with earlier blockchain research [12],[32]. In addition, the development phases suggest new special method fragments for incorporation into the conventional ISD lifecycle or an existing in-house ISDM that suits a blockchain project, as explained further.

The analysis phase calibrates further phases by identifying organizational challenges and existing points in business workflows for which the implementation of a

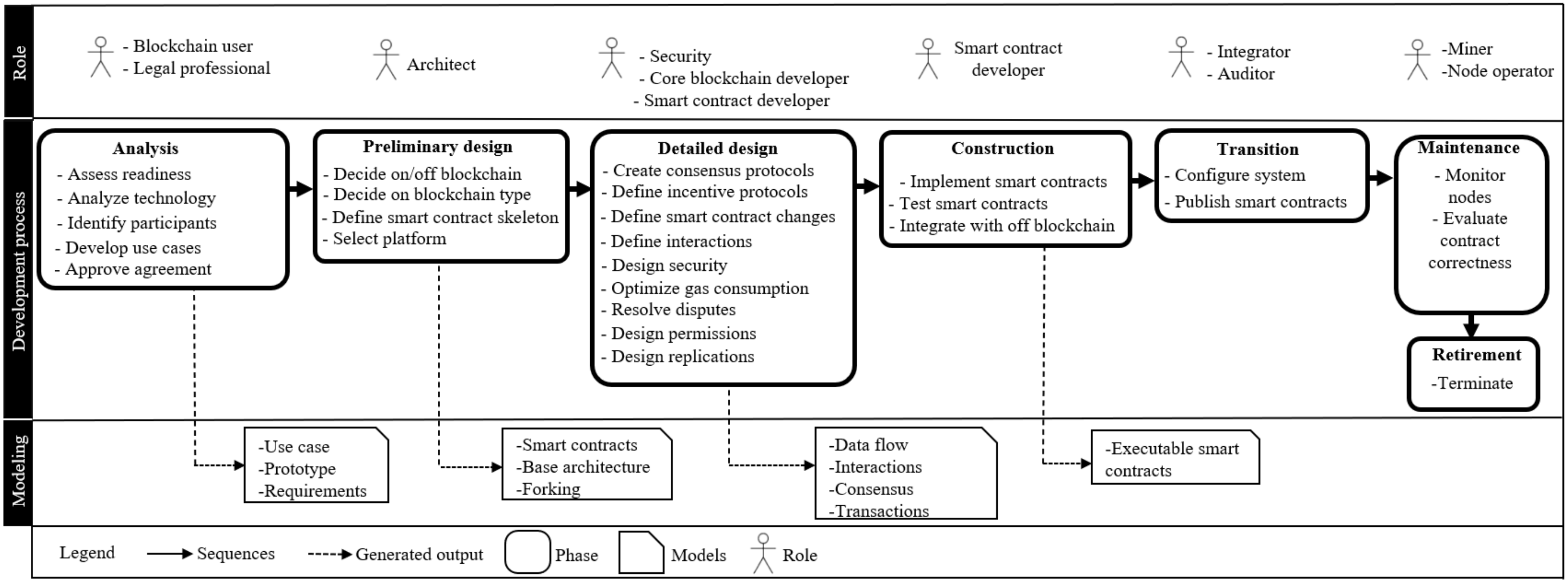

Figure 2. Framework as a backbone providing constituent method fragments classified under development process, modeling, and role aspects. Many means are available for actually applying the framework method fragments in real settings: they can be applied sequentially, in an iterative and ongoing incremental manner, or according to any other development lifecycle deemed suitable by development teams.

blockchain system is a solution. In the preliminary design phase, decisions are made regarding the mapping of blockchain use cases to candidate smart contracts. This phase includes an off/on blockchain identification task to define the overall architecture (e.g., system blueprint) of a target blockchain system, showing how business workflows and existing systems will use the blockchain smart contracts. The skeleton of smart contracts is crafted; that is, clauses of legal (textual) contracts, business transaction logic, and backend codes are transformed into smart contract codes such as Ethereum Solidity scripts that are executable on blockchain platforms. The detailed design phase is responsible for elaborating the system architecture and smart contract models (e.g., operations, parameters, and states), which, in turn, act as guidelines for the construction phase. The validated smart contracts are configured and deployed on a selected blockchain platform during the transition phase. The maintenance phase is concerned with managing postdelivery operations and supporting smart contracts to maintain their operations prior to the retirement phase, where the retirement phase is performed to move back data from on-chain to off-chain.

Furthermore, a blockchain system development endeavor can be viewed as a collaboration among human resources, actors, and other stakeholders to realize the final system [60],[61],[62]. The role aspect in the framework indicates the responsibilities assumed by IS teams that lead to effective organization of the development process and regulations. Beyond the typical system development roles (e.g., project manager/technical leader developer, developer, and data modeler), a blockchain system development endeavor entails new specific roles with different associated responsibilities, such as legal professionals, auditors, smart contract developers, and integrators, as shown in Figure 2. These roles may be combined in practice, where an individual can be a smart contract developer, miner, and integrator.

Finally, in the context of system development, it is crucial to ensure that all aspects of the system are adequately represented [63]. This includes models such as the system structure, processes, transformations, and defined solutions. In this framework, the modeling aspect, which includes diagrams, images, and pure sentential text, offers a means of understanding and obtaining knowledge of the domain of interest, and a consistent method of communication among the roles involved. Furthermore, models enable a precise representation of different components of a blockchain system; for example, tracing stakeholder requirements, starting from use cases towards actual executable smart contracts. In this vein, the role aspect characterizes a continuum of models that are created and read as the outcome of performing task method fragments under the development process aspect by the different roles. It should be noted that the modeling aspect in our framework is not a substitute for the well-known modeling practices recommended in conventional ISD; however, as shown in Figure 2, it extends to a new set of blockchain-specific modeling associated with each phase of the development lifecycle. An ISDM may accommodate multiple modeling techniques that vary from simple block diagrams to semi-formal languages, such as the Unified Modeling Language (UML) and Entity-Relationship (ER) diagram, for modeling the compositional facets of a blockchain system (e.g., smart contracts). Models may impose a costly burden in terms of update and maintenance, and are not generated in a vacuum; rather, they depend on the lifecycle focus and decisions of IS teams.

Some of the listed method fragments in the framework (Figure 2), such as *assess readiness* or *develop use cases* in the development process aspect, are general and already known in conventional ISD. We assume that they offer practical relevance to blockchain system development, as confirmed by our findings through the iterations of conceptualization (1st iteration) and empiricism (2nd and 3rd iterations).

5. Function of framework: utility application in organizations

Two qualitative case studies are presented that serve two purposes. First, they demonstrate the efficacy of the framework in characterizing real-world scenarios of blockchain system development. Second, they aim to highlight the value of the framework in analyzing the shortcomings and inadequacies of the in-house ISDMs of organizations regarding blockchain system development.

Table 5 summarizes the case studies with two development teams: (i) *Food Trust:* a large multinational IT corporation that is headquartered in the US and operates over 170 countries, and gave us access to its Australian branch, and (ii) *Token Exchanger:* a start-up blockchain service provider in Switzerland.

Table 5. Details of case studies

	Case 1: Food Trust	Case 2: Token Exchanger
Domain	Supply chain	Finance
Business problem and implemented blockchain system	In the occurrence of a food-borne disease outbreak, it can take days to identify the reason. If investigators cannot point to farms, the government advises consumers to avoid products grown in certain areas. A blockchain food traceability system could help save lives by allowing companies to act faster and protect the livelihoods of farmers by only discarding products from the affected farms. The system enabled tracking of mangoes sold in Walmart's US stores and pork sold in its China stores. For pork in China, it allowed uploading certificates of authenticity to the blockchain, resulting in more trust, and for mangoes in the US, the time needed to track the provenance of over 25 products from five different suppliers was reduced from days to seconds.	Users are often concerned by the complexity of transferring tokens over multiple blockchain platforms, for example, purchasing a non-fungible token from other users or blockchain systems in multi-chain environments. The project aimed at providing a multiple blockchain ecosystem known as Squid, i.e., a third party for interoperable business to business integration, e.g., users and systems, which simplifies token exchange (or cross-chain logic) in multiple/cross-chain blockchain environments. Squid allows the exchange of tokens between platforms. Users can integrate their systems via either Squid's APIs and smart contracts or by using Squid's front-end application.
Type	Permissioned private	Permissioned public
Project duration	Ongoing	18 months
Base ISDM	Agile scrum	Agile scrum
Team size	6–30	10
Development team composition	Project leaders, architects, promontory, blockchain advisors, blockchain developers, project manager	Community manager, architect, blockchain core developer, backend developer, user

		experience, frontend engineer, data designer, DevOps lead, business development
Team location	Australia (co-located)	Switzerland (distributed)

To help to discern the commonalities across and differences in the enacted in-house ISDMs among these case studies, Figure 3 succinctly shows exemplar method fragments that were either instantiated as evidence of their soundness in practice (blue labels) or left unaddressed in the in-house ISDM of organizations as areas for improvement (red labels). Every blockchain development project is driven by specific business problems and objectives. Therefore, each case study incorporated a subset of the method fragments of the framework into its core ISDM. For example, in the Food Trust case, the method fragments *identify participants*, *approve agreement*, *decide on/off blockchain components*, *design permissions*, and *create consensus protocols* were instantiated by the team, but in the Token Exchanger they were not (grey labels). The rationale was that, in the Token Exchanger case, the blockchain system was aimed at serving as a public service to enable interoperability and cross-chain token exchange across multiple blockchain platforms. In the same vein, some other grey labelled method fragments were not observed in either in-house ISDMs, given that either of the blockchain tools can automatically take care of their executions or are subsidiary to the project. For example, at Token Exchanger, the Axelar technology was adopted by the development team to operationalize method fragments relevant to the construction and transition phases, specifically for implementing and publishing smart contracts. The Axelar technology provided protocols, tools, and APIs that allowed core blockchain developer roles to build on blockchain platforms for interoperable token exchanges. However, in the Food Trust case, Hyperledger Fabric was used to implement, test, and deploy smart contracts.

Figure 3 is largely self-explanatory, showing the observed method fragments instantiated in each in-house ISDM in light of our framework. With respect to the development process, the task method fragments *develop use cases*, *design security*, *implement smart contracts*, *test smart contracts,* and *monitor nodes* were instantiated in both in-house ISDMs. The ISDM of neither Food Trust nor Token Exchanger necessitated the instantiation of *define smart contract skeleton* and *define smart contract change* as explicit method fragments. Regarding the role aspect, *system architect* was a major player in both projects. While it was absent in the Food Trust case, the *core blockchain developer* played an active role in the Token Exchanger case. The role involved constructing the necessary APIs, system-level protocols, and tools to allow smart contract developers to engage in cross-platform communication and construct interoperable smart contracts. In comparison, both case studies aimed to develop smart contracts for different groups of the *blockchain user* role; that is, a limited group of stakeholders in Food Trust (permissioned private) vs. a broad group of stakeholders (permission public) in the Token Exchanger. Regarding the modeling aspect, from the project data, we observed that for both development teams, the models (system) *prototype*, *base architecture*, *smart contract models*, and *data flow* were mostly upfront. For example, once the business case for blockchain technology was established, Food Trust started working on two proofs of concept for a food traceability system.

Our framework artifact aims to provide actionable recommendations for the improvement of the in-house ISDMs when the costs, resources, overheads, on-time delivery, and quality of the blockchain system development become significant. At the outset, the fact that the in-house ISDM in the Food Trust case did not provide adequate support for the method fragments *analyze technology* and *optimize gas consumption* (red labels in Figure 3.1), which were perceived as important by the development team, was a concern. This suggests improvement areas that should be prioritized when adopting an ISDM for blockchain development. For example, the interviewed project leaders highlighted that the *optimize gas consumption design* task deserves special attention during the development process when implementing smart contracts. Each transaction that is executed by a smart contract charges a certain amount of gas, which means that a higher gas fee is paid when the smart contracts are more computationally intensive.

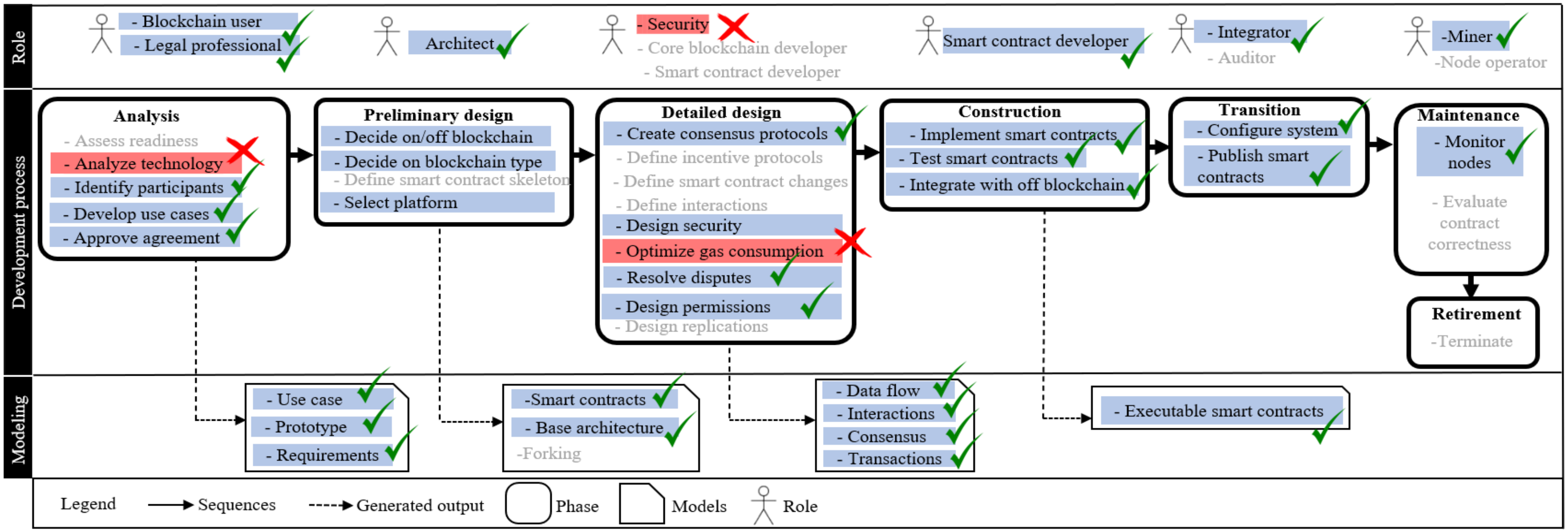

Figure 3.1. Instantiation of framework in Food Trust in-house ISDM

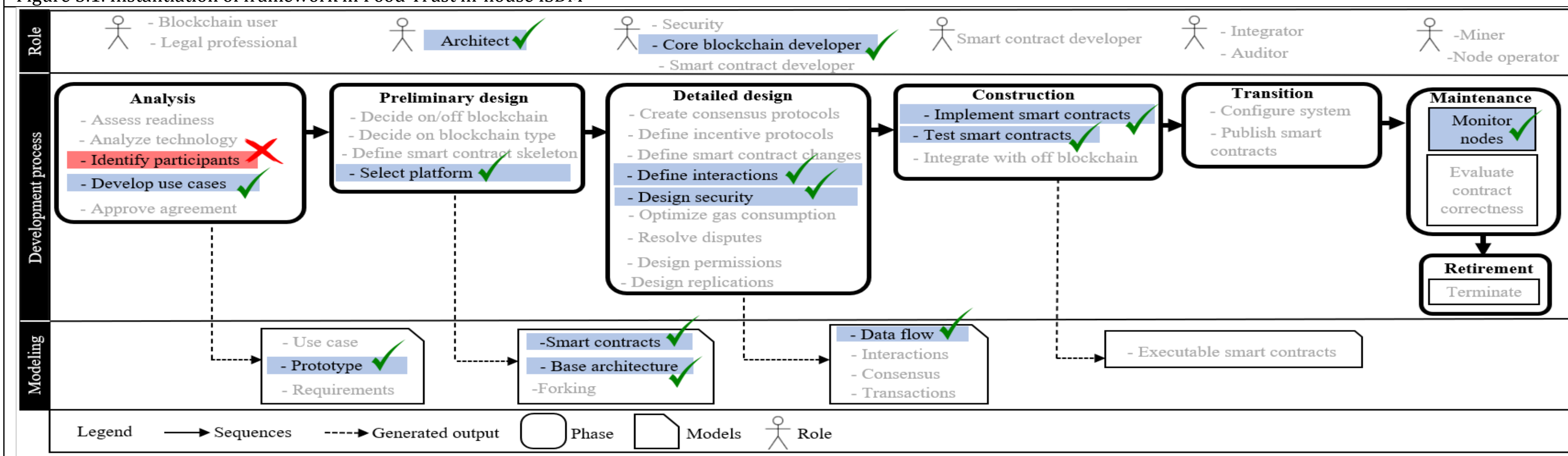

Figure 3.2 Instantiation of framework in Token Exchanger in-house ISDM

The trivial method fragments of in-house ISDMs and practices (e.g., project management, risk management, and quality assurance) are not presented to preserve the parsimony of our diagrams. Legend: Instantiated method fragment Not necessary to instantiate Unaddressed area of the in-house ISDM for improvement

A comparison of the ISDM of Food Trust with the framework highlighted that performing the comprehensive *analyze technology* task was relatively unaddressed during the development process. Notably, the same observation was made regarding the *security designer* role in Food Trust. Among the method fragments perceived as important in the Token Exchanger case, the scrum post-mortem review revealed that only *identify participants* had not been adequately supported as an explicit task in earlier scrum sprints (Figure 3.2), which indicates a lack of attention to end users of the target blockchain system at the early stage of development. This deficiency caused complexity in the coordination of the subsequent phases. Finally, another observation made upon examining both cases was the inclusion of conventional IS practices (e.g., the system prototype model in both projects) in the blockchain development, which was a confirmatory finding to [9] indicating that conventional IS can be well connected and accommodated in blockchain development endeavors.

6. Discussion

6.1. Theoretical contributions

This study is the first to directly explore the concept of ISDMs in this area and it makes three contributions. First, the proposed framework outlines the implementation of blockchain systems in a core set of method fragments associated with the three key aspects of the development process, roles, and modeling. Our study elaborates on how the method fragments underlying the ISDM structure are incorporated into a blockchain system implementation endeavor. This framework elevates the discussion from a purely technical (e.g., smart contract programming, etc.) to the managerial level. This shift allows the IS community to gain valuable insights into the entire developmental lifecycle of blockchain systems. It also creates a separation layer between defining (what) and operationalizing (how) an ISDM, thus reducing the complexity of ISDM maintenance and updates.

In addition, the proposed framework offers a solution to the knowledge integration problem in the context of blockchain, that is, the meta-method. Prior studies [63],[64],[65],[66] discussed that the availability of multiple views on ISDMs is beneficial, as they allow for pluralist interpretations at the inception of emerging information technology. On the other hand, an integrated unified view that binds these differences, which Avison and Fitzgerald [6] referred to as a *method jungle, i.e., a seemingly impenetrable maze of competing ideas*, is also required for consensus creation and standard knowledge sharing regarding domain-specific ISDMs. The same axiom holds true for ISDMs in the blockchain domain. Most existing studies (see section 2.2) provide various means of implementing systems that leverage blockchain platforms. However, they often remain overly general, limited to a specific development phase, focused solely on technical concerns, or restricted to platform choices (e.g., Ethereum, Hyperledger Fabric, and EOSIO). In contrast, our framework systematically consolidates the essence of all classes of ISDMs for the blockchain domain instead of individual instances [65], providing a *distinction between essences and accidents*. This is an important contribution as it encourages a comprehensive understanding of the range of key aspects and method fragments that can facilitate the institutionalization of integrated blockchain system development, which has not been attempted in the previous literature.

Moreover, Goldkuhl et al. [19] called for the need to design ISDMs using proper research frameworks that meet the standards in both rigor and relevance. Our framework is a first response to their call and, in the context of blockchain, it supports and guides researchers (especially novices) in the design and evaluation of ISDMs. The framework assists researchers in evaluating their newly proposed ISDMs or framing emerging ones in the literature in terms of three aspects: the development process, roles, and modeling. Therefore, our framework provides a more comprehensible theoretical foundation for organizing ISDMs for blockchain technology.

6.2. Practical contributions

Beyond its theoretical contributions, our study provides important practical contributions as well. First, to increase the likelihood of successful blockchain adoption, the framework can identify deficiencies in the in-house ISDM of an organization. More specifically, the framework provides several indications of what went wrong in the implementation of a blockchain system that failed, experienced costly security errors, and did not attain the expected goals of its stakeholders. For example, if a blockchain system is implemented but does not operate as planned, the framework can identify the aspects that have not been covered or adequately operationalized during the development lifecycle. For example, in the Token Exchanger case study, the post-mortem review of the project sprints revealed a lack of attention to the requirements analysis and identification of actual users of smart contracts before the design and implementation of smart contracts. This highlighted that the in-house ISDM had to reemphasize the feasibility and requirements analysis method fragments in further sprints. Without such a framework, organizations are left unprepared to trace the sources of system development errors and rectify them when things go wrong. Our framework unites the current body of knowledge to guide organizations that are interested in defining new ISDMs for blockchain development.

Moreover, the framework can be used as a guide to identify the required method fragments when defining a new or augmenting an existing ISDM. For example, to determine which tasks and outputs should be included in an ISDM covering the blockchain system architecture design, blockchain practitioners can take steps to incorporate relevant method fragments under the development process and modeling aspects; that is, the preliminary design phase of the framework, as suggested by the framework, into the ISDM.

Evaluation frameworks within the IS field have inspired a consistent research stream in the IS literature [67]. These frameworks help to identify the strengths and weaknesses, and facilitate the comparison and selection of appropriate ISDMs for specific projects. A long trajectory of ISDM evaluation framework variants [5],[24],[68],[69],[67],[70] with well-established constructs is available for analyzing the characteristics of ISDMs, including structured, object oriented, and agile. Neither key blockchain elements (such as smart contracts) nor essential blockchain-specific method fragments were defined in these studies. However, one may be interested in knowing when the adoption of a specific ISDM (or a combination of them) occurs in a real-world scenario of blockchain system development [71]. Without a sound evaluation, the choice of an ISDM for blockchain development may be merely assumed to work without any evidence. The proposed framework allows the ISDM selection process to occur in a consistent manner. An important caveat to note here, in conjunction with the falsifying *one-size-fits-all socio-technical blockchain characteristics* [72], is that some ISDMs may merely focus on certain features and ignore others. In this spirit, the concepts of method engineering suggest that ISDMs should be tailored to particular circumstances to obtain organizational alignment for use [73],[74]. In this regard, our framework provides a repository of method fragments that can be reused to construct bespoke ISDMs or to augment an existing one to meet the requirements of a given blockchain project.

7. Conclusions and future work

This study needs to be understood in light of some shortcomings that open avenues for future research. First, our framework can be scrutinized from the scope perspective. Although the framework provides an integrated reference to blockchain-specific ISDMs, the manner in which it can be tailored with respect to situational factors and boundary conditions related to a blockchain project scenario has yet to be addressed. Situational factors relevant to blockchain adoption have been discussed in the literature [16],[75]; however, the manner in which such factors circumscribe ISDM tailoring has not yet been investigated. Extending the framework to include supplementary customization guidance and tailoring techniques [76],[77] will enhance its applicability and ensure its relevance and effectiveness in diverse blockchain development scenarios. This will certainly be a fruitful area for future work that will aid in the situational configuration of the development process, roles, and modeling in the framework.

Second, given that blockchain technology is still in the introductory stage and adopters are concerned about its lack of technical immaturity and well-established business models [28], it was challenging to find domain experts and comprehensive case studies that could effectively demonstrate the application of our framework for an extended duration. However, we attempted to achieve an optimal sample size of interviewees and carefully selected two case studies that met certain criteria. For example, the selection of interviewees in the 2nd iteration of the framework creation (Table 4) was based on their extensive years of real-world experience in blockchain adoption, industry background, geographical representation, and diverse domain expertise to offer varying feedback on the framework quality and prevent attrition bias. However, we do not claim generalizability of our proposed framework application or that it is an exhaustive representative of all blockchain practitioner opinions and application domains. Future research can be oriented towards statistically validating the framework to reinforce and expand its application within boundary conditions.

Third, a potential issue related to our 3rd DSR iteration, which could have affected the framework artifact design and validation, is the retrospective nature of the personal interviews. As a countermeasure to alleviate the critique of recall-precision errors and post-hoc project rationalizations in retrospective responses [78], we aimed to have multiple follow-up conversations with the interviewees to avoid misunderstanding of comments or missed method fragments. For example, we shared the final version of the framework after refinement and our case analysis report with the interviewees to increase the accuracy of our data analysis. We also cross-checked our interviews with the research data from the 1st iteration to ensure that the framework was consistently refined with the interpretations of others over time.

Fourth, our framework contributes significantly to the IS blockchain literature by enriching the scientific underpinnings of ISDMs for the blockchain domain, upon which new ISDMs can be constructed, evaluated, and extended. Ideally, we can empirically apply the framework throughout the entire project lifecycle to observe its perceptual efficacy in developing blockchain systems. However, such an evaluation is impractical because of the different timeframes in the selected case studies and the time constraints of our study. We acknowledge that this is a limitation of our study and that a more prolonged and periodic longitudinal evaluation is required.

Overall, the proposed framework artifact can be viewed as a method for accumulating existing knowledge from previous literature as well as empirical findings on developing systems using blockchain platforms. The framework establishes a holistic view of the ISDM for blockchain, which has been overlooked in previous studies.

Acknowledgment

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Appendix A

List of selected studies used in 1st iteration of framework creation

Note: J: Journal, C: Conference, S: Symposium, W: Workshop, B: Book chapter, M: Magazine, V: Multi-vocal literature

#	Author and title	Channel	Source	Year	Validation technique	Relevant method fragment(s)		
						Process	Role	Model
[S1]	C. Lin, D. He, X. Huang, *BSeIn: A blockchain-based secure mutual authentication with fine-grained access control system for industry*	J	Elsevier	2018	Simulation	√	√	-
[S2]	L. Hang, D.H. Kim, *Design and implementation of an integrated IoT blockchain platform for sensing data integrity*	J	Sensors	2019	Simulation	√	-	√
[S3]	M. Marchesi, L. Marchesi, R. Tonelli, *An agile software engineering method to design blockchain applications*	C	ACM	2018	Example scenario	-	√	-
[S4]	I. Karamitsos, M. Papadaki, N.B. Al Barghuthi, *Design of the blockchain smart contract: A use case for real estate*	J	Scientific Research Publishing	2018	Example scenario	√	-	-
[S5]	M. Jurgelaitis, V. Drungilas, L. Ceponiene, R. Butkiene, E. Vaiciukynas, *Modeling principles for blockchain-based implementation of business or scientific processes*	C	IVUS	2019	Example scenario	-	√	-
[S6]	Y. Shi, Z. Lu, R. Tao, Y. Liu, Z. Zhang, *A trading model based on legal contracts using smart contract templates*	C	Springer	2019	Example scenario, Theoretical evaluation	√	-	√
[S7]	A. Badr, L. Rafferty, Q.H. Mahmoud, K. Elgazzar, P.C. Hung, *A permissioned blockchain -based system for verification of academic records*	C	IEEE	2019	Simulation	√	-	√
[S8]	G. Destefanis, M. Marchesi, M. Ortu, *Smart contracts vulnerabilities: a call for blockchain software engineering?*	W	IEEE	2018	Case study	√	-	√
[S9]	P. Chakraborty, R. Shahriyar, A. Iqbal, A. Bosu, *Understanding the software development practices of blockchain projects: a survey*	C	ACM	2018	Survey of practitioners	√	-	√
[S10]	C. Udokwu, H. Anyanka, A. Norta, *Evaluation of Approaches for Designing and Developing Decentralized Applications*	C	ACM	2020	Case study, Theoretical evaluation	√	√	√
[S11]	Y. Yuan, F.Y. Wang, *Towards blockchainbased intelligent transportation systems*	C	IEEE	2016	Example scenario	√	-	-
[S12]	W. Dai, C. Wang, C. Cui, H. Jin, X. Lv, *Blockchain-Based Smart Contract Access Control System*	C	IEEE	2019	Simulation	√	-	√
[S13]	W. Zou, D. Lo, P.S. Kochhar, X. D. Le, X. Xia, Y. Feng, Z. Chen, B. Xu, *Smart contract development: Challenges and opportunities*	J	IEEE	2019	Survey and semi-structured interview of practitioners	-	√	-
[S14]	A.Y.L. Chong, et al. *Business on chain: A comparative case study of five blockchain-inspired business models*	J	Association of IS	2019	Case study	√	-	√
[S15]	B. Marino, A. Juels, *Setting standards for altering and undoing smart contracts*	S	Springer	2016	Example scenario	-	√	√
[S16]	K. Yue, *Blockchain-augmented organizations*	C	AIS Library	2020	Example scenario	√	-	-
[S17]	L. Luu, D.-H. Chu, H. Olickel, *Making smart contracts smarter*	C	ACM	2016	Simulation	-	-	√

[S18]	R. Bettín-Díaz, A.E. Rojas, *Methodological approach to the definition of a blockchain system for the food industry supply chain traceability*	C	Springer	2018	Case study, industrial experience	√	-	-
[S19]	X. Xu, Q. Lu, Y. Liu, L. Zhu, H. Yao, A.V. Vasilakos, *Designing blockchain-based applications a case study for imported product traceability*	J	Elsevier	2019	Case study	√	-	√
[S20]	W. Cai, Z. Wang, J.B. Ernst, Z. Hong, C. Feng, V.C. Leung, *Decentralized applications: The blockchain-empowered software system*	J	IEEE	2018	Industrial experience	-	-	√
[S21]	N.B. Truong, K. Sun, G.M. Lee, Y. Guo, *GDPR-compliant personal data management: A blockchain-based solution*	J	IEEE	2019	Example scenario	√	√	-
[S22]	A. Bosu, A. Iqbal, R. Shahriyar, P. Chakraborty, *Understanding the motivations, challenges and needs of blockchain software developers: a survey*	J	Springer	2019	Survey of practitioners	√	-	√
[S23]	L. Marchesi, M. Marchesi, R. Tonelli, *ABCDE—Agile blockchain DApp engineering*	J	Elsevier	2020	Example scenario	-	-	-
[S24]	B.A. Scriber, *A framework for determining blockchain applicability*	J	IEEE	2018	Semi-structured interviews	√	√	-
[S25]	L. Cocco, A. Pinna, G. Meloni, *A Blockchain Oriented Software Application in the Revised Payments Service Directive context*	W	IEEE/ACM	2020	Example scenario	√	-	√
[S26]	X. Xu, C. Pautasso, L. Zhu, Q. Lu, I. Weber, *A pattern collection for blockchain-based applications*	C	ACM	2018	Theoretical evaluation	√	-	-
[S27]	G. Al-Mazrouai, S. Sudevan, *Managing blockchain projects with agile methodology*	C	Springer	2020	Example scenario	-	√	-
[S28]	L. Wang, et al. *Value creation in blockchain-driven supply chain finance*	J	Elsevier	2022	Case study	√	√	-
[S29]	Q. Lu, A. Tran, I. Weber, *Integrated model-driven engineering of blockchain applications for business processes and asset management*	J	Wiley	2020	Example scenario	-	-	√
[S30]	I. Weber, X. Xu, R. Riveret, G. Governatori, *Untrusted business process monitoring and execution using blockchain*	C	Springer	2016	Simulation	√	-	-
[S31]	P. Garamvölgyi, I. Kocsis, B. Gehl, A. Klenik, *Towards model-driven engineering of smart contracts for cyber-physical systems*	C	IEEE/IFIP	2018	Example scenario	√	√	-
[S32]	T. Górski, J. Bednarski, *Applying model-driven engineering to distributed ledger deployment*	J	IEEEE	2020	Example scenario	√	√	√
[S33]	F. Glaser, *Pervasive decentralization of digital infrastructures: a framework for blockchain enabled system and use case analysis*	C	IEEE	2017	Theoretical evaluation	√	√	-
[S34]	A. Mavridou, A. Laszka, E. Stachtiari, A. Dubey, *VeriSolid: Correct-by-design smart contracts for Ethereum*	C	IEEE	2019	Example scenario	√	-	√
[S35]	P. Zhang, J. White, D.C. Schmidt, G. Lenz, *Design of blockchain-based apps using familiar software patterns with a healthcare focus*	C	ACM	2017	Case study	√	-	-
[S36]	M. Wöhrer, U. Zdun, *Design patterns for smart contracts in the Ethereum ecosystem*	C	IEEE	2018	Simulation	√	√	-
[S37]	Y. Liu, Q. Lu, X. Xu, L. Zhu, H. Yao, *Applying design patterns in smart contracts*	C	Springer	2018	Case study, Industrial experience	√	√	-
[S38]	H.D. Bandara, X. Xu, I. Weber, *Patterns for blockchain data migration*	C	ACM	2020	Theoretical evaluation	√	-	√
[S39]	M. Wohrer, U. Zdun, *Smart contracts: security patterns in the Ethereum ecosystem and solidity*	W	IEEE	2018	Theoretical evaluation, Example scenario	√	-	-
[S40]	M. Bartoletti, L. Pompianu, *An empirical analysis of smart contracts: platforms, applications, and design patterns*	C	Springer	2017	Case studies	√	-	-

[S41]	J. De Kruijff, H. Weigand, *Understanding the blockchain using enterprise ontology*	C	Springer	2017	Theoretical evaluation	-	√	√
[S42]	H.M. Kim, M. Laskowski, *Toward an ontology-driven blockchain design for supply-chain provenance*	J	Wiley	2018	Example scenario	√	-	-
[S43]	O. Choudhury, N. Rudolph, I. Sylla, N. Fairoza, A. Das, *Auto-generation of smart contracts from domain-specific ontologies and semantic rules*	C	IEEE	2018	Case study	√	-	-
[S44]	H. Baqa, N.B. Truong, N. Crespi, G.M. Lee, F. Le Gall, *Semantic smart contracts for blockchain-based services in the Internet of Things*	S	IEEE	2019	Example scenario	√	√	-
[S45]	G. Governatori, F. Idelberger, Z. Milosevic, *On legal contracts, imperative and declarative smart contracts, and blockchain systems*	J	Springer	2018	Example scenario, Theoretical evaluation	√	-	-
[S46]	M. Giancaspro, *Is a smart contract 'really a smart idea? Insights from a legal perspective*	J	Elsevier	2017	Expert validation, industrial experience	-	√	√
[S47]	W.D. Du, S.L. Pan, D.E. Leidner, *Affordances, experimentation and actualization of FinTech: A blockchain implementation study*	J	Elsevier	2019	Interview	√	-	-
[S48]	A.M. Langer, *Blockchain analysis and design*	B	Springer	2020	Example scenario	-	√	√
[S49]	C. Hebert, F. Di Cerbo, *Secure blockchain in the enterprise: A methodology*	J	Elsevier	2019	Example scenario	√	√	-
[S50]	J. Plansky, T. O'Donnell, K. Richards, *A strategist's guide to blockchain*	M	PWC	2016	Industrial experience	√	-	-
[S51]	S. Almeida, A. Albuquerque, A. Silva, *An approach to develop software that uses blockchain*	C	Springer	2018	Example scenario, Theoretical evaluation	√	-	-
[S52]	G. Fridgen, J. Lockl, *A solution in search of a problem: a method for the development of blockchain use cases*	C	AIS e-Lib	2018	Case study	√	√	-
[S53]	H. Rocha, S. Ducasse, *Preliminary steps towards modeling blockchain oriented software*	W	IEEE	2018	Example scenario	√	√	-
[S54]	X. Xu, C. Pautasso, L. Zhu, V. Gramoli, A. Ponomarev, S. Chen, *The blockchain as a software connector*	W	IEEE	2016	Industrial experience	-	√	-
[S55]	X. Xu, I. Weber, M. Staples, *A taxonomy of blockchain-based systems for architecture design*	C	IEEE	2017	Theoretical evaluation	√	-	-
[S56]	A. Takyar, *Blockchain development process – A complete guide for innovators*	V	-	2022	Experience report	√	-	-
[S57]	C.K. Frantz, M. Nowostawski, *From institutions to code: Towards automated generation of smart contracts*	W	IEEE	2016	Example scenario	√	√	-
[S58]	G. Vaia, et al. *Digital governance mechanisms and principles that enable agile responses in dynamic competitive environments*	J	Elsevier	2022	Case study	√	-	√
[S59]	W. Zhang, et al. *Beyond the block: A novel blockchain-based technical model for long-term care insurance*	J	Taylor & Francis	2021	Experiment	-	√	√
[S60]	C.T.B. Garrocho, et al. *A Complete Step-by-Step Methodology for Defining, Deploying and Monitoring a Blockchain Network in Industry 4.0*	C	Springer	2021	Prototype	√	-	√
[S61]	S. Demi, M. Sánchez-Gordón, M. Kristiansen, *Blockchain for requirements traceability: A qualitative approach*	J	Wiley	2022	Interview	√	-	-
[S62]	D. Geroni, *7 Stages of New Blockchain Development Process*	V	-	2021	Experience report	√	-	-
[S63]	R. Stambolija, *Blockchain Development Lifecycle Explained*	V	-	2020	Experience report	√	-	-
		Percentage (aspect / total number of studies)				50/63	25/63	24/63

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