7-29-2023

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Received: 19 October 2022 | Revised: 3 July 2023 | Accepted: 20 July 2023

IET Blockchain

DOI: 10.1049/blc2.12038

The Institution of Engineering and Technology | WILEY

REVIEW

Towards CRISP-BC: 3TIC specification framework for Blockchain use-cases

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Funding information
Ag Research of New Zealand

Abstract

The application of Blockchain and augmented technologies such as IoT, AI, and Big Data platforms present a feasible approach for resolving the implementation challenges of trusted, decentralized platforms. This article proposes a DevOps framework for the specification of Blockchain use-cases that enables evaluation, replication, and benchmarking. Specifically, it could be applied to specify the requirements and design characteristics of Blockchain applications in terms of key attributes such as: (i) transparency; (ii) traceability; (iii) tamper-resistance; (iv) immutability; and (v) compliance. The article first introduces the design characteristics of Blockchain as a Platform and then examines successful use-cases for its implementation using the above attributes. It may be conjectured that the 3TIC framework would serve as the basis of a cross industry process for Blockchain. The intended contribution is that such a standard process will support industry-academia collaboration in the development of Blockchain platforms and services of relevance and utility as it can be applied by firms to structure their requirements and design specifications.

1 | INTRODUCTION

Blockchain-enabled platforms and services have been rolled out as promising game-changers to a range of industry applications. When augmented with technologies such as AI, IoT, and Big Data Analytics, Blockchain has been used as an open, decentralized platform that by-passes intermediaries and provides greater data sharing among transacting firms. In an executive overview, [1] suggests that the decentralized, distributed, and transparent nature of a Blockchain-enabled ecosystem provides secure and efficient sharing of transactions among actors through greater visibility and accountability in fields ranging from equitable healthcare to fair-trade apparels to safety-assured food supply [1]. However, a cautionary report by McKinsey & Co acknowledges that while billions of dollars had been sunk but hardly any use cases made technological, commercial, and strategic sense or could be delivered at scale [2]. Another estimate suggested that only about 3% of Blockchain projects are truly decentralized [3].

How can we address this gap? This article provides a framework for thinking about the requirements and design specifications of a potential application of Blockchain. Known as a use-case in the parlance of software engineering, the implementation success of such a use-case is invariably a function of the correct specifications of design attributes. Such a framework could serve as the foundation for understanding the requirements of a Blockchain application and then designing a solution using the same specification vocabulary. Much like its established counterpart in the field of Data Mining, CRISP-DM [https://www.datascience-pm.com/crisp-dm-2/], which was first proposed in 1999 by an industry consortium and now widely-adopted as the methodology of choice for data mining projects, the potential utility of a CRISP-BC framework would be that the partners of any given use-case of Blockchain would use standard terminology and implementation processes for its development and validation.

Central to the value proposition of Blockchain is the notion of trust. To quote the Editors-in-Chief of IET Blockchain in their inaugural issue: At its core, blockchain is a decentralized, immutable, public ledger that permanently records transactions between two parties without third-party authentication. This creates digital trust that opens the door to disruptive innovations in many areas including digital twin, artificial intelligence, data management, network science, and privacy-preserving [https://doi.org/10.1049/blc2.12008]. As Zhang and others [4] concluded: "As a trusted platform, Blockchain finds itself a good fit in many use cases, especially when multiple untrusted participants need to be involved." They illustrate this ideal with use-cases of Walmart and IBM in using a Hyperledger Fabric to enable the safety, transparency, and efficiency of food supply chains (FSC), involving producers, distributors, and grocers. Another example is financial institutions using Blockchain to facilitate the process of onboarding customers (with credit checks etc.) and building faster inter-bank payment systems. [4] also go on to state that "the use of the Blockchain reduces the cost of having a third party to validate all the transactions, improves the traceability and auditability of the recorded data, and thus makes the whole process more efficient." Typically, the use of Blockchains reduces the overhead of a trusted third party needed to validate all the transactions and improves the traceability and auditability of the transaction data. In yet another case, [5] discussed how IoT devices can collect data on commodities and inputs and how blockchain technology can be used for data storage, validation, and security.

Evidence scholars traditionally distinguish between two kinds of trustworthiness: (1) the reliability of a record, which refers to its truth-value as a statement of fact by a dependable observer; and (2) authenticity of a record, which refers to its truth-value as a representation of its original instantiation [6, 7]. As we will elaborate here, Blockchain and smart contracts offer both the above sources of trustworthiness provided the design of such a platform meets the requirements of several stringent characteristics.

However, Blockchain research has yet to address how design considerations should be stated in requirements as well as design specification documentation such as RFPs. This article presents a conceptual design framework with a long-term agenda for future validation through use-cases. To our knowledge, a framework for the articulation of requirements and design specifications of Blockchain applications does not exist. The remainder of this article outlines the formulation of such a framework using an inductive approach to glean design attributes from Blockchain use-cases. The next section provides a brief description of Blockchain architectures and the role of smart contracts. Section 3 introduces the 3TIC framework for the specification of Blockchain requirements and design. Section 4 is an attempt at field validation with thought experiments by inducting framework with a set of use-cases of Blockchain in industry. We conclude with a discussion of some challenges and open issues in the design of Blockchain platforms.

2 | BLOCKCHAIN AS A PLATFORM (BAAP)

At a logical layer, Blockchain architectures may be categorized as public with no access restrictions, private with strict access controls, and hybrid which may offer read access to all but write, edit and delete to members of a consortium. At a physical layer, large-scale use-cases of Blockchain solutions may be specified with five configuration parameters [1]:

1. Distributed architecture: in a public or permission-less Blockchain, the database as well as the entire history of transactions, are decentralized and accessible for each member without any centralized control of read, write, edit functions. Any member is allowed to authenticate transaction records directly. The opposite characteristics hold for private or permissioned Blockchain where members are part of a consortium with preassigned validators who authenticate transaction logs. Hybrid Blockchains fall within the two extremes.
2. Peer-to-peer transmission: members directly communicate with the Blockchain rather than using a central authority. Each member may receive and send messages to peers directly. The significance of this feature is that both ownership and control of data are decentralized.
3. Transparency and pseudonymity: all transactions and related data, are transparent and open to read access for members of the Blockchain. More specifically, each node or member uses a unique alphanumeric key as their immutable identity using encryption and hashing functions. Members may choose to be unidentified or present a proof of identification to other members
4. Immutability of records: when a transaction is added to the Blockchain and updates take place, it would not be possible to edit or delete the records. The immutability of encrypted keys containing member identities as well as prior transactions (hence the term chain). Several computational algorithms and sophisticated methods may be applied to assure the immutability of records in the Blockchain, chronologically ordered and accessible to all other members.
5. Computational logic: the digital fabric of a distributed ledger enables Blockchain transactions to be mixed with complex computations and then programmed as smart contracts. Consequently, members may implement rules and algorithms that would activate transactions among nodes automatically.

In typical Blockchain implementations, layer-1 refers to native Blockchain suite of protocols including consensus mechanisms such as PoS and PoW. Layer-2 refers to third-party integration with layer-1 including smart contracts. Hence, the core configuration of Blockchain platforms determine the required attributes to be designed and implemented. Blockchain eco-systems have evolved from decentralized consensus mechanisms (v 1.0) to programmable smart contracts (v 2.0) to peer-to-peer networking (v 3.0), and currently to AI-augmented platforms. Table 1, adopted from [8], summarizes the enablers and value drivers of each milestone of Blockchain platform design and implementation.

An important design consideration of Blockchain platforms is the choice of a consensus algorithm which enforces general agreement among participants. As per technopedia.com, since the Blockchain is a distributed ledger that records

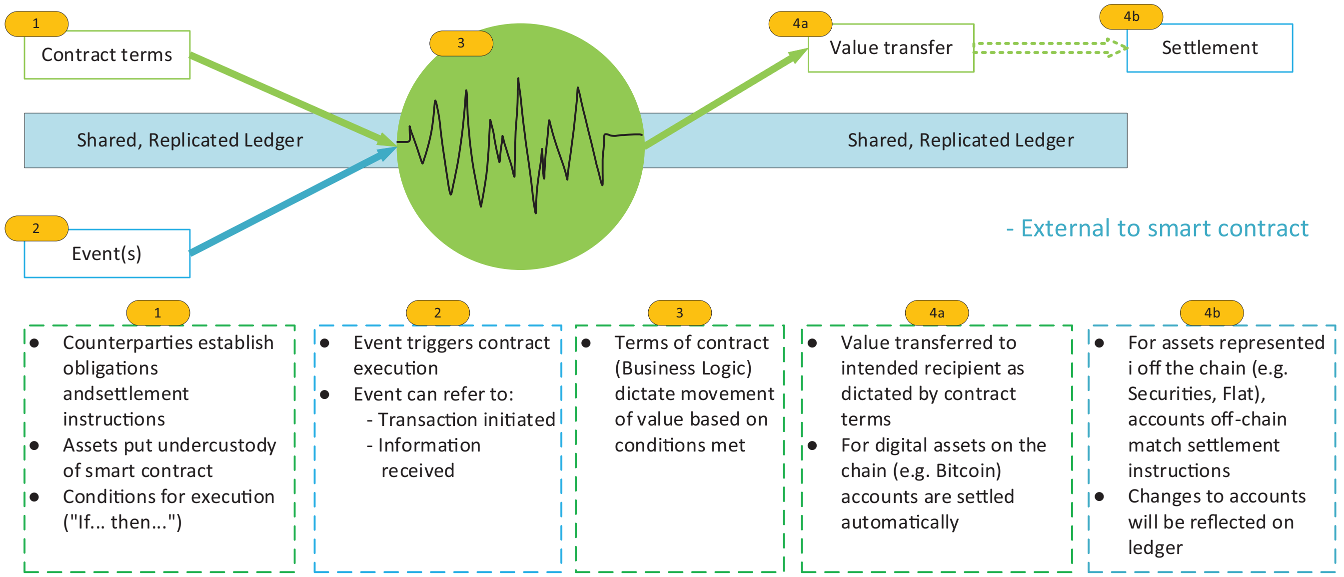

FIGURE 1 Implementing smart contract compliance.

TABLE 1 Stage model of blockchain platforms.

	Enablers	Value drivers
Blockchain 1.0	Decentralized consensus	Transaction cost reductions
Blockchain 2.0	Programmable smart contracts	Value added services
Blockchain 3.0	Decentralized, autonomous storage and computing	Organisational boundaries
Blockchain 4.0	Decentralized artificial intelligence	Autonomous decision-making

transactions and account balances, there needs to be agreement on the state of the ledger among all participants. Hence, the consensus algorithm is the process where blockchain nodes (computers validating and recording transactions) have to reach an agreement on the state of the ledger. This is crucial to a blockchain because it prevents bad actors from cheating the system and prevents malicious activities like double-spending of digital assets and Sybil attacks by incentivizing honest actors. Therefore, the establishment of a consensus mechanism is necessary in order to verify and validate rules and incentives that allow the network to agree on the state of a blockchain.

Another important aspect of the effective implementation of Blockchain use-cases is the programming of smart contracts [9] which execute automatically when certain conditions are met. Conditions such as the verification of authenticity, tampering of QR seals, or expiry of use-by timestamps. Since smart contracts are enforced by software codes, many of the interpretation-related problems of decentralized transactions are less likely to occur in Blockchain platforms. This can dramatically reduce costs associated with verification and enforcement by providing higher speed, precision, efficiency, and transparency. Figure 1 illustrates the sequence of smart contract operations that implement business logic in Blockchain use-cases.

Figure 1 illustrates the point that the design and implementation of Blockchain use-cases require the specification of business processes comprising conditions for execution, event triggers, computational logic, and compliance with settlement instructions [10, 11]. There have been a diverse number of real-world, use-cases adopting blockchain platforms. Some interesting examples in terms of novelty of specification and application are examined in the next section. Suffice to state, the research gap in the use-case and adoption of blockchain has motivated the quest for a specification framework.

In order to formulate our conceptual framework, a Design Thinking (DT) approach was adopted to examine the key attributes of blockchain platforms and how each of these may be clearly documented in requirements and design specifications. DT [12] is an iterative process that seeks to understand user requirements, challenge assumptions, and redefine problems to identify alternative strategies and specification of solutions that might not be instantly apparent with our initial level of understanding. Generally speaking, DT may be used when the phenomenon is artificially created as opposed to being created by nature. The computational scientist, Herbert Simon, referred to this as the science of the artificial. However, research using such an approach is phlegmatic with no agreement on the validity and reliability of the resulting design artefacts [13]. The art of performing effective DT is to first empathize with a problematic situation, next explore feasible approaches to resolving the problem, and as the final step experiment with the design of a minimum viable solution. Design artifacts such as requirements and design specifications documents serve an experimental purpose for prototyping a proof-of-concept. The next section presents our 3TIC framework for the requirements and design specifications using a

DT lens. Specifically, 3TIC attributes of Blockchain use-cases shall be placed in the context of the requirements specification and design specification cycles of the systems development life-cycle.

3 | SPECIFICATION OF 3TIC FRAMEWORK

There is considerable research on the implementation of Blockchain in addressing shared data applications. [14] makes the compelling argument that approaches to Blockchain formalization should address vulnerabilities relating to security and privacy of data records and transactions. Hence, adopting a DT lens for analyzing requirements and design specifications of Blockchain published use-cases enabled the discovery of the following trust-related functionalities: traceability, transparency, tamper-resistance, immutability, and compliance. For instance, recent research [4] has reported that transparency, traceability, and immutability are among the fundamental considerations of implementing trust-worthy Blockchain solutions. Thus, we have Yadav and his co-workers [15] concluding that because the Blockchain is a decentralized, immutable database, it would work well as a settlement platform in agri-food supply chains via smart contracts. Furthermore, the immutability of data in blockchain prevents forgery in paperwork and improves authenticity. Therefore, such immutability could contribute to the traceability, provenance, and certification of agri-food products. Another use-case concerned food security involving the FDA's Hazard Analysis and Critical Control Points (HACCP) system which verifies whether food products are safely handled throughout the entire cycle of growing, harvesting, procurement, manufacturing, distribution, and consumption. We postulate that the attributes collectively referred to as the 3TIC framework creates trust in a Blockchain platform by explicitly fulfilling user requirements and enabling purposeful design of the use-cases. In this section, each attribute shall be defined and supported.

In addition to [15], there have been other empirical research which confirm that transparency is an important element in evaluating Blockchain performance. Disclosing information in centralized systems is one way to achieve transparency. However, Blockchain's capabilities in data transparency are more potent than centralized systems due to the other 3TIC features. Since the main goal of a distributed database is to support information exchange, building digital pairs of the records, transactions, and workflows authenticate the quality of items as it traverses throughout the chain [16]. In the case of blocks, these objectives are achieved by way of letting each party share assertions, proofs, and assessments of others' assertions about the object of interest. The power of transparency in the Blockchain provides trusted interactions since it is not possible to modify or manipulate interactions undetected. The unique value of Blockchain platforms is that transactions are authenticated before being recorded, and once authenticated, further manipulation becomes impossible [17]. The data in a public Blockchain is universally visible and accessible whereas for a private Blockchain access control is typically enforced. In both cases, transaction data is visible to those authorized to access them, and the history of transactions is the key to providing transparency [18].

Since Blockchains record transaction history over a period of time, construct or chain the records in a straightforward manner, and detect the source of any given chain, they can handle traceability [19]. It is intuitive to apply Blockchain platforms for traceability solution because of this aspect. The same outcome could be accomplished with a centralized traceability system with event logs. Speed of response is important since dealing with critical items such as food, medicines, and emergency services require verification before consumption and proof of origin to be detected quickly.

Tamper-resistant or tamper-evident approaches are applied as a protection against counterfeiting. Tamper-evident solutions serve to disclose any irregular modification either to the labelling or the object itself [20]. As product tampering incurs heavy reputational damage to firms, there would be tangible advantages in investing in tamper-evident solutions for manufacturers and service providers. The OECD estimates that counterfeiting caused approximately $509 billion of losses in revenue globally which accounts for up to 3.3% of the total world trade [2016 figures, https://www.oecd.org/newsroom/trade-in-fake-goods-is-now-33-of-world-trade-and-rising.htm]. Blockchain assures trust-worthy through its proof-of-work functionality [21]. Hence, the public Blockchain operates as a transparent, decentralized, and tamper-evident ledger which accounts for the ownership of the value tokens. Using Blockchain, data and statements cannot be distorted or tampered with and instantly available or accessible to all parties through a reliable and distributed platform, without mediators [22]. In other words, Blockchain offers a novel mechanism for stakeholders to access and contribute to tamper-proof, historical records of transactions.

Blockchains are deemed highly immutable by providing decentralized data availability and smooth data exchange in order to decrease the possibility of manipulation and corruption [23]. This is because a Blockchain is considered a decentralized ledger which consists of a sequential set of blocks irrevocably interconnected like a chain while each block keeps a copy of the entire network activity since the time it was connected to the chain [24]. The data is generally accessible, and any member can add and update data to the Blockchain through a recognizable transaction data package. Members can always check and copy them, whereas it is extremely computationally expensive to alter it. Thus, Blockchains can be seen as immutable records of network transactions that all members may access across the distributed network.

Finally, compliance is another functionality that promotes trust. Using smart contracts, Blockchain platforms can automatically run certain secure activities according to predefined regulations [9, 11]. The quickness of the process is increased by assigning run-time executions to smart contracts and the process is allocated to individual contracts rather than the entire system. Simultaneously, the platform enables compliance by allowing the distribution of private data in a safe and protected method. Blockchain technology can hence improve regulatory compliance and also be useful for regulatory enforcement. This is achieved as Blockchain serves compliance processes and may be employed to assist compliance practitioners check essential steps for implementing complex regulations [25]. For example, using Blockchain smart contracts, financial firms may distribute their confidential data and give accessibility to financial regulatory agencies according to changes in the regulatory environment. A similar remedy may be applied to listed companies' accounting data for auditing and financial compliance statements [26].

The next section illustrates how the requirements and design phases of use-cases may be specified with the 3TIC attributes discussed above.

4 | USE-CASE SPECIFICATIONS

In this section, we adopt an inductive approach to formulating the 3TIC framework though observations and lessons from published use-cases. Specifically, inductive research involves collecting data first and then analyzing it to identify patterns and themes in the data, which can be used to develop hypotheses and theories. The main difference between inductive and deductive research approaches is their starting points and the way they develop their hypotheses or theories. Inductive research starts with data, whereas deductive research starts with a theory or hypothesis. A third approach—abductive research—begins with incomplete or insufficient data, and seeks to generate new hypotheses or explanations to fill these gaps in knowledge.

Use-Cases of Blockchain in the industry suggest that the technology is at a nascent stage and several challenges remain in order to be commonly adopted [22, 23]. In a 2018 pilot trial on FSC, Alibaba's online payment affiliate Ant Financial teamed up with the Wuchang municipality in China's Heilongjiang province to track the rice supply chain along with other partners such as Alibaba's global marketplace (Tmall). Their goal was to stop counterfeit versions of the famously expensive Wuchang rice, which is of high quality with limited production and supply. The bags of rice that were sold on the Tmall platform were affixed with tamper-resistant QR codes. Consumers could scan the code using a smartphone app before purchase. The details provided included the location where the rice was grown, seeds and fertilizers used, and information related to shipments. Before introducing Blockchain, Alibaba had launched its Blue Stars campaign in 2015. The campaign mainly focused on high-end food products and used the next generation dotless QR-codes. Participating merchants who traded on Alibaba's online marketplace could display a QR-code label with a colour-coded image to verify authenticity. Consumers could use a secure scanner developed by Visualead to scan each unique QR-code designed to self-destruct after purchase and rendered non-reusable and hence tamper-resistant.

Alibaba has scaled up from the above pilot use-cases to the cold distribution of milk to China with a leading diary producer in New Zealand and also created a paperless and unhackable Blockchain platform for the export of meat to Korea. The export of high-value honey has been tracked on a Blockchain platform in order to provide complete traceability to ensure global confidence in product authenticity, integrity, and provenance. Elsewhere, Ripe.io is an agriculture company that uses Blockchain to monitor produce along the supply chain [22, 23]. The 3TIC functionalities of Blockchain platforms that track products could also be extended to services. Some examples are, the use of forced, illegal or unfair labour practices, the monitoring of electoral fraud, the registration of living wills, and the ownership or transfer of land title deeds. In all the use-cases, Blockchain platforms engender trust and confidence in order to create value through adoption in the marketplace.

In the DT philosophy, sufficient political, economic, social, and technological support is essential for the development of Blockchain use-cases. For example, user buy-in to a design process could be technically dependent on some core Blockchain platform attributes including performance targets such as transaction volume and velocity. In parallel, the integration of strategies and processes to drive adoption at an appropriate scale are necessary. In order to aggregate some of these field practices, we mined the trade literature on the use-cases of Blockchain platforms such as the cited references in order to discover specifications for requirements as well as design. Table 2 highlights the definitions of each 3TIC attribute and how they could be used in the requirements and design specifications of Blockchain Use-Cases. In the domain of software engineering, IEEE-STD-610 defines verification as "a test of a system to prove that it meets all its specified requirements at a particular stage of its development" which help in the identification and resolution of any bugs later in the development life-cycle. The same standard defines validation as "an activity that ensures that an end product stakeholder's true needs and expectations are met" which technically, takes place upon completion of the development. Therefore, in a typical Blockchain use-case, we might expect the DevOps team to first define the requirements specifications and then proceed to do a review, walkthrough or inspection to ensure that the 3TIC requirements have been accurately understood. Then, when the design specifications are completed, the DevOps team would validate that the prototype or proof-of-concept is in fact what the stakeholders need or expect.

Using Table 2, we put the 3TIC Framework to industry use with a selection of Blockchain applications in industry [27–40] that are recent, relevant, and representative. The references were selected from a wider search of "Specification of Blockchain use-cases and adoption" with Google Scholar, Research Gate and Semantic Scholar. We do not claim that they are exhaustive but that they provide a convenience sample of non-trivial use-cases. [27] has proposed a new traceability platform based on the Algorand Blockchain to trace the supply chain of Fontina PDO cheese with minimum environmental and cost impact. This use-case has demonstrated how a Blockchain-based traceability platform may be designed to improve data exchange and transparency across consortium

TABLE 2 Requirements and design specifications of attributes.

	Transparent [15–18]	Traceable [19]	Tamper-resistant [20–22]	Immutable [23, 24]	Compliant [9, 11, 24]
Context	In the context of Blockchain use-cases, transparent means that all transactions and changes made to the data stored on the Blockchain are visible to all participants on the network. This promotes transparency and helps to build trust among the users.	Traceable refers to the ability to track the origin and history of a particular piece of data on the Blockchain. Every transaction on the Blockchain is recorded and linked to the previous one, creating a chain of blocks that can be traced back to the original entry.	Tamper-resistant means that the data stored on the Blockchain cannot be altered or deleted once added to the network. This is achieved through advanced encryption and hashing techniques, which make it virtually impossible for hackers to tamper with the data.	Immutable means that the data stored on the Blockchain is permanent and cannot be changed or removed once added to the network. This ensures that the integrity of the data is maintained and that it cannot be altered or manipulated by any party on the network.	Refers to the adherence of the Blockchain network to regulatory and legal requirements. This is particularly important in industries like finance and healthcare, where compliance with regulations is necessary to ensure the safety and security of users' data.
Requirements	Public keys and private keys to ensure that only authorized users can access certain information; implementing robust auditing and reporting mechanisms to ensure that all transactions are recorded accurately and can be traced back to their source. RWED accesses to data in Blockchain are visible to all (public, permission-less) or authorized (private, permissioned) users.	Logs and audit trails of any RWED access to data in the Blockchain. The use of protocols that track and trace supply chains should support streamlined operations and a reduction in errors.	The consensus algorithm must be designed to prohibit any unauthorized changes to data or records. This means that any new data entries or modifications to existing records must be reviewed and approved by the consensus mechanism, which typically involves a network of nodes verifying the transaction.	The Blockchain itself (data, links, etc.) is encrypted and cannot be edited nor deleted. It should have an audit trail or immutable ledger that records all changes to the blockchain, making it possible to track any malicious activity and ensure accountability.	SC will not execute any transaction that violates agreed data protection policies of the Blockchain. Typically, a smart contract can be programmed to only allow certain parties to participate in the transactions, or to automatically execute certain actions based on specific conditions being met.
Design	Creating user-friendly interfaces and tools that allow users to easily access and analyze data on the network. This can include data visualization tools, dashboards, and real-time analytics. Tools for clear demarcations of data collection, storage, and utilization stages with mechanisms for pseudonymity and RWED permissions established in smart contracts.	Protocols for traceability (e.g. GSI) may be embedded in audit trails and transaction logs. QR codes that self-destruct after they are used to handle double spending.	Tamper sensors such as RFID labels and IoT-based location tracking monitor unauthorized modifications and provide validation of identification labels. The use of cryptographic techniques such as hash functions and digital signatures to ensure the integrity and authenticity of the data at each step of the transaction.	Audit trails and data assurance procedures are regularly performed to conform to requirements (e.g. HACCP); Reporting violations and computational costs inhibit modifications and provide verification and validation.	Private or permissioned Blockchain is usually implemented with platform stringent for access, authorization, and accounting controls. Integrate the necessary compliance rules into the smart contract code, such as restrictions on the types of transactions that can be processed, exceptions reporting, or requirements for documentation and verification.

operators by making the data gathered along the Fontina PDO supply chain available in real-time. Data immutability across the supply chain is also guaranteed by the designed attribute of Blockchain.

In order to digitally transform the reverse supply chain (RSC) for asbestos waste treatment, [28] integrated and combined Blockchain and IoT. It suggests two new conceptual models for both open and close-loop digital RSCs, an important part of the sustainable, circular economy. The findings of this use-case demonstrated how effectively Blockchain has filled in gaps in data security, traceability, and reliability, while combining Blockchain and IoT may be used to create higher value in the RSC.

The influence of a Blockchain platform on the role and significance of trust in long-standing buyer-supplier relationships was investigated in [29]. This use-case examined how a Blockchain PoC affects supply chain trust using case studies of two wine supply networks. They discovered that a well-designed Blockchain platform brings about trusted data-sharing hence minimising data duplication and enhancing supply chain operations. In other agricultural use-cases, [30, 32] analysed how the formation of a Blockchain-based solution could improve traceability. Examining implementation details in two small businesses, the authors used the results to demonstrate how blockchain technology enhances data collecting and transforms how businesses exchange information and engage with stakeholders and clients, so creating a trust-worthy business environment.

To examine the potential and current challenges of blockchain applications at German OEMs, [30] combined a collective case study with in-depth interviews. The findings suggested that blockchain applications are advantageous for gathering product data, protecting transaction data, and constructing a trustworthy supply chain. In several of the above use-cases, Blockchains have shown to improve the transparency and traceability of food and agricultural supply chain networks. For instance, [31] designed and evaluated a distributed, trustless and secure architecture for FSC traceability, and presented a dairy company's food traceability case study in order to theorise how FSC process management, security, and resilience could be enhanced.

The work of [32] has described the use of blockchain in invoice processing used by Walmart Canada and its freight carrier partners. Its novel contribution was to analyze the roles of blockchain in facilitating fast, and accurate transaction processing systems at a low cost in interfirm relationship. But neither the specification nor design were benchmarked by the 3TIC attributes. IBM Blockchain's [33] explain how blockchain networks like Hyperledger can address data tampering and falsification. Organizations use the REST application programmer interface (API) to create and record transactions on the blockchain that are then validated by the other participating organizations in the network. The primary contribution is to describe features such as protocol and consensus algorithm of IBM's blockchain and benefits of private blockchain networks. But again, neither the requirements nor design can be sufficiently specified by the REST API. Even when features are specified, they are in non-standard vocabulary.

For example, [34] surveyed the applications of blockchain in genomics, from both commercial and academic perspectives. They also outlined blockchain features that underpin the adoption of such a technology in genomic applications. Seeking to also understand the factors that drive blockchain adoption, [35] undertook a multiple-case study of 19 blockchain consortia, which included interviews with 53 stakeholders. The authors identified 19 different motives that justify engagement with the technology in practice. However, as noted by several other researchers, factors such as interoperability can also hinder the broader adoption of blockchain technology and there are properties and functionalities (e.g. rewards and incentives) that should be further studied to broaden blockchain adoption in practice [36, 37].

It is noteworthy that in several use-cases in food safety and healthcare domains [38–40], Blockchain has been supported by augmented technologies which create conditions of trust and confidence. For example, Global Standard for Identification (GSI) provides a standard method for assigning unique identification numbers to products, assets, and locations. This identification system helps companies track and manage their supply chain by creating a traceable record of each item's movement from creation to consumption. The protocol covers everything from serial numbers to barcodes to RFID, enabling businesses to streamline operations, reduce errors, and improve compliance. By implementing GSI standards, companies and consortia can create a more efficient, transparent, and trustable supply chain that benefits all stakeholders.

Table 3 captures a high-level overview of the utility of the 3TIC framework in the requirements and design specifications. Taken together, the above 3TIC attributes could form an aggregation of the necessary functional descriptions of Blockchain use-cases for the verification of requirements specifications and validation of design specification. Using abductive reasoning, we posit that the specification of 3TIC attributes at the requirements stage of DevOps affords stakeholders the terminology to specify their requirements and perhaps justify why. For instance, in a Blockchain-enabled Electronic Health Records use-case, it would be necessary to specify and verify the extent to which traceability, tamper-resistance and immutability are necessary, so as to comply with a legal requirement. Using the 3TIC framework would allow the DevOps team to specify each attribute as defined in the context row of Table 2. These specifications would then lead to a greater clarity of whether the use-case design meets stakeholder needs or expectations, subject to validation. We may further conjecture that when 3TIC requirements and design specifications of use-cases are documented, and the extent to which requirements are fulfilled by design, the resulting trust and confidence in the Blockchain platform would be enhanced. This would in turn positively influence adoption intentions of users and contribute to implementation success. The concluding section of this article discusses open and unresolved challenges.

TABLE 3 Application of 3TIC framework.

	Verification of requirements	Validation of design
Transparency	[27] specified the traceability requirement of a consortium Blockchain to improve data exchange and transparency among operators for cost and environmental advantages.	[27] used a consortium Blockchain to implement traceability feature that enhanced trust among operators. Along with immutability, this led to greater fulfilment of stakeholder expectations.
Traceable	[30, 31] specify the requirements for traceability as a function of trust in FSCs. Ref. [38–40] specified the requirements for safety in the food and health contexts with unique identification.	[28] augmented Blockchain with IoT to provide traceability features in reverse supply chains. Ref. [38–40] implemented traceability requirement with GSI labels and RFID sensors.
Tamper-resistant	Ref. [32, 33] specify requirements for data tampering and falsification in the freight forwarding context for lowering costs in inter-firm transactions.	The use of REST API is conceptually mention but no details of its design specifications are available.
Immutable	Ref. [27] specified data immutability as a key requirement in the supply chain of branded cheese.	Ref. [27] efficiently implemented immutability with Algorand, which also provides traceability and transparency features.
Compliant	Ref. [34–37] specify compliance to other features such as interoperability, rewards etc as stakeholder requirements	The combination of GSI labelling and RFID monitoring has improved compliance [38–40].

5 | CHALLENGES AND OPEN ISSUES

Notwithstanding the requirements and design specifications of 3TIC functionalities in Table 2, there remain several other parameters such as speed-scalability and latency-volume benchmarks and thresholds that need to be stated as requirements and their implementation as PoCs validated for performance. No standards for interoperability across Blockchain platforms exist currently and such performance requirements also need to be validated. From a security perspective, potential design flaws should be identified. Some examples of security flaws are: open-source PoCs provide vulnerability of rootkit entry into distributed ledgers and smart contacts, cyber-threats such as malicious attacks may occur, and even innocuous web-scraping which intrude on member privacy. Secure implementation mechanisms such as strong encryption, off-chaining personally identifiable information (PII) may be provisioned for private, permissioned Blockchains.

In several use-cases of Blockchain, altruism alone did not provide a sufficient incentive model to share data, algorithms, and contribute to network effects. Consequently, incenting responsible, peer-to-peer interactions may also require specification. Finally, on the question of computational sustainability, calculations of PWC's Blockchain specialist Alex de Vries suggests that a single bitcoin transaction consumes an equivalent amount of energy as 780,650 Visa transactions or 52,043 h of viewing YouTube [41], or the power consumption of a mid-sized town [https://widgets.weforum.org/blockchain-toolkit/summary/index.html]. This is obviously not justifiable in the emerging era of climate change and carbon controls. It is for this reason that Delegated Proof of Stake (DPoS) emerged as a workaround to consensus mechanisms such as energy-inefficient PoW and PoS which are inherently vulnerable to malicious intentions of stakeholders. A clear specification of off chain partitioning and their associated RWED permissions may be a solution for secure and sustainable Blockchains.

Following from the above, we suggest several potentially fruitful avenues for future research. Using a holistic PEST world view, researchers could consider Blockchain platforms from a cost-benefit angle by benchmarking such systems with non-Blockchain alternatives. Some examples of costs include direct costs associated with implementing Blockchain applications as well as costs associated with potential security and privacy breaches. Estimates suggest that the costs to enter and store data in Blockchain systems are significantly less than those associated with cloud services such as AWS [42]. These would constitute tangible cost savings. It would be important to look at non-economic costs and benefits such as the perceived value of privacy in not sharing full transaction records within digital health eco-systems and psychological benefits associated with users' confidence in the security and privacy afforded by Blockchain applications. The design of dashboards, benchmarking and prescriptive analytics over Blockchain platforms are also worthy of research.

Harmonizing Blockchain solutions and their inherent immutability with the European Union's GDPR and particularly, the right to be forgotten is another open challenge that remains to be resolved. Hybrid blockchains that allow Edit and Delete operations by elected validators have been suggested but there is as yet no demonstrable PoC. It is therefore timely for industry and researchers to work towards a CRISP-BC specification that standardizes 3TIC functionalities and specifies performance requirements and design validation of their capabilities. For example, IBM Food Trust is an example of a cross-industry platform that utilizes Blockchain functionalities for effective inter-operability [https://www.ibm.com/se-en/Blockchain/solutions/food-trust]. As was the case with CRISP-DM, which was quickly adopted and is today the most utilized approach to implementing data mining solutions; an industry-academe partnership in a standard process for requirements and design for Blockchain will fulfil a gap. We may conjecture that such specifications would bring clarity to the value and benefits of Blockchain use-cases [43].

The performance specification of Blockchain technology remains another unaddressed gap. Recent research [36] has concluded that since no blockchain testbed supports the execution and benchmarking of different consensus protocols in a unified testing environment, it is necessary to develop and validate such a blockchain testbed that supports the execution of five state-of-the-art consensus protocols—PoW, PoS, PoET, PBFT, Round-Robin, and Clique. Using real data from an audit system (that could similarly track 3TIC attributes), [44] validated the claim that the Clique protocol was best for audits in terms of scalability features.

In the final analysis, the value and competitive advantage that a Blockchain platform brings to an enterprise is all about trust. [45] practically demonstrated how resource allocation (of budgets and people, for example) by a firm may be optimized by first understanding the needs and requirements of a Blockchain application. And then designing a trustworthy solution that is fit-for-purpose and scales accordingly. As a co-inventor of Ethereum,—Vitalik Butanerin—conceded at the onset: The main advantage of Blockchain technology is supposed to be that it's more secure, but new technologies are generally hard for people to trust [4]. More use-cases bring about greater familiarity with nacent technologies. The 3TIC framework proposed here and the system requirements and design specifications of Blockchain platforms is a step to address any nascent technology trust deficit by providing definitional clarity on how needs may be best met.

AUTHOR CONTRIBUTIONS

Pouyan Jahanbin: Conceptualization; Formal analysis; Methodology; Project administration; Writing—original draft; Writing—review and editing. Ravi S. Sharma: Conceptualization; Investigation; Methodology; Supervision; Writing—original draft; Writing—review and editing. Stephen T. Wingreen: Conceptualization; Formal analysis; Investigation; Methodology; Supervision; Validation; Writing—review and editing. Nir Kshetri: Formal analysis; Investigation; Methodology; Validation; Writing—review and editing. Raymond Choo: Investigation; Methodology; Validation; Writing—review and editing.

ACKNOWLEDGEMENTS

The conceptual framework discussed in this technology brief was developed at a CeIDE Colloquium with Ph.D. candidates of IS at the University of Canterbury Business School. Adil Bilal, Jitendra Hushare, Shriniket Patil, Amit Sarkar, Ravi Sharma, Steve Wingreen and Arnob Zahid participated in that session led by Pouyan Jahanbin. Steve and Ravi supervised the research as part of Pouyan's doctoral research. Many thanks are also due to AgResearch, a Crown Research Institute in New Zealand, for supporting part of this work. Software tools used in the preparation of this manuscript include MS Office, Grammarly, EndNote, Google Scholar, Nvivo, and ChatGPT. The authors gratefully thank the anonymous reviewers, AE and EiC for their careful reading of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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How to cite this article: Jahanbin, P., Sharma, R.S., Wingreen, S.T., Kshetri, N., Choo, K.-K.R.: Towards CRISP-BC: 3TIC specification framework for Blockchain use-cases. IET Blockchain 1–10 (2023). https://doi.org/10.1049/blc2.12038