# Blockchain technology for projects: a multi-criteria decision matrix

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## Abstract

This research aims to develop a multi-criteria decision matrix (MCDM) for project management (PM) professionals, which will support blockchain type selection, evaluate blockchain platforms, and plan blockchain systems. The MCDM is substantiated through a case study that includes a questionnaire and an illustrative example pertinent to the construction industry. It is discovered that in this study, consortium blockchain is superior in dealing with the characteristics of projects, and Hyperledger Fabric is chosen as the best applicable platform. In planning a blockchain-based PM system, PM professionals should consider user requirements such as network participants, principal transactions, communication channels, and smart contracts.

**Keywords:** Blockchain; Project; Multi-criteria decision-making; Decision matrix; Construction

## Introduction

Blockchain first emerged as a cryptocurrency transaction ledger and has now found applications in other spheres, including intellectual property and digital identity management (Perera et al., 2020), philanthropy (Lamba et al., 2019), democracy and governance (Diallo et al ., 2018), agriculture (Yang et al., 2020), health (Griggs et al., 2018), logistics and supply chain management (Kaijun et al., 2018), built environment provision (Mukne et al., 2019), education and human rights (Turkanović et al., 2018), energy and environment (Pop et al., 2018), and finance (Chen et al., 2017). A blockchain is a list of blocks, and each block contains a block header and a set of transactions (Hyperledger, 2020). Xue and Lu (2020) identify three essential components of blockchain technology, sometimes also simply called blockchain: cryptographic algorithms, distributed databases, and consensus mechanisms. Together, these components allow important transaction data to be collected, agreed upon, and distributed with minimal risk of alteration or tampering. Its widely propagated benefits, therefore, include enhanced security, improved traceability, increased efficiency, and reduced costs (Penzes et al., 2018).

Researchers and practitioners in the project world are also exploring this disruptive technology. They are encountering its different types, often inconsistently named but distinguished by privileges such as access rights, querying transactions, and submitting transactions to the ledger. Perera et al. (2020), for instance, propose three types of blockchain: (1) public, (2) private, and (3) consortium, and note different blockchain platforms, both commercial and open source. Projects may also be perceived in differing ways in the literature. A project may be viewed as a temporary organization (Turner & Müller, 2003), a unique setting beyond the dichotomous view of markets and hierarchies (Powell, 1990), an intrafirm endeavor or an interfirm coalition (Winch, 1989), or a network of stakeholders and their interactions (Lu et al., 2020). Projects emerged because people noticed that work related to film making, media production, construction, information and technology, and research and development (R&D), for example, can be better delivered if organized in such a way. In the case of blockchain selection, however, the uniqueness, temporariness, uncertainty, discontinuity, and one-off nature of projects present challenges. Unlike banking transactions, project transactions happen infrequently amongst limited parties. In addition, some transaction information is urged to be shared among project team members, while other information is strictly treated as a commercial secret.

Recent studies have compared blockchains but few, if any, have provided a holistic method for their selection in a project setting. This research aims to develop a decision-support tool for project management (PM) professionals, helping them to select proper blockchain to enhance project value delivery. The rest of the paper is organized as follows. Next section is a literature review introducing blockchain. The following section reviews projects and their salient features in the context of blockchain. The subsequent section introduces our research methods. After that, the decision matrix is presented and substantiated using a case study. Finally, the discussion and conclusions are presented.

## Blockchain

### *Blockchain basics*

As introduced briefly above, blockchain combines cryptography, distributed databases, and consensus mechanisms (Xue and Lu, 2020). Cryptography has one main sub-component: hash algorithm, which ensures the immutability of the recorded transaction information (e.g., transaction personnel, time, location). Due to its emphasis on the security, blockchain is an excellent fit in institutional economics as economic infrastructure (Allen et al., 2018). Transaction records are connected as blocks in sequence, starting with the genesis block (Figure 1). Hashing sequentially interconnected blocks means that transaction data (e.g., $Tx_0$ to $Tx_n$) is used as input to a hash function that converts the data into a fixed length string (Xue & Lu, 2020). The resulting hash value is unique for each input, so if someone changes transaction data, the corresponding hash value will also change immediately. Each block also contains the previous block hash, ensuring that it cannot be changed without also changing the previous block (Li et al., 2021).

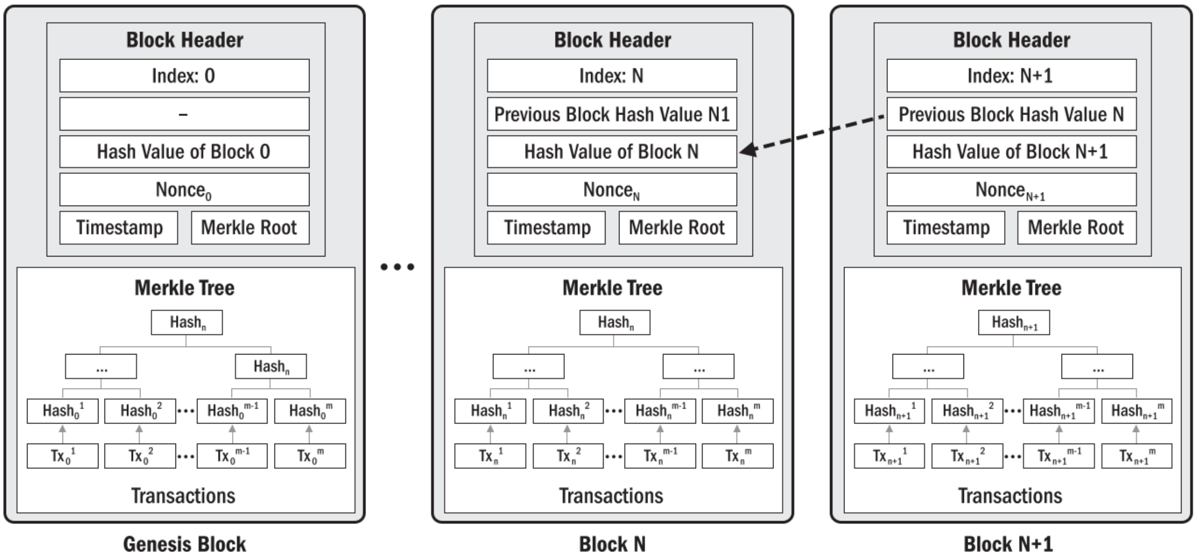



**Figure 1. A blockchain (Adapted from Li et al., 2021)**

The distributed database of the blockchain, mainly composed of ledgers, is achieved through a decentralized network. A ledger is an accounting technique used to record when anything of value is transacted (Taghizadeh-Hesary & Yoshino, 2019). Peer nodes are network entities that maintain a copy of the ledger and/or run smart contracts to perform query/write operations on the ledger (Hyperledger, 2020). A smart contract is a program stored in a blockchain system wherein the outcome of any self-execution of the program is recorded on the distributed ledger (ISO, 2020). All nodes are related to each other in a planar rather than hierarchical, centralized topology, and this protects the network from a single point of failure.

Consensus is a protocol for verifying the facts on the fundamental datum of an economy: of identity, property, contract, and value, and regularly recording time (Davidson et al., 2018). There are many consensus algorithms. The most common one is proof of work (PoW), which is used to confirm transactions then initiate new blocks to the chain. A relatively energy-saving mechanism to save computing/mining power, proof of stake (PoS) assumes that participants with a greater stake (e.g., coins) display less opportunistic behavior, so have more opportunities to verify blocks. Stakeholders may also elect delegates to validate blocks, a method called delegated proof of stake (DPoS). Hyperledger Fabric 2.0 uses practical Byzantine fault tolerance (PBFT), a low-energy mechanism that requires three rounds of voting (Hyperledger, 2020). Other consensus algorithms are proof of authority (PoA) (Kaur & Oza, 2020), proof of authentication (PoAh) (Puthal et al., 2020), proof of conformance (PoC) (Zhang & Lin, 2018), Kafka consensus (Mukne et al., 2019), and AlgoRand consensus (Zhang & Wang, 2019), while customized consensuses have also been observed (e.g., Kim & Yu, 2018).

Blockchain has a set of unique terminologies. In the case of PM professionals, these are unnecessarily accessible. Therefore, Xue and Lu (2020) have proposed a two-sided strategy, leaving the system R&D in the lower layers to blockchain professionals such as computer scientists, and the applications in the upper layers to users to solve their domain problems. PMs should nonetheless be involved in defining their requirements and in blockchain selection.

***Available blockchain options***

Various blockchain taxonomies can be found in the literature. Perera et al. (2020) summarizes popular platforms into public, private, and consortium categories (see Table 1). Public blockchain is accessible to the public for use. It is a system wherein control is distributed among the persons or organizations participating in the operation of the system. Therefore, it provides transparency and auditability, and it is difficult for hackers to manipulate data across the decentralized network (ISO, 2020). The consensus mechanism is driven by financial incentives, motivating all to improve the network. It is much work for block validators to verify transactions every day. As compensation for their efforts, after validators approve and add a new block of transactions to the blockchain, they will receive coins (e.g., Bitcoins). However, the security-oriented method may compromise privacy, scalability, and transaction efficiency (She et al., 2019).

Private blockchain has just one owner organization, and only pre-authorized participants can perform particular activities (ISO, 2020). Due to its restrictive nature, it tends to have better privacy, scalability, and efficiency than the public blockchain (Lee et al., 2019). In addition, because the consensus is based on permissions, operating costs can be lower (Halloush et al., 2019). However, the controlled environment may reduce transparency, auditability, and resistance to hackers (Penzes et al., 2018).

Consortium blockchain operates under a selected set of nodes (She et al., 2019). It shares many advantages with private blockchain including access control, privacy, efficiency, and scalability. A subset of organizations can have dedicated communication channels and private data, or in some cases, all participants can have transparent information (Hyperledger, 2020). Consortium blockchain reduces the counterparty risk of private blockchain because it has more than one organization to manage the network but provides no incentive for parties to participate in the network. It provides customizability through governance structures. However, establishing well-defined regulatory rules and censorship systems may be difficult.

Some studies categorize blockchain as permissioned or permissionless, based on whether the blockchain has access control to ledgers. Users are pre-authorized to participate in a permissioned blockchain. Private and consortium blockchains are permissioned (Perera et al., 2020), while public blockchain is permissionless.

**Table 1. Snapshot of popular blockchain platforms**

| Blockchain platforms | Type | Permission type | Year of implementation | Governance | Focus domain | Smart contract | Source model |
|---|---|---|---|---|---|---|---|
| Bitcoin | Public | Permissionless | 2009 | Bitcoin developers | Cryptocurrency | No | Open source |
| Ethereum | Public | Permissionless | 2015 | Ethereum developers | Cross-industry | Yes | Open source |
| EOS.IO | Public | Permissionless | 2018 | EOS.IO core arbitration forum | Cross-industry | Yes | Open source |
| NEO | Private | Permissioned | 2016 | NEO holders & NEO foundation | Smart Economy | Yes | Open source |
| Hyperledger Sawtooth | Private | Permissioned | 2018 | Linux foundation | Cross-industry | Yes | Open source |
| R3 Corda | Consortium | Permissioned | 2016 | Hedera hashgraph council | Cross-industry | Yes | Commercial & Open source |
| Ark | Consortium | Permissioned | 2017 | Ark developers | Cross-industry | Yes | Open source |
| Hyperledger Fabric | Private/ Consortium | Permissioned | 2016 | Linux foundation | Cross-industry | Yes | Open source |

Note: Compiled from Turkanović et al. (2018), LeewayHertz (2019), Ark (2019), Hyperledger (2020), Perera et al. (2020)

**Projects**

Perceptions of projects vary. The Project Management Institute (2000) considers a project to have a production function and sees it as a temporary endeavor. Turner and Müller (2003) add that it is an agency that manages uncertainty and assigns resources. Winch (1989) differentiates projects as an intrafirm endeavor or interfirm coalition. Following the central tenet of Allen (1984) that production organizations, projects are not only technical systems but also social systems of personal and group interactions. Wang et al. (2018b) and Lu et al. (2020) view the project as a social network, using Engwall's (2003) proposition that "no project is an island" to emphasize projects' social embeddedness. DeFillippi and Sydow (2016) and Sydow et al. (2016) perceive projects as networks at two different levels. From a PM perspective, the network is a single interorganizational project consisting of temporal and internal relationships facilitating its coordination and ensuring its foreseeable delivery. From a business perspective, the network is a series of projects that are interrelated through interorganizational relationships. In this study, we focus on the former.

A project has several key characteristics differentiating it from "business as usual" or production. Firstly, it has a unique purpose to do things that have not been done previously (Smyth, 2018). Secondly, a project is temporary, involving a project team and broader coalition temporarily coming together (Turner & Müller, 2003). Thirdly, it involves uncertainties since it creates change in a changing environment (Lu et al., 2020). In the early stages of project in particular, it is difficult to define the objectives, determine the required funds, and evaluate the completion time. Fourthly, a project is one-off, with a definite start and end (Wright & Kersner, 2004). Finally, a project suffers discontinuity (Smyth, 2018). Project members are often established and dispersed, and human resources allocated to them change constantly.

These characteristics pose considerable challenges for blockchain selection. Project uniqueness requires customization of each blockchain solution according to scope of use and degree of network centralization. The temporariness and one-off nature of projects imply that the cost of blockchain should not be high and appropriately distributed to the project members. Uncertainties subject a project to opportunistic behavior, so project-oriented blockchain solutions must enhance auditability, build trust and improve transparency and traceability. Discontinuity may lead to file tampering and loss and resource changes, so blockchain solutions must protect privacy and security of documents. Finally, blockchain should remain scalable so that it can continue to be used as the project progresses. These challenges imply that the project, as a special organizational form, should have a preference for a specific type of blockchain. To the best of our knowledge, no previous study has consciously considered which blockchain is preferential in a project setting with its various characteristics.

## Research methods

To develop a blockchain decision-support tool for PM professionals, this research adopts a methodology comprising literature review, decision matrix method (DMM), and case study. The critical literature review was to collect criteria for selecting type of blockchain, blockchain platform, and planning a blockchain system in various industries or settings. We searched Google Scholar using the keywords "public blockchain", "private blockchain", "consortium blockchain", and "block chain". The search initially produced 1570 hits including journal and conference papers, books, dissertations, and reports. The titles and abstracts were screened for suitability. The hits that do not have a specific application but a general review was excluded. The full texts of 214 papers passing the primary screening were then downloaded and furthered refined by the authors based on criterion: providing the necessary descriptive information including year of publication, type of blockchain and platform used, and whether a smart contract was used. A total of 41 publications were finally collected for analysis. The number of hits seems somewhat small in light of broad promotion of blockchain in various industries. However, the selected papers, together with the 214 papers searched, forms an instrumental information foundation from which useful findings can be derived.

Based on the literature review, a multi-criteria decision matrix (MCDM) was developed through DMM: a method enabling decision makers to identify various factors and analyze the relationships between them (Salmeron & Smarandache, 2008). Firstly, the collected criteria were divided into three categories: type of blockchain-related (Organization criteria); platform-related (Performance criteria); and system-related (Application criteria). Then, categorized criteria further refined through consensus in focus group meetings. The refinement process was repeated to fine-tune the MCDM because some criteria were feasible but not the most advantageous. Besides, Organization criteria were linked to project characteristics to ensure blockchain suitability from the beginning. The resulting MCDM was proposed and graphed.

The resulting MCDM is based on the literature and examples in non-project settings. Ideally it should be substantiated by real-life PM practices, but these proved difficult to find as blockchain is quite new in projects. Therefore, we designed a semi-hypothetical study contextualized in the construction industry where projects have been adopted as the norm across a wide range of activities. By "semi-hypothetical", we mean that our cases are generalized from recurring construction industry phenomena. The scenario is to use blockchain to improve the document endorsement process, one of the most onerous processes in contemporary construction PM, and to use smart contracts to streamline the process automatically and logically.

The case study is divided into three stages. Table 2 lists these stages and the aim, substantiation method and expected outcome of each. Through a 3-part questionnaire and an illustrative example, three criteria dimensions of the MCDM, namely Organization, Performance, and Application were substantiated. Part 0 of the questionnaire gathered the demographic characteristics of the respondents and their firms. In Stage I/Part I of the questionnaire, assuming a construction project client planned to build a blockchain infrastructure. The overarching aim is to use blockchain to enhance the security and traceability of the document endorsement process. The blockchain solution should maintain scalability for different applications (client may use it for multiple projects) and protect user privacy. Thus, respondents were asked questions pertinent to MCDM Organization criteria. It was assumed that respondents familiar with document endorsement in a project setting would have sufficient knowledge to help prospective users select Organization criteria to determine choice of blockchain type. In Stage II/Part II of the questionnaire, questions related to the Performance criteria of the MCDM were asked to substantiate that these criteria could help clients understand which blockchain platform is preferred by project teams.

We coded the questions in an online survey platform called “Questionnaire Star” (https://www.wjx.cn). A pilot questionnaire was conducted before the full-scale questionnaire. In this study, the target population was clients, contractors, designers, consultants, and researchers serving China’s construction industry. Drawing on the authors’ contacts, the questionnaires were distributed in early August 2020 and recipients invited to respond by mid-August.

**Table 2. Semi-hypothetical case study stages**

| Stage | Aim | Substantiation method | Expected outcome |
|---|---|---|---|
| Start | To gather demographic characteristics of the respondents and their firms | Questionnaire (Part 0): 8 multiple-choice questions | The information is collected |
| I | To substantiate the Organization criteria of the MCDM | Questionnaire (Part I): each Organization criterion in the MCDM constitutes a multiple-choice question (8 in total). The public, private and consortium blockchain information in Figure 3 corresponding to each Organization criterion constitutes the three options for each question. Respondents were asked to select the most suitable option for each question. The type of blockchain that “wins” is determined by summing the selected options. In this study, it is assumed that the weighting of each Organization criterion is equal. | The type of blockchain with the most selected options is adopted |

| | | | |
|---|---|---|---|
| II | To substantiate the Performance criteria of the MCDM | Questionnaire (Part II): each type of blockchain has three alternative platforms in Figure 4 (Hyperledger Fabric is used as both a private and a consortium blockchain platform). Each Performance criterion in MCDM constitutes a multiple-choice question (6 in total), and platform information under each Performance criterion in Figure 4 constitutes options. Respondents evaluated the platforms under the selected type of blockchain by choosing the most suitable option for each question. The final platform is chosen by adding preferences. In this study, it is considered that the weighting of each Performance criterion is equal. | The blockchain platform with the most selected options is adopted |
| III | To substantiate the Application criteria of the MCDM | Completing the tasks corresponding to each Application criteria with information collected from commercial publications | A blockchain prototype system is produced |

Of the questionnaires distributed, we received 110 responses, but some were abandoned due to incompleteness. Finally, 85 were output, edited, and analyzed in Excel spreadsheets. Regarding demographic characteristics, 85% of respondents held a bachelor’s degree or above. About 54% had 1–5 years’ experience in the construction industry, 29% had 6-10 years’ experience, and 17% had more than 10 years’ experience. Companies were a mix of clients, designers, consultants, and main contractors. For Stage III, data collected from commercial publications was used to answer the task questions corresponding to each application criterion, the purpose being to substantiate that the user requirements of a blockchain system can be specified using the Application criteria.

## Review, proposition, and substantiation

### *Blockchain applications in non-project settings*

Based on our literature review, Table 3 shows the results of blockchain selection in 41 cases in 10 industrial settings. Among them, 10, 6, and 19 cases adopted public, private, and consortium blockchains, respectively, and 6 adopted a combination. Ethereum was the most popular public blockchain platform. Hyperledger Fabric was the favored consortium blockchain platform and was implemented as a private blockchain in 3 cases. Some scholars built their own new platforms instead of using existing ones. Smart contracts and different consensus mechanisms were widely used.

**Table 3. Blockchain choices in the included studies**

| ID | Reference | Type of blockchain | | | Platform/ Framework | Smart contract | Consensus |
|---|---|---|---|---|---|---|---|
| | | Public | Private | Consortium | | | |
| **Intellectual property and digital identity** | | | | | | | |
| 1 | Kim and Yu (2018) | | | v | New | Yes | Customized |
| 2 | Halloush and Yaseen (2019) | | v | v | New | N/A | PoA |
| **Philanthropy, aid, and donors** | | | | | | | |
| 3 | Nor et al. (2017) | v | | | Ethereum | Yes | PoW |
| 4 | Sirisha et al. (2019) | v | | | New | Yes | BFT |
| 5 | Lamba et al. (2019) | | | v | Hyperledger Fabric | Yes | BFT |
| 6 | Saleh et al. (2019a) | v | | | Ethereum | Yes | PoW |
| **Democracy and governance** | | | | | | | |
| 7 | Zhang et al. (2018) | | | v | Hyperledger Fabric | Yes | N/A |
| 8 | Yu et al. (2018) | | | v | Hyperledger Fabric | Yes | PBFT |
| 9 | Diallo et al. (2018) | v | | | New | Yes | PoW |
| **Agriculture** | | | | | | | |
| 10 | Ge et al. (2017) | | | v | Hyperledger Fabric | Yes | PBFT |
| 11 | Shih et al. (2019) | v | | | Ethereum | Yes | N/A |
| 12 | Yang et al. (2020) | | | v | New | Yes | Customized |
| 13 | Hang et al. (2020) | | | v | Hyperledger Fabric | Yes | PBFT |
| **Health** | | | | | | | |
| 14 | Zhang and Lin (2018) | | v | v | JUICE | N/A | PoC |
| 15 | Griggs et al. (2018) | | v | | New | Yes | PBFT |
| **16** | Liu et al. (2018) | | | v | New | Yes | DPoS |
| 17 | Xu et al. (2019) | v | | v | New | N/A | PoW/PBFT |
| **Logistics and supply chain management** | | | | | | | |
| 18 | Kaijun et al. (2018) | v | | | New | Yes | PoS |
| 19 | Ding et al. (2019) | | v | v | Hyperledger Fabric | Yes | Customized |
| 20 | Mao et al. (2019) | | | v | New | Yes | PBFT |
| 21 | Chen et al. (2020) | | | v | New | Yes | PBFT |
| 22 | Li et al. (2020) | | | v | New | Yes | MCPBFT |
| **Built environment** | | | | | | | |
| 23 | Brousmiche et al. (2018) | | | v | Quorum | Yes | Quorum Consensus |
| 24 | Mukne et al. (2019) | | | v | Hyperledger Fabric | Yes | Kafka Consensus |
| 25 | She et al. (2019) | | | v | Hyperledger Fabric | Yes | BFT |
| 26 | Zhang and Wang (2019) | | | v | New | Yes | AlgoRand consensus |
| 27 | Puthal et al. (2020) | | v | | New | N/A | PoAh |
| 28 | Kaur and Oza (2020) | | v | | New | Yes | PoA |
| 29 | Luo et al. (2019) | | | v | New | Yes | Customized |
| **Education and human rights** | | | | | | | |
| 30 | Turkanović et al. (2018) | | | v | Ark | N/A | DPOS |
| 31 | Choudhury et al. (2018) | | v | | Hyperledger Fabric | Yes | N/A |
| 32 | Saleh et al. (2019b) | | | v | Hyperledger Fabric | N/A | N/A |
| 33 | Wang et al. (2019) | v | v | v | Hyperledger Fabric; Ethereum | Yes | PoW/PBFT/ BFT |
| **Environment and energy** | | | | | | | |
| 34 | Niya et al. (2018) | v | | | Ethereum | Yes | N/A |
| 35 | Mengelkamp et al. (2018) | | v | | New | Yes | PoI |
| 36 | Pop et al. (2018) | v | | | Ethereum | Yes | PoS |
| 37 | Van Leeuwen et al. (2020) | | v | | New | Yes | ADMM |
| 38 | França et al. (2020) | v | | | Ethereum | Yes | N/A |
| **Finance and economy** | | | | | | | |
| 39 | Chen et al. (2017) | v | | | Bitcoin | N/A | PoW |
| 40 | Wang et al. (2018a) | | | v | Hyperledger Fabric | N/A | OMMS |
| 41 | Xu and Viriyasitavat (2019) | | v | v | New | Yes | PBFT |

Note: New=building a custom blockchain or forking an established blockchain; BFT= Byzantine fault tolerant; MCPBFT=Multi-center practical byzantine fault tolerance; ADMM=Alternating direction method of multipliers; OMMS=Orchestration of multiple modules and steps; PoI= Proof of identity; N/A= Not available

### *A proposed multi-criteria decision matrix*

Figure 2 shows our MCDM. Organization criteria help interested users choose a blockchain type based on project characteristics; Performance criteria help evaluate existing blockchain platforms; and Application criteria assist in planning blockchain systems. Users should follow the order from Organization, Performance to Application criteria to use MCDM.

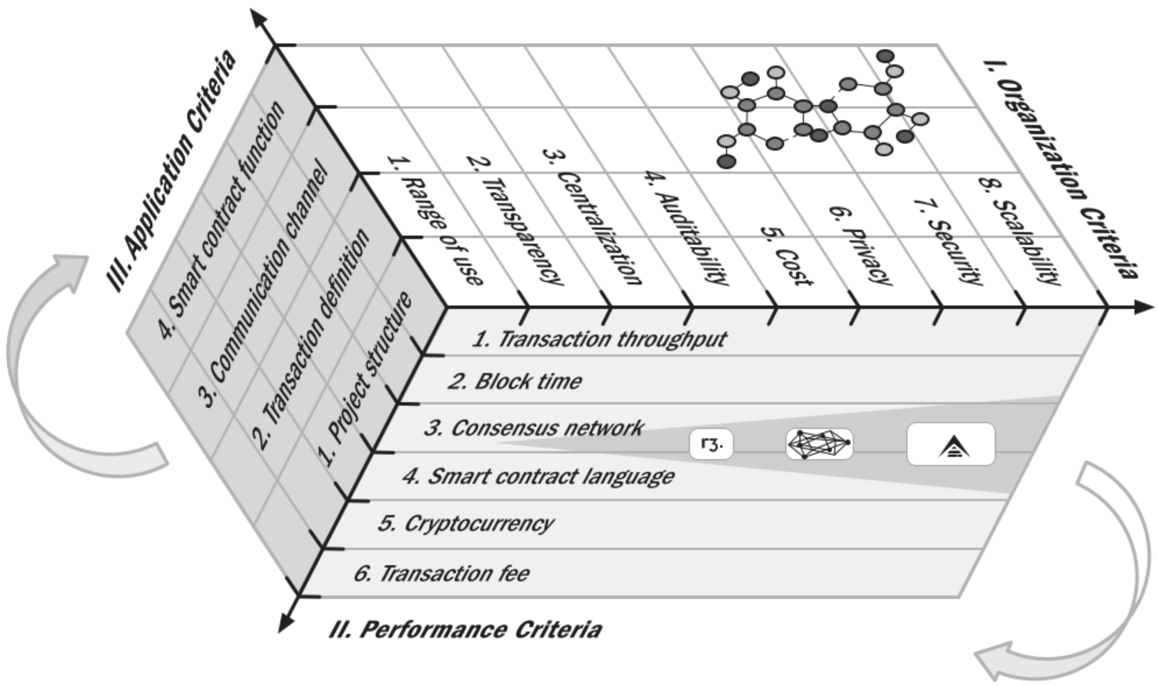
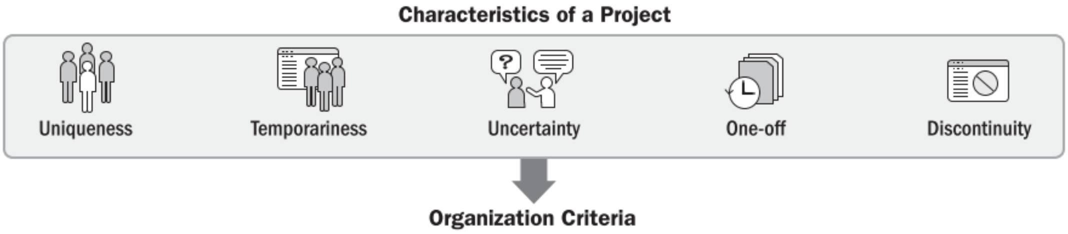



**Figure 2. The MCDM for choosing blockchain for projects**

Figure 3 shows public, private, and consortium blockchain information corresponding to Organization criteria. The first step is to define the range of blockchain use, project transparency, and centralization levels. The next is to determine whether a project should be highly auditable or reserve some space to retain sensitive business information. After that, we estimate the cost of a blockchain solution. For example, according to Ernst & Young (2019), private blockchains are usually adopted in projects with high transaction volumes because high costs are averaged over a large number of transactions. Finally, we determine the privacy, security and scalability requirements in projects. The notes in Figure 3 elaborate upon the Organization criteria.




| | 1. Range of use | 2. Transparency | 3. Centralization | 4. Auditability | 5. Cost | 6. Privacy | 7. Security | 8. Scalability |
|---|---|---|---|---|---|---|---|---|
| Public Blockchain | Public | Public | No | High | - Low (low transaction volume) - High (high transaction volume) | Low | High | Low |
| Private Blockchain | One organization | All members | Yes | Moderate | - Low (high transaction volume) - High (low transaction volume) | High | Low | High |
| Consortium Blockchain | Authorized multi-stakeholders | All members or submembers | Partial | Moderate to high | Moderate | Moderate | Moderate | Moderate |

**Notes:**

1. **Range of use:** The network can be used by all the public, one organization, or multiple authorized organizations.
2. **Transparency:** All the public can view the information or only disclose the information to all members of any organization or all members or submembers of multiple authorized organizations.
3. **Centralization:** Refers to the control of the concentration of activities. "Centralized" means that it cannot provide robustness, nor can it eliminate many-to-one-traffic, leading to delays and single points of failure. "Not centralized" refers to delegating activities (especially activities related to decision-making) away from the authoritative group. For example, in a decentralized model, the transaction process of book sales will be endorsed and recorded by multiple parties (seller, buyer, and multiple certifiers). All participants have the same transaction records on their ledger to prevent fraud.
4. **Auditability:** Transactions are verified and recorded on the blockchain with a timestamp, allowing users to easily track and trace previous records by accessing the ledger of any node in the distributed network.
5. **Cost:** The cost of initial platform construction, deployment, cloud storage, continuous maintenance and monitoring (high transaction volume means that the daily transaction volume is greater than 1912, and low transaction volume means that the daily transaction volume is less than or equal to 1912.
6. **Privacy:** Participants' right to keep their communication and data secretly.
7. **Security:** Blockchain uses encryption mechanisms involving PKI and hash algorithms to ensure the validity of stored information and prevent fraud.
8. **Scalability:** The ability to operate as usual when tasks or workloads increase

**Figure 3. Organization criteria for choosing blockchain types**

Figure 4 elaborates on the MCDM Performance criteria applied to 8 popular blockchain platforms. The first criterion, transaction throughput, refers to the number of transactions the blockchain can commit per second. Block time is the time required to generate the next block in a chain. Regarding consensus network, depending on the use case, a platform must support single or multiple consensuses, or a pluggable consensus. The number of languages supporting smart contract writing and the need for cryptocurrency should then be evaluated. Lastly, the cost per transaction should be considered.

| Performance Criteria / Existing Platforms | Bitcoin | Ethereum | EOS.IO | NEO | Hyperledger Sawtooth | R3 Corda | Hyperledger Fabric | Ark |
|---|---|---|---|---|---|---|---|---|
| **Transaction Throughput** (transactions per second) | 3–7 | 10–20 | 1,000+ | 10,000 | 1,300 | 100+ | 10,000+ | 19 |
| **Block Time** (seconds) | At least 10 minutes | 13–30 | 0.5 | 15–25 | 5–25 | Real-time | 10–35 | 8 |
| **Consensus Network** | PoW* | PoS* | DPoS* | dBFT* | Devmode, PBFT, PoET, Raft | Notary node** | PBFT** | DPoS* |
| **Smart Contract Language** | Possible (0) | Solidify, Serpent, LLL, Mutan (4) | C, C++ (2) | C#, Java, Python, Golang, Kotlin, Javascript (6) | Java, JavaScript, Ethereum virtual machine, Rust, C++, Python (7) | Kotlin (2) | Java, JavaScript, TypeScript (3) | Smartbridge (1) |
| **Cryptocurrency** | Bitcoin | Bitcoin | EOS | NEO | N/A | N/A | EOS | Ark coin |
| **Transaction Fee** (US$ per transaction) | About $1.19 | About $1.19 | Free | Free | Free | 0–10k: free, 10–20k: $0.1, 20k+: $0.01 | Free | About $0.028 |

**Note:** Etherium 2.0 updates PoW to PoS; *Supports single consensus; **Supports plugable consensus; dBFT = Delegated Byzantine Fault Tolarance; PoET = Proof of Elapsed Time; The number in brackets indicates the number of languages that support writing smart contracts.

**Figure 4. Performance criteria for choosing blockchain platforms**

Figure 5 elaborates on the Application criteria used to specify user requirements based on use cases so that developers can better plan blockchain systems. Blockchain system architecture normally consists of six layers: application, blockchain as a service (BaaS), execution, consensus, data, and network. The consensus layer managing the agreement between stakeholders through various consensus algorithms and the data layer, which handles the blockchain content organization using components such as hash functions, chain structure, and timestamps, are hosted by existing or newly built platforms. So for successful system development, one should perform tasks corresponding to the Application criteria to specify user requirements for the other four layers.

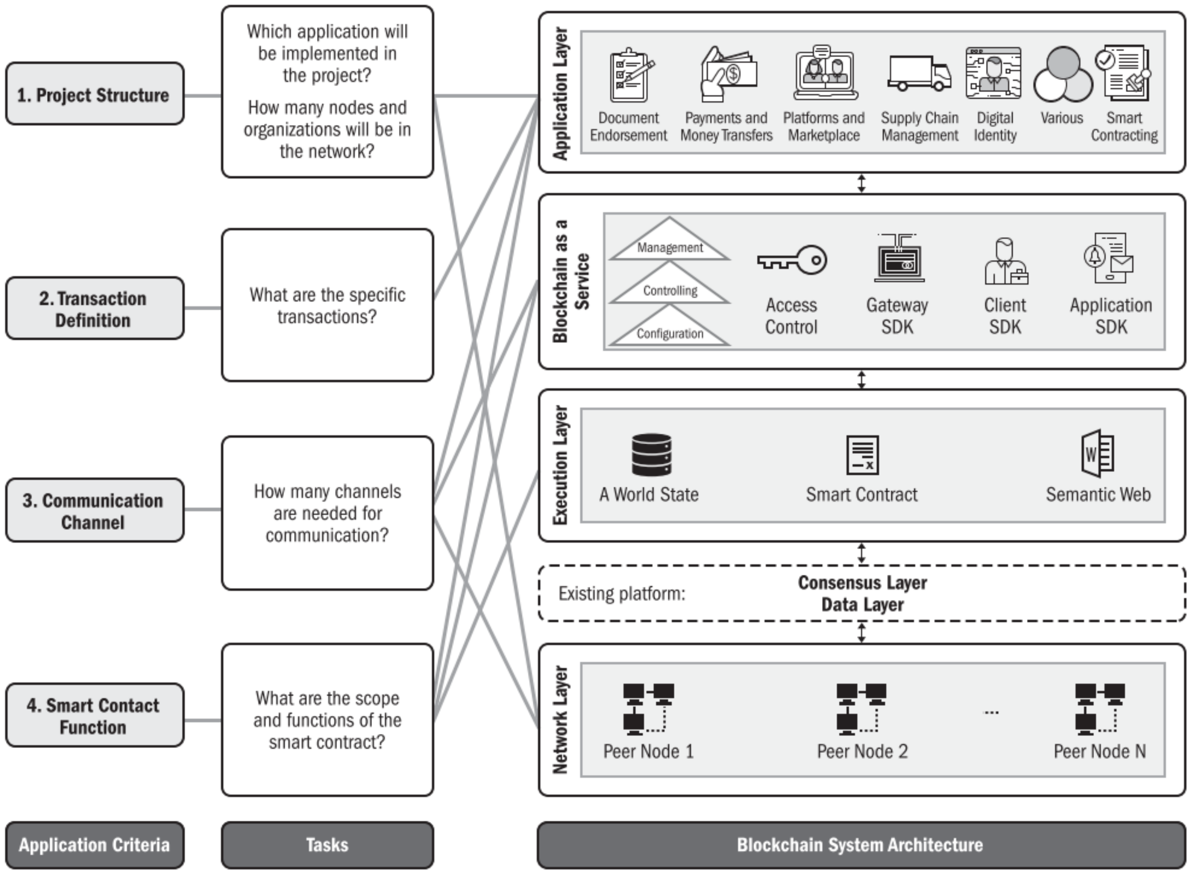



**Figure 5. Application criteria for planning blockchain systems**

Using the Project structure, we can first specify what applications in the application layer will be implemented with blockchain and determine the number of nodes and organizations that will participate in the network layer. The Transaction definition aims to determine specific transactions so that applications can interact with the blockchain network by submitting transactions to the ledger or querying the ledger's contents. Based on the defined transaction and the mutual trust relationship of nodes, the Communication channel criterion helps plan the number of communication channels (if dedicated channels are available). In this way, the BaaS layer, especially its various software development kits (SDKs), can realize the management, access control, and communication between the network and application layers. Finally, the Smart contract function helps specify its scope and the functions it needs to perform at the execution layer.

### *Substantiation via a semi-hypothetical case study*

*Stage I—Organization criteria*

Figure 6 shows the results of evaluating blockchain types according to the Organization criteria. Of the questionnaire respondents, 55% chose a consortium blockchain between multiple authorized organizations in a construction project; 65% preferred information to be transparent among all involved organization members or certain sub-members; and 61% believed that partial centralization in the consortium blockchain could meet their requirements. For auditability, 60% chose the auditability of the public blockchain, and 40% accepted that its “cost and transaction volume are positively correlated”. Regarding project privacy, 50% chose the private blockchain’s privacy. For security, 60% chose the security of the public blockchain. Regarding scalability, 41% believe that the scalability of private blockchains can meet the needs of construction projects, while 43% believe that moderate scalability of consortium blockchains is appropriate. Only 16% preferred the scalability of public blockchains.

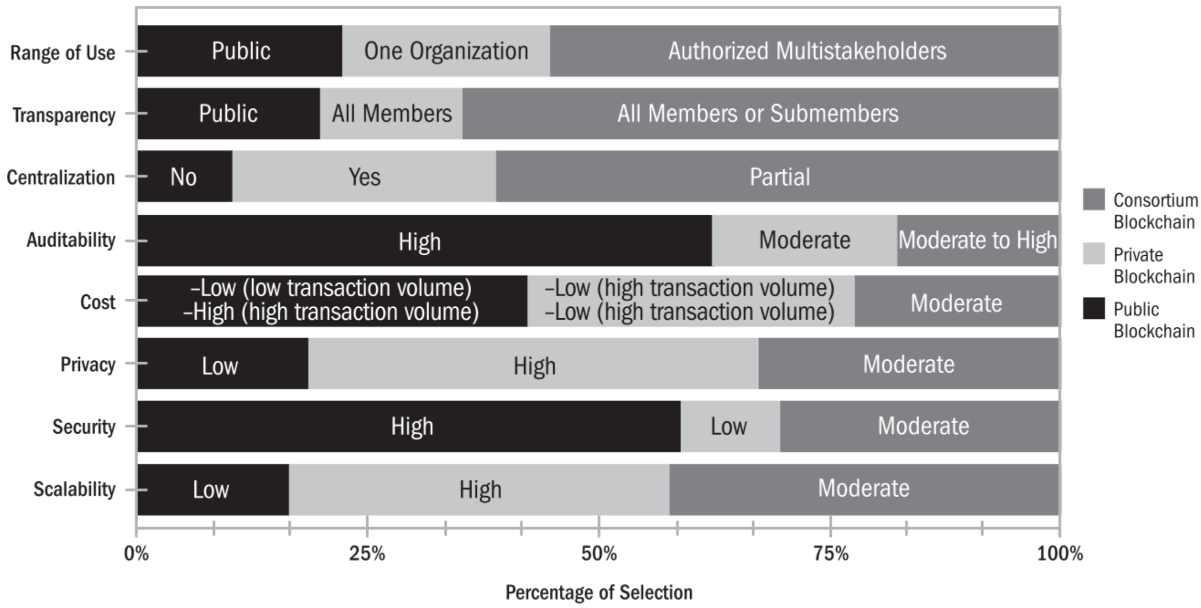



**Figure 6. Evaluation results of blockchain type against the Organization criteria**

Answering the 8 questions on Organization criteria, 55%, 25%, and 18% respondents chose more options corresponding to the consortium, public and private blockchain, respectively (1% had no preference; 1% chose both public and consortium blockchains). Based on this result, consortium blockchain is most feasible for this study.

*Stage II—Performance criteria*

In Stage II, according to Stage I results, 56%, 26%, and 18% evaluations based on Performance criteria were received for consortium, public and private blockchain platforms, respectively (1 evaluated all platforms; 1 assessed both public and consortium blockchain platforms).

Evaluation results of consortium blockchain platforms R3 Corda, Hyperledger Fabric, and Ark are shown in Figure 7a. For transaction throughput, 45% chose Hyperledger Fabric. The block time preference was R3 Corda (57%). More than 67% selected the pluggable consensus of Hyperledger Fabric, 88% because it supports multiple languages for writing smart contracts Regarding cryptocurrency, 37% did not need the platform to provide it (R3 Corda do not have a native cryptocurrency), 49% thought it might be needed (Hyperledger Fabric can provide development opportunities), and only 14% specified that a platform should have a native cryptocurrency (i.e., Ark). For transaction fee, 43% preferred R3 Corda, 51% chose Hyperledger Fabric, and 6% Ark. Overall, more respondents chose options corresponding to Hyperledger Fabric.

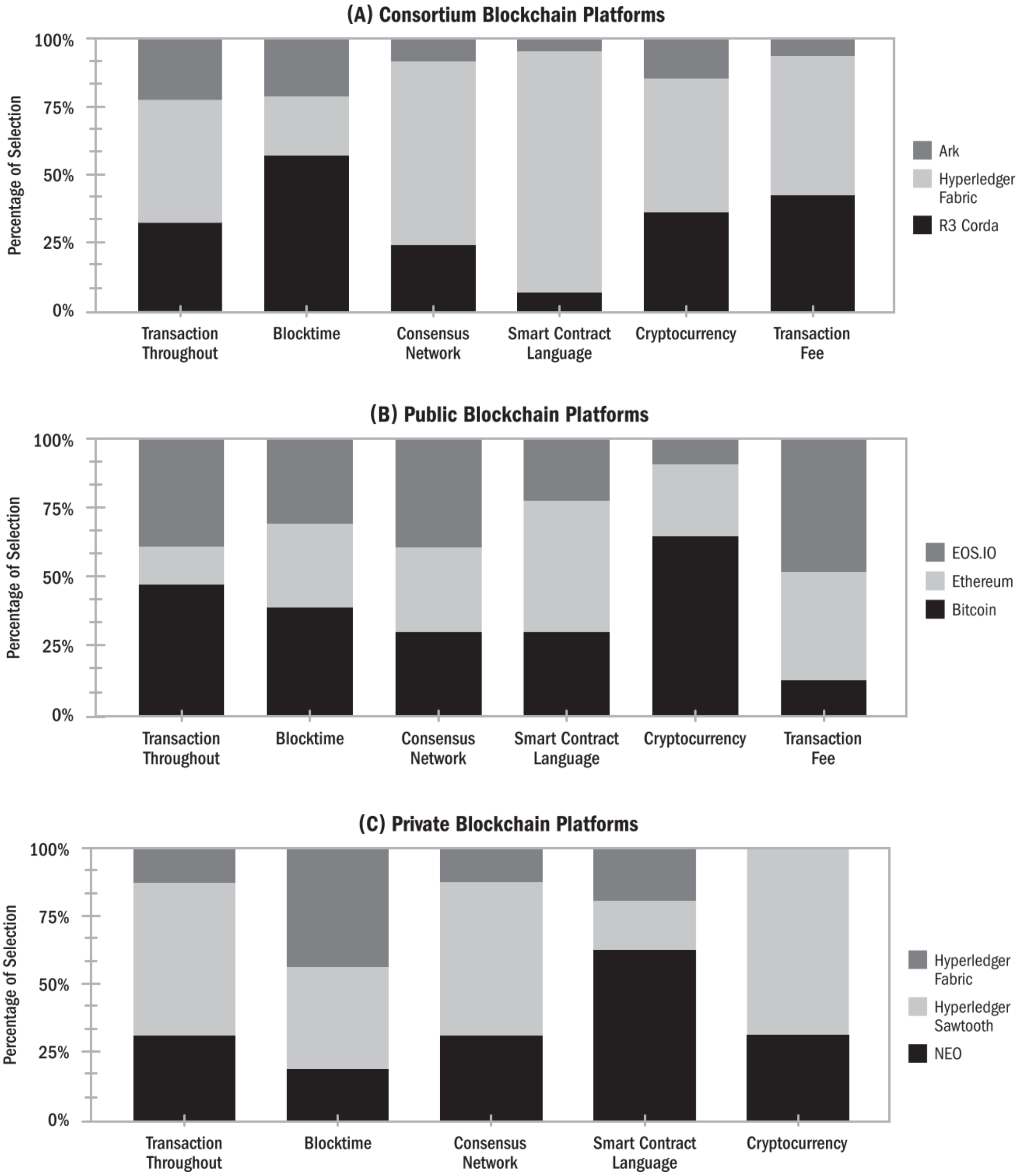



**Figure 7. Evaluation results of blockchain platforms against the Performance criteria**

Evaluation results of public and private blockchain platforms are shown in Figures 7b and 7c, respectively. For public blockchain platforms, more respondents chose Bitcoin's transaction throughput and block time (48% and 39%, respectively), EOS's consensus network (40%) and transaction fees (48%), and Ethereum's smart contract language (48%). For native cryptocurrency, respondents specified that the platform should have it (65% designated Bitcoin, 26% Ether, and 9% EOS). Overall, more respondents chose options corresponding to

Bitcoin. Those choosing private blockchain leant towards Hyperledger Sawtooth's transaction throughput (56%) and consensus network (56%), Fabric's block time (44%), and NEO's smart contract language (63%). For native cryptocurrency, 31% respondents specified that a platform should have it (e.g., NEO), 69% thought it might not be needed (e.g., Hyperledger Sawtooth), and none answered "it might be needed" (e.g., Hyperledger Fabric). Since none of these three private platforms charge transaction fees, the "transaction fee" criterion was not used. Overall, Hyperledger Sawtooth was more selected.

*Stage III—Application criteria*

Based on Stages I and II, Stage III collects user requirements of the Hyperledger Fabric system by deploying Application criteria. By referring to commercial publications and scenario building in the construction industry, an example of how to perform tasks related to each application criterion is given (Table 4). In this way, developers can plan a user-centered system.

**Table 4. User requirements in a typical construction project**

| Application criteria | Tasks | Blockchain architecture |
|---|---|---|
| Project structure | Applications: Document endorsement, Smart contracting | Application |
| | Four organizations: Client, designer, consultant, and contractor<br>Four peer nodes: Project leader, Architect, inspector, project manager<br>Two ordering nodes: Administration points (assigned by both client and contractor) | Network |
| Transaction definition | Preliminary design plan, Final design submission, Design and construction changes, modifications, worked hours, additional work claims, Quality assurance approvals, Key performance indicator (KPI) inquiring | Application |
| Communication channel | Two channels: Channel C1 for preliminary design plan related documents, and Channel C2 for other transactions | BaaS |
| Smart contract function | Scope: Smart contract S1 executes business logic in C1 and smart contract S2 defines executable logic in C2 | Execution |
| | Functions: Collect approvals, Check, Report and update KPI, Notify results | Execution |

Figure 8 shows the planned blockchain system. In this study, Client, Designer, Consultant, and Contractor agree that they will use and build the consortium blockchain in Hyperledger Fabric for document endorsement and smart contracting. The Client is the network initiator. Organizations can have applications that can perform transactions in two channels. The Client and Designer need to communicate about the design plan privately via an isolated channel. Peer nodes Project leader and Architect maintain a copy of the Ledger L1 associated with Channel C1 for the preliminary design plan and maintain a copy of the Ledger L2 associated with Channel C2 for other transactions indicated in Table 4. The peer nodes Project manager and Inspector maintain a copy of the Ledger L2 associated with Channel C2. There are two Ordering services O1 and O2 that service as network administration points for network and support application Channels C1 and C2. Smart contract S1 is installed on Project leader and Architect to execute the logic of business in C1. Smart contract S2 is installed on all peer nodes to define the executable logic for C2.

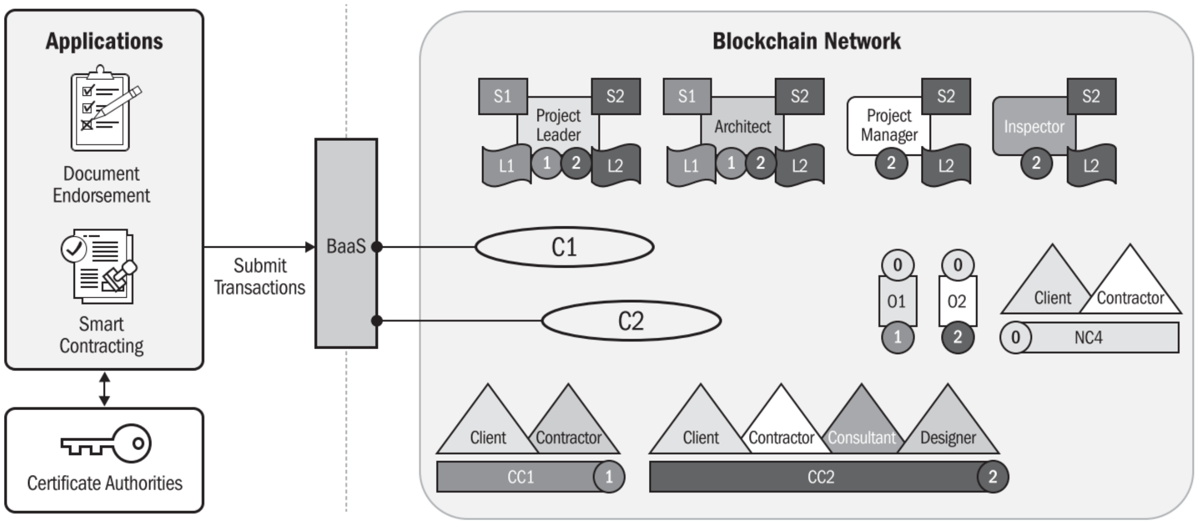



**Figure 8. Final system configuration against the Application criteria**

The network is managed according to rules specified in Network Configuration NC4 (e.g., both Client and Contractor need to agree if new organizations want to join the network). When it comes to consensus, transactions in Channel C1 are managed according to rules specified in channel configuration CC1 (only the Project leader and Architect need to endorse the preliminary design plan-related documents); the Client and Designer manage C1. All organizations manage Channel C2 according to Rules CC2 (all peer nodes need to endorse transactions). Organizations have certificate authorities defined in the data layer. This successful planning of a blockchain system substantiates our Application criteria feasibility.

## Discussion

The MCDM developed in this study provides a structured methodology to help prospective PM professionals choose suitable blockchain and plan implementable blockchain-based PM systems. Organization, Performance, and Application pertinent criteria have been investigated in various industries or non-project settings, but this study links the criteria with projects and enriches their meaning in PM discourse. Our case study provides a vivid example of how the MCDM can be implemented to choose a blockchain and plan a blockchain system for a client in construction projects. Respondents in this study had different blockchain projects in mind when they completed the surveys. In real-life practice, project clients may wish to build a blockchain infrastructure for different applications. Therefore, the proposed MCDM can help project clients mine the actual requirements of different project teams and then decide on blockchain options. Overall, this research is a meaningful step towards demystifying blockchain in the project world.

Blockchain presents enormous prospects and challenges for project management. At a technical level, the hash algorithms, distributed ledgers, consensus mechanisms, and other components are still developing rapidly. At the service level, smart contracts are probably the most promising application for safeguarding information, expediting reporting and endorsement, and paying on time. The hash algorithm, distributed database, and decentralized consensus mechanism make it difficult for any party in the blockchain to tamper with the project's information. However, one cannot underestimate security vulnerability or make assumptions about blockchain risks, such as 50% vulnerabilities, code vulnerabilities, private key security, criminal activity, and identity exposure (Perera et al., 2020). A typical misunderstanding is that the technology can guarantee the genuineness of information in the off-chain, project world. Traditional quality assurance and inspection technologies in the physical project world are still needed to enable blockchain power.

This research has some limitations. Firstly, the weighting of each Organization and Performance criterion were assumed to be equally important. Secondly, in the case study, criteria (Organization, Performance, and Application) were adopted independently. Thirdly, in this research, the proposed MCDM was used as a decision-support tool to help users choose blockchain options, thereby not naturally considering detailed information governance of projects. Fourthly, PM professionals would ideally evaluate systems based on real-life construction projects, but such projects using blockchain are few and far between. We developed a prototype of the system on the Hyperledger Fabric platform. But in the case study, the blockchain system, like any blockchain system in various industries, mainly works on the background. Evaluators do not even notice such system being at play. The unique terminologies further prohibited the users from evaluating the system sensibly.

Amid the global blockchain hype, a word of caution is that prospective users should carefully choose the parts of their PM tasks to be blockchained, and to ask whether they really need blockchain at all. The technology introduces redundancy (e.g., by placing the blocks in multiple places) and sacrifices efficiency for improved security (Xue & Lu, 2020). It incurs extra, sometimes excessive, cost. Therefore, a highly selective strategy is desired based on more thorough cost-benefit analyses when better empirical data is available. Blockchain implementation is not just about using new software. It is more about implementing novel business technologies and philosophies (Penzes et al., 2018). It has the potential to support digitization in projects and provide solutions to many challenges, but before using the technology, organizations need to dissect their existing business models. Therefore, we need to understand more about the in-depth relationship between project governance and blockchain system and their impacts on project performance.

## Conclusions

Project management (PM) professionals are exploring the potential of blockchain, a disruptive technology promising benefits such as greater transparency, enhanced security, improved tractability, and increased efficiency. However, no previous study examines blockchain technologies suitable for projects, whose unique characteristics may impose particular challenges to this emerging technology. This research addresses this knowledge gap by proposing a multi-criteria decision matrix (MCDM) for PM professionals to choose blockchain for their projects. The MCDM has three staged components organized sequentially. Stage I is to choose a generic blockchain type (e.g., public, private, or consortium) against organization-related criteria range of use, transparency, centralization, auditability, cost, privacy, security, and scalability. Stage II is to choose a specific blockchain platform against performance-related criteria transaction throughput, block time, consensus network, smart contract language, cryptocurrency, and transaction fee. Stage III is to specify user requirements to plan a blockchain system against the application-related criteria project structure, transaction definition, communication channel, and smart contract function.

The MCDM was tested and evaluated through a case study that includes a questionnaire and an illustrative example pertinent to the construction industry. The results show that consortium blockchain is superior to public or private blockchains in dealing with the unique characteristics of projects. Hyperledger Fabric, a commercial platform, was chosen as the best solution. Based on the platform, developers need to consider user requirements such as network participants, principal transactions, communication channels, and smart contracts to realize a blockchain-based PM system.

This is one of the first studies to truly “soft land” the technology in projects as a widespread yet unique organization and governance setting. It makes several original contributions. Firstly, it examined the challenges arising from project characteristics when choosing a type of blockchain. Secondly, it isolated blockchain selections in 10 industrial settings and identified the criteria for selecting blockchain types/platforms. Thirdly, it guides system developers to consider both the blockchain type/platform and the project characteristics/processes in developing a blockchain system. Not only useful for demystification purposes, the MCDM is a readily deployable methodology for developing blockchain systems for PM.

The limitations of this study provide opportunities for further investigations. Firstly, the weighting of each Organization and Performance criterion were assumed to be equal. More research is desired to assess the relative importance of the criteria by considering more real-life projects. Future research can also link criteria and their weightings to business outcomes. Therefore, users can understand the value that blockchain can instigate before implementation. Secondly, criteria (Organization, Performance, and Application) were adopted independently in the case study. With the rapid development of blockchains, understanding the interdependence of the criteria can make the MCDM more robust in the face of new capabilities. Thirdly, the proposed MCDM is an infrastructure for selecting blockchain options, thereby not naturally considering complicated information governance. Therefore, future investigations are encouraged to form logical information structures so that project participants can determine how important issues such as data privacy level and transaction throughput exactly are for their blockchain use cases. Lastly, in-depth investigations of the relationship between project governance and blockchain system and their impacts on project performance are much desired when more cases are available. Blockchain is novel, and there are numerous challenges, but the potential of this technology to reshape the PM domain is too great to be missed.

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**Data availability statement**

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to their containing information that could compromise the privacy of research participants.

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