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ORIGINAL RESEARCH

Blockchain in project management: a systematic review of use cases and a design decision framework

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Abstract
Blockchain presents a novel technology for improving existing paradigms in a wide span of domains, including project management. In this paper, we first review the state of the art blockchain use cases in project management to reveal the current status of blockchain research and to identify the blockchain application domains in project management. We then present a framework based on the review results, to guide implementers and researchers on blockchain design decisions about privacy, transparency, decentralization, blockchain type, and platform decisions, which are unique for a particular project management domain. The review results indicate that blockchain includes a variety of unique properties simultaneously, and presents multiple contributions for management of projects. However, technical blockchain design decisions are crucial for maximizing the benefits of the blockchain systems. The proposed novel framework enables a structured methodology for resolving crucial technical design decisions for maximizing the benefits of blockchain systems in project management and the review provides directions to the new blockchain research.

Keywords Blockchain technology · Project management · Design decision framework

1 Introduction

In recent years, blockchain has emerged as a revolutionary technology and has received interest across a wide span of sectors (Hughes et al. 2019). Blockchain was originally developed to record transactions across a peer-to-peer network of computers (nodes). In a blockchain, the transactions are recorded on a distributed ledger, which are secured using a cryptographic proof. New transactions are added to the blockchain according to a decentralized consensus protocol. The decentralized consensus protocol, which enables execution of transactions without the need of a central authority, is one of the major innovations of the blockchain technology.

In a blockchain, data is held on all of the nodes at the same time, which eliminates a single point of failure. Distributed storage of the ledger through cryptographic proof and decentralized consensus protocol ensures the security of the blockchain. Developments in the blockchain technology have led to the discovery of smart contracts, which are computerized protocols whose execution is guaranteed through a code that runs on the decentralized blockchain. A smart contract enables automated execution of contract clauses without requiring any trusted intermediaries.

The unique features of blockchain enables major advantages for development of decentralized applications (Ahmadisheykhsarmast and Sonmez 2020). Blockchain presents serious disruptions to the traditional business processes, which is mainly based on centralized architectures requiring trusted third parties (Casino et al. 2019). In particular, smart contract technology promise a major potential to reshape conventional industry and business processes as they can decrease administration and service costs, improve efficiency, and enhance trust among stakeholders by providing a decentralized trustless automated system (Zheng et al. 2020).

The applications of blockchain for financial services (Ali et al. 2020), construction (Li et al. 2019, Hunhevicz and Hall 2020), operations and supply chain (Wamba and Queiroz 2020), energy (Poptawski and Szczypiorski 2018), manufacturing (Kawaguchi 2019), government (Ølnes et al. 2017), and public sectors (Warkentin and

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Orgeron 2020) were included in the previous research. Hargaden et al. (2019) provided insights into the adoption of blockchain technology in the construction industry. Hewavitharana et al. (2019) sought to identify how blockchain can address purchase management, contract management, asset and inventory management, finance management and subcontractor management in the construction industry. Kim et al. (2020) mentioned the potential of blockchain to improve project management practices. However, very limited research has focused on the state-of-the-art of blockchain applications in project management. Hence, within this context, the first objective of this paper is to fill this gap, and to provide a systematic review and analysis of the state-of-art blockchain research in project management, mainly focusing on the use cases. Along with the review, a taxonomy of blockchain applications is identified and contributions of blockchain in project management are determined.

The design of the blockchain system is among the key technical factors impacting adoption of blockchain technologies (Janssen et al. 2020). The second objective of the paper is to present a decision framework based on the review findings, to guide implementers and researchers on technical design decisions for maximizing the benefits of blockchain applications in project management. Along with the review and the framework, future research directions are suggested to enhance adoption of blockchain in the project management domain.

2 Blockchain and smart contracts

Blockchain, which was originally introduced as a peer-to-peer electronic cash system (Nakamoto 2008), is a distributed database that is formed of a growing chain of records called blocks. Blockchain provides a globally consistent and secure database and is secured by cryptographic proof. In a blockchain, the nodes reach to an agreement on the new blocks through a decentralized consensus protocol. Once the agreement is reached, the new blocks are broadcasted to the nodes. Hence, all the nodes has always have the latest copy of the blockchain in nearly real-time.

The most well known consensus protocol is the Proof-of-Work (PoW) in which nodes compete to solve a moderately hard, but trivial-to-verify problem. The node that wins the competition is rewarded with incentives such as cryptocurrencies (digital currency), after 51% or more nodes verify the solution. In recent years, Proof-of-Stake (PoS) protocol was proposed as an efficient, fast, and inexpensive consensus alternative. A PoS blockchain can achieve consensus through a process in which each node can participate as a validator, according to the amount of the cryptocurrency it holds (Buterin and Griffith 2017).

The blockchains can be classified as public, consortium, and fully private blockchains (Buterin 2015). In public blockchains, anyone can participate in the consensus process and the blockchain is usually made publicly available to ensure the transparency, accessibility, and stability of the transactions. Consortium blockchains on the other hand, enable only a number of few permissioned nodes to participate in the consensus. In fully private blockchains, the new blocks are usually verified and added by only one node. Hence, private blockchains are centralized, and consortium blockchains are partially decentralized. The right to read the blockchain may be public or restricted in consortium and private blockchains.

Blockchain enabled development of smart contract technology, which was first proposed by Szabo (1996). Smart contracts are computerized transaction protocols that implement the terms of a contract. Once a smart contract is deployed on the decentralized blockchain, it cannot be modified or cancelled by anyone. The agreed terms are automatically executed by the smart contract without requiring a third party. Hence, smart contracts enable a trustful system for guaranteed execution of contract terms, which present a major potential to eliminate or reduce some of the issues that prevents successful completion of projects such as; distrust, fraud, and lack of transparency (Ahmadisheykhsarmast et al. 2020). Blockchain and smart contracts also provide an efficient and secure alternative for project information management.

3 Systematic literature review

The first objective of this paper is to perform a systematic review of the blockchain use cases in project management to identify the blockchain application domains, to determine contributions of blockchain in project management, and to form a basis for the framework. In this section the systematic literature review methodology is described along with the initial findings of the review.

3.1 Review methodology

The systematic review methodology of Tranfield et al. (2003) is used as it presents a process that was mainly developed for the management domain. The review methodology consists of three main stages; (1) planning the review, (2) conducting the review and, (3) reporting and dissemination. In the planning stage, first the scope of review is defined to assess the relevance and size of the literature, and to specify the subject area. In this paper, the scope of review is defined as the blockchain use cases in project management. Hence, the keywords “blockchain” and “project management” are identified for the search. The planning stage also requires development of a review protocol which is a crucial part of the systematic review to achieve a scientific, replicable, and transparent process and to minimize the bias through an exhaustive literature search (Tranfield et al. 2003).

In the review protocol, three electronic, academic databases namely, Web of Science, Scopus, and ScienceDirect were included. These databases provide complementary bibliographic information of majority of the academic publications related to project management including journals, books, and conference proceedings. All of the journal articles, technical notes, discussions, books, book chapters, and conference proceedings were selected from the search results without any publication time limit. Publications that do not include a specific use case in project management were not included.

Content analysis was employed to analyze the text in an organized manner and to identify the patterns in the current body of knowledge. The content analysis comprised of descriptive analysis and category analysis of the use cases. The descriptive analysis included general information of the selected sources. Categories were identified and the use cases were classified into the defined categories based on the review results. In the thematic analysis the text of the publications were examined to identify common themes on the project management knowledge areas and properties and advantages of blockchain applications. Use cases were analyzed to determine the potential contributions of blockchain for project management. Finally, a framework is developed based on the review findings to enable a structured methodology for resolving crucial technical design decisions during implementation of blockchain systems in project management. The research methodology is presented in Fig. 1.

3.2 Identification and collection of use cases

In the review stage, the academic databases Web of Science, Scopus, and ScienceDirect were searched using the combined keyword of "blockchain" and "project management". Thirty-four publications were identified from the Web of Science database, 384 from Scopus, and 119 from ScienceDirect. However, majority of these publications consisted of duplicates and studies that are not related to the blockchain

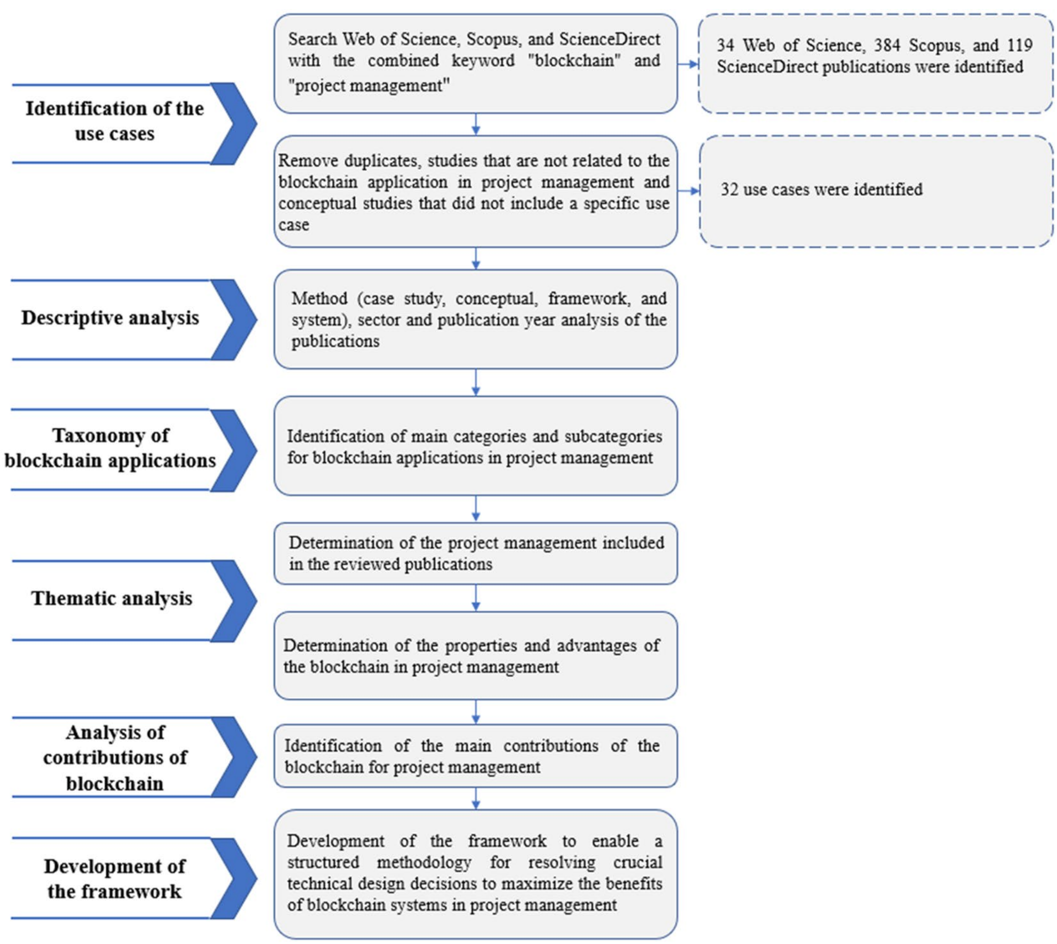

Fig. 1 Research methodology

applications in project management. Conceptual studies that did not include a specific use case that is related to project management were also removed. Hence, a total of only 30 publications were included according to the review protocol. Two of the publications included two different use cases, therefore 32 use cases were identified as shown in Fig. 1.

The methods used in the selected publications were classified in four groups; (1) case study, (2) conceptual, (3) framework, and (4) system. Case studies investigated the application of blockchain in project management using a real-life example, and conceptual studies presented concepts or ideas for the application of blockchain in project management. In this research, a framework is defined as a context that presents a structure for a blockchain application. Whereas, a system is defined as a blockchain application formed from organized collection of parts that are highly integrated. All of the publications included at least one use case within the project management domain.

3.3 Descriptive analysis

The publications included in the review consisted of one book chapter, one discussion, eight conference proceedings, and 20 journal articles. The literature reviewed included one publication from food sciences and transportation sectors, two publications from information technology and research and development (R&D) sectors, three from energy, logistics and manufacturing sectors, and 15 publications from the construction sector. The methods of the publications consisted of three conceptual studies, four case studies, six systems, and 17 frameworks. The majority (17) of the publications were published in 2020, nine in 2019, two in 2021 and two in 2018. The results of the descriptive analysis indicate that majority of the blockchain applications (80%) in project management consist of conceptual studies, case studies, and frameworks. Only few research has developed systems to reveal the real potentials of blockchain in project management. The publication year of the studies reveal that the blockchain adoption in project management is at its very early stages. However, blockchain applications in project management are receiving increasing attention. The construction industry is currently the leading sector in terms of considering the blockchain for the project management related tasks. On the other hand, majority of the sectors that use project management are also showing interest in blockchain..

3.4 Taxonomy of blockchain applications in project management

The 32 identified use cases were used to determine and analyze the blockchain application domain categories in project management. An application-oriented classification based on the procedure proposed by Casino et al. (2019), was used to identify the categories and sub categories for the blockchain application domains in project management. Casino et al. (2019) identified the main categories and sub categories for general applications of blockchain. The general categories included; financial, integrity verification, governance, internet of things, healthcare management, privacy and security, business and industrial applications, education, data management, and miscellaneous applications. In this research main categories and sub categories that are specific to blockchain applications in project management are identified.

Three main categories were determined based on the analysis of the reviewed literature, which were: information management (IM), payments (PY), and contract management (CM). Twenty-two use cases focused on solely to information management and four case studies only included payments domain. Three use cases included both payments and contract management, two included both information management and contract management, and one use case focused on all three domains.

Eleven sub categories were identified for the application domains as follows: (1) supply chain management, (2) life cycle management, (3) design, (4) environmental sustainability, (5) quality management, (6) research management, (7) bidding, (8) financial transactions, (9) progress monitoring, (10) progress payments and, 11) security of payments. The sub categories life cycle management, design, environmental sustainability, research management, bidding, progress monitoring were included for the use cases which solely focused on the information management category, and the remaining sub categories were included for the use cases that are concentrating to multiple categories as shown in Fig. 2. The numbers that are given in parentheses are the numbers of use-cases classified under each sub category. Seven use cases focused on the supply chain management under the category information management as shown in Table 1. These use cases included an integrated blockchain and distributed data storage model (Kawaguchi 2019), a smart contract design for logistics management (Yang et al. 2019), a blockchain architecture for project deliveries (Helo and Shamsuzzoha 2020), a blockchain and IoT framework for supply chain network optimization (Kadadevaramth et al. 2020), a blockchain based tracing anti-counterfeiting platform for supplier evaluation (Liu et al. 2020), a conceptual framework for adoption of blockchain in construction supply chains (Tezel et al. 2020), and a framework for improving supply chain information management in precast construction (Wang et al. 2020)..

The sub category life cycle management ranked second within the information management main category with four use cases; a single shared-access building information model (BIM) for whole asset life cycle uses (the first use

Fig. 2 Main and sub categories of use cases

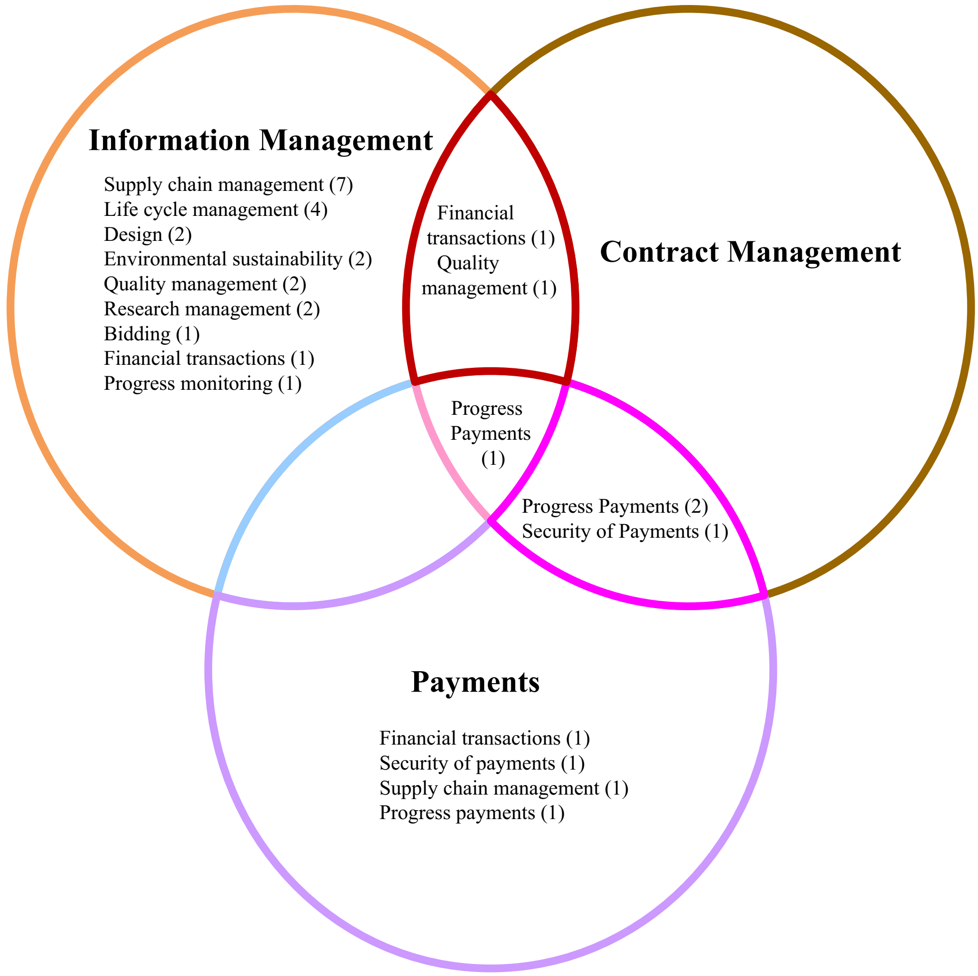

Table 1 Use cases focusing solely to information management

Sub category (no.)	Blockchain use case
Supply chain management (1)	A data storage model (Kawaguchi 2019), an information management scheme (Yang et al. 2019), a pilot system (Helo and Shamsuzzoha 2020), a blockchain and IoT framework (Kadadevaramth et al. 2020), an anti-counterfeiting platform (Liu et al. 2020), a conceptual framework (Tezel et al. 2020), and a framework for precast construction (Wang et al. 2020)
Life cycle management (2)	A single shared-access BIM model (Li et al. 2019, first use case), a blockchain-aided BIM model (Liu et al. 2019), a blockchain and IoT based smart product-service (Li et al. 2021), and a framework for power communication assets (Zhang et al. 2020)
Design (3)	A framework for automating the design review process (Nawari and Ravindran 2019), and a blockchain process for cladding design (Yang et al. 2020, first use case)
Environmental sustainability (4)	A communication model for sustainable power investments (Poptawski and Szczypiorski 2018), and a framework for green logistics (Tan et al. 2020)
Quality management (5)	A system for managing quality information (Sheng et al. 2020), and a quality traceability framework (Zhang et al. 2020)
Research management (6)	A platform for information management of research projects (Lee and Yoon 2019), and a framework for food sciences research management (Machado et al. 2020)
Bidding (7)	A framework for secure online bidding (Sarfaraz et al. 2021)
Financial transactions (8)	A platform to control and track financial transactions (Elghaish et al. 2020)
Progress monitoring (9)	A platform for information management of research and development projects (Lee et al. 2020)

case in Li et al. 2019), a blockchain-aided BIM model for design coordination and collaboration in building life cycle management (Liu et al. 2019), a blockchain and IoT based smart framework for life cycle information management of prefabricated housing construction (Li et al. 2021), and a blockchain mechanism for life cycle management of power communication assets (Zhang et al. 2020). There were two use cases within the each sub categories of design, environmental sustainability, quality management, and research management, under the category information management. Nawari and Ravindran (2019) proposed a blockchain and BIM framework for automating the design review process, and Yang et al. 2020 (in the first use case) presented a case study for blockchain integrated design of external cladding for an apartment. Blockchain based smart contracts for sustainable power investments (Poptawski and Szczypiorski 2018), and a blockchain-based framework for green logistics (Tan et al. 2020) were the use cases within the sub category environmental sustainability. Sheng et al. (2020) developed a system for construction quality information management and Zhang et al. (2020) proposed a quality traceability framework for prefabricated buildings. The use cases under the information management category within the research management sub category consisted of two platforms designed for information management of research projects (Lee and Yoon 2019) and research management of food sciences projects (Machado et al. 2020). There was only one use case within each of the bidding, financial transaction, and progress monitoring sub categories of the information management main category. These use cases included a framework for secure online bidding (Sarfaraz et al. 2021), and platforms for controlling financial transactions (Elghaish et al. 2020) and information management of research and development projects (Lee et al. 2020).

Each of the four use cases that focused solely to the payments category had different sub-categories as shown in Table 2. These use cases included a robotics process automation case study of a large technology firm within the financial transactions sub category (Carden et al. 2019), a framework for blockchain based project bank accounts (second use case in Li et al. 2019) within the security of payments sub category, a case study involving procurement of an equipment (Yang et al. 2020, second use case) within the supply chain management sub category, and a conceptual design of a blockchain based payment system (Hamledari and Fischer 2021) within the progress payments sub category. Three use cases were related to both payments and contract management categories. Luo et al. (2019) presented a smart contract framework for automating construction progress payments, and Ye and König (2021) proposed a framework for automated billing using BIM and smart contracts within the progress payments sub category. Ahmadisheykhsarmast and Sonmez (2020) developed a decentralized application (DApp) for security of payment of construction contracts within the security of payments sub category. There were two use cases involved with both information management and contract management. Gürcan et al. (2018) presented a decentralized system for trusted energy performance contracts within the financial transactions sub category, and Abbas et al. (2020) suggested a blockchain knowledge-sharing platform for the maintenance of rolling stock within the quality management sub category. The final use case was related to all three categories and was in

Table 2 Use cases that are not focusing solely to information management

Category	Sub category (no.)	Blockchain use case
PY	Financial transactions (8)	A case study of robotics process automation (Carden et al. 2019)
	Security of payments (10)	A framework for automated project bank accounts (Li et al. 2019, second use case)
	Supply chain management (1)	A case study involving procurement of an equipment (Yang et al. 2020, second use case)
	Progress payments (11)	Design of an automated payment system (Hamledari and Fischer 2021)
CM and PY	Progress payments (11)	A framework for construction payment automation (Luo et al. 2019) and a BIM and smart contract framework for automated billing (Ye and König 2021)
	Security of payments (10)	A DApp for for security of payment of construction contracts (Ahmadisheykhsarmast and Sonmez 2020)
IM and CM	Financial transactions (8)	A prototype DApp for trusted energy performance contracts (Gürcan et al. 2018)
	Quality management (5)	A blockchain-led knowledge-sharing platform (Abbas et al. 2020)
IM, PY and CM	Progress payments (11)	A model that enables selective-transparency in payment records (Das et al. 2020)

IM Information management, *PY* payments, *CM* contract management the progress payments sub category, which consisted of a blockchain-based framework for securing progress payments (Das et al. 2020).

The review of the use cases based on the category and sub category classifications reveal that the application of blockchain technology in project management has been used for many different purposes across several industries. A majority of use cases has focused on solely information management (68.8%), while few adopted blockchain for payments and contract management. At the sub category level, supply chain management (25.0%) was the most studied area followed by progress payments (15.6%), life cycle management (12.5%), financial transactions (9.3%), quality management (9.3%), environmental sustainability (6.3%), design (6.3%), research management (6.3%), security of payments (6.3%), and bidding (3.1%).

3.5 Properties and advantages of blockchain in project management

A thematic analysis of the reviewed publications is performed to determine the properties and advantages of blockchain. The common properties of blockchain are identified as; security, transparency, reliability (trustworthiness), decentralization, immutability, traceability, authenticity, real-time, and self-execution. On the other hand, the publications indicate that use of blockchain is leading to following advantages; builds trust, eliminates the need for a third party, enhances communication, reduces disputes and conflicts, prevents fraud, provides a single source of truth, guarantees execution of contract clauses, acts as a proof for digital documents, eliminates bureaucracy, and decrease ambiguity. The frequencies of the occurrence of properties and advantages of blockchain that are identified in the reviewed publications are shown in Fig. 3.

3.6 Project management knowledge areas in blockchain research

A project management knowledge area is a set of concepts, terms, and activities that make up a professional project management field, or area of specialization. In PMBOK Guide (2017) ten project management areas are specified as; integration management, scope management, schedule management, cost management, quality management, resource management, communications management, risk management, procurement management, and stakeholder management. A thematic analysis of is performed to determine the project management areas that are included in the project management blockchain research.

The results of the thematic analysis reveal that the blockchain research in project management involved all of the project management areas. Communications management is included in 80% of the publications, which is followed by the stakeholder (70%), cost (67%), procurement (53%), quality (33%), and schedule (30%) management areas. The project management areas; risk (20%), resource (17%), integration (10%), and scope management (10%) are included in fewer publications.

3.7 Main contribution areas of blockchain for project management

In thematic analysis, the common themes for properties and advantages of blockchain was identified by text search. However, some of the publications highlighted contributions of blockchain for project management with specific use case examples. These specific case examples are analyzed to identify the potential contributions of blockchain for management of projects. The use case analysis revealed that the perceived contributions of the blockchain for project management fall in to four main groups namely; (1) building trust, (2) enhancing communication, (3) reducing disputes and claims, (4) preventing fraud.

The analysis of use cases indicate that blockchain presents a major potential for contributing to management of projects

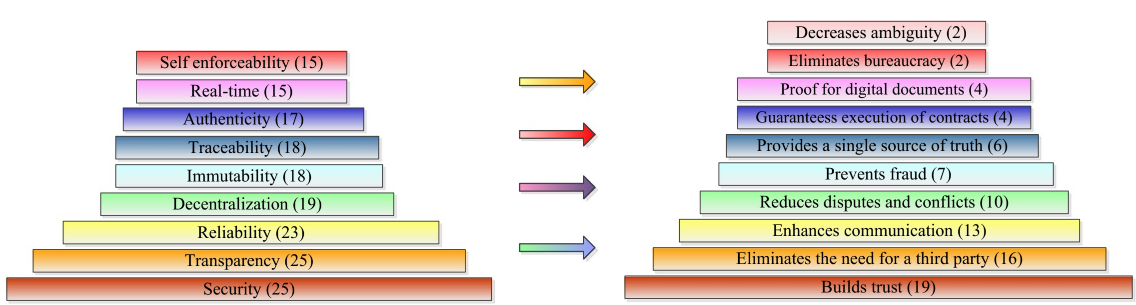

Fig. 3 Properties and advantages of blockchain in project management

in various aspects. In this section the main contributions of the blockchain for project management are discussed.

3.7.1 Building trust

The importance of trust among the project participants for achieving project success, particularly for mega-projects, has been emphasized extensively in the project management literature in recent years (Cerić et al. 2020). Despite its importance, development of trust is regarded as a major challenge for management of inter-organizational projects (Maurer 2010). Blockchain, with its unique simultaneous properties of security, transparency, reliability, decentralization, immutability, traceability, authenticity, real-time, and self-execution provides a major opportunity for building trust among project stakeholders. Building trust was identified as the most cited advantage of the blockchain technologies in the selected publications and was also the top highlighted contribution of blockchain among the use cases reviewed.

The contribution of blockchain for building trust was emphasized in the use cases for all application categories. Yang et al. (2019), Helo and Shamsuzzoha (2020), and Tan et al. (2020) mentioned that blockchain establishes trust among the stakeholders for logistics management as it provides immutability, traceability, and transparency. Lee and Yoon (2019) presented a trust based information project platform based on the blockchain technology. Integration of blockchain with the BIM models for enhancing trust between parties was emphasized by Tezel et al. (2020) and Li et al. (2019). Elghaish et al. (2020) and Abbas et al. (2020) highlighted that blockchain-based information sharing platforms can be used for sharing critical asset information in a transparent manner to enhance trust between stakeholders. Hamledari and Fischer (2021) presented a different perspective and stated that blockchain reduces the need for trust. Ahmadisheykhsarmast and Sonmez (2020) developed a decentralized application to show how blockchain and smart contracts could enable a secure, and trustworthy platform for security of payments of construction contracts, without requiring trusted intermediaries such as lawyers or banks. Finally, Gürcan et al. (2018) underlined the potential of blockchain for improving the trust between the client and the service provider.

3.7.2 Enhancing communications

Poor communications among project stakeholders leads to confusion, misunderstandings, and conflicts among project stakeholders (Wu et al. 2017), and may result in a project failure. Blockchain not only provides a powerful and secure alternative for peer to peer communication, but also enables a trusted and real-time single source of truth to eliminate confusions and misunderstanding for enhancing communications between the project participants. The highlighted contributions of the blockchain in the reviewed use cases for enhancing communications include promotion of information sharing (Li et al. 2019), reduction of the possibility of tampering (Yang et al. 2020), access to identical data that is verified by a consensus (Poptawski and Szczypiorski 2018), and creation of a single source of truth (Hamledari and Fischer 2021).

3.7.3 Reducing disputes and claims

The contributions of blockchain to enhance trust and communication among the project stakeholders are expected to reduce the disputes and claims that are related to these issues. However, the highlighted contributions of blockchain in use cases for reducing disputes and claims were not limited to only those associated with enhanced trust and communication. The blockchain is stated to facilitate resolving disputes regarding precast components, as it enables tracking the operation details in the precast construction use case (Wang et al. 2020). Similarly, the potential of blockchain to reduce disputes caused by inaccurate documenting of non-conformances was emphasized in the pile inspection use case (Sheng et al. 2020). The contributions of smart contract enabled automated systems for eliminating disputes and claims that are related to payments were highlighted in Li et al. (2019) and Yang et al. (2020).

3.7.4 Preventing fraud

Fraud and corruption may seriously affect the efficiency of projects and can be cause major project cost overruns (Aguilar et al. 2000). Corruption worsens both cost and time performance and is a crucial phenomenon within the context of project management, particularly in public projects and megaprojects (Locatelli et al. 2017). Development of anticorruption strategies is crucial for preventing fraud and corruption and eliminating project failures as a result of this problem (Le et al. 2014). Blockchain enables a novel strategy for preventing fraud and corruption with its security, transparency, decentralization, immutability, traceability, and self-execution properties. Smart contracts empower control of financial and non-financial assets by an automated code that runs on the decentralized blockchain. Hence, decentralized smart contracts could be used to eliminate or reduce human control of financial assets to prevent fraud and corruption. The benefits of blockchain for preventing fraud were emphasized in the reviewed publications and also in the specific use cases. The use case examples include an anti-counterfeiting platform for supplier evaluation (Liu et al. 2020), a quality information management system to reduce possibility of upload of fraudulent data (Sheng et al. 2020), and an energy performance contracts prototype that has a potential to prevent malicious manipulation of contract terms (Gürcan et al. 2018).

4 A Design decision framework for blockchain applications in project management

Despite the fact that blockchain includes several properties simultaneously and presents a major potential for improving the management of projects, the properties and advantages of the blockchain applications depend on technical design decisions including; privacy, transparency, decentralization, type of the blockchain, and the blockchain platform used to develop the blockchain system. In this section based on the review findings, a design decision framework is presented to guide implementers and researchers on these blockchain design decisions for maximizing the benefits of blockchain applications in project management.

4.1 Selection of the blockchain type

The key properties that defines the type of the blockchain are the decision mechanism for the blockchain permissions and the ownerships. If the blockchain is public than no permission is needed and there is no ownership, on the other hand for private and consortium type of blockchains, the company or consortium running (owning) the blockchain has the control and can easily change the rules of the blockchain, revert transactions, modify balances or smart contract codes, etc. This control mechanism decreases the level of decentralization, but enables control of the blockchain activities to some extent, hence brings flexibility (Buterin 2015). But on the other hand along with decentralization; transparency, reliability, immutability, authenticity, and self-execution properties of public blockchains are not fully guaranteed in permissioned private and consortium blockchains. However, permissioned blockchains present an efficient and low cost alternative particularly for organizations that seek privacy.

Public, private, and consortium blockchains were developed based on similar concepts. However, there are major differences among their purposes and properties, hence selection of the most adequate blockchain type for a particular application is an important decision for maximizing the benefits of the desired blockchain. Decentralization versus control, transparency versus privacy are some of the trade-off that needs to be considered as shown in Fig. 4. Hybrid blockchains, which leverage both public and private blockchain infrastructures are proposed in recent years, to enable blockchain applications that include a fully decentralized part, but at the same time, provide efficiency along with privacy (Desai et al. 2019).

Among the reviewed use cases, eleven uses cases included the information of the type of the blockchain along with the platform suggested or used. The selections of the use cases that specified the type of the blockchain and the platform are summarized in Table 3. Five use cases used or proposed consortium blockchains, four public, and two private blockchains.

4.2 Selection of the blockchain platform

Once the type of the blockchain is determined, the next crucial decision for the blockchain design is the selection of the platform that the application will be developed. Few studies presented methodologies for selection of blockchain platforms. In a recent study, Nanayakkara et al. (2021) presented a methodology for selection of a blockchain platform to develop an enterprise system in which permissionless blockchain platforms were eliminated and only one platform is recommended for development of enterprise systems without considering the trade-offs between decentralization versus control, and transparency versus privacy. The technical decision framework presented in this research has a different focus. The objective of the proposed framework is to enable selection of the most adequate platform for a particular project management application, hence the framework enables selection of different platforms for different applications.

In this section popular public, private and consortium blockchain development platforms are evaluated in terms of their advantages and disadvantages for project management applications. Since majority of the blockchain applications in project management require automated transaction protocols that are executed on the blockchain, only the platforms

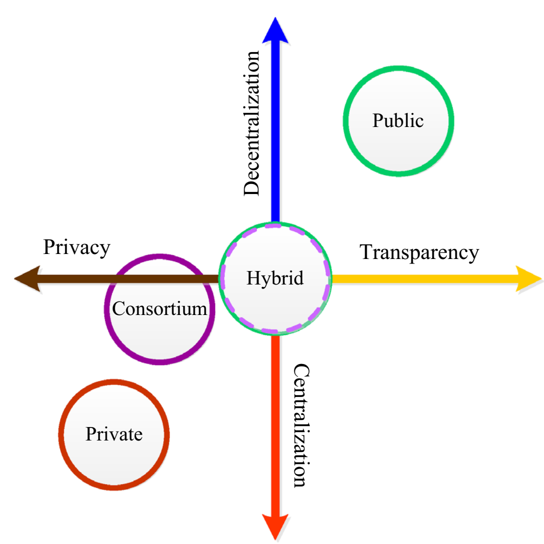

Fig. 4 The impact of blockchain type decision on decentralization and privacy

Table 3 Blockchain type and development platform recommended or used in the use cases

Use case	Area–sub area	Method	Type	Platform
Helo and Shamsuzzoha (2020)	IM-1	System	Public	Ethereum
Wang et al. (2020)	IM-1	System	Consortium	Hyperledger fabric
Yang et al. (2020) (first case)	IM-3	Case study	Private	Hyperledger fabric
Nawari and Ravindran (2019)	IM-3	Framework	Consortium	Hyperledger fabric
Sheng et al. (2020)	IM-5	System	Consortium	Hyperledger fabric
Machado et al. (2020)	IM-6	Conceptual	Consortium	Hyperledger fabric
Elghaish et al. (2020)	IM-8	Framework	Consortium	Hyperledger fabric
Yang et al. (2020) (second case)	PY-1	Case study	Public	Ethereum
Ahmadisheykhsarmast and Sonmez (2020)	CM&PY-10	System	Public	Ethereum
Abbas et al. (2020)	IM&CM-5	System	Private	Hyperledger fabric
Das et al. (2020)	IM, PY & CM-11	Framework	Public	Ethereum

that support development of smart contracts are included in the evaluations, blockchains that are mainly used for cryptocurrency transactions are not considered.

4.2.1 Public blockchain development platforms

Ethereum, Cardano, and EOSIO are among the top blockchain platforms based on their technical maturity and popularity within the developing community (Zheng et al. 2020), as well as, their suitability for decentralized smart contract development (Garriga et al. 2020). In recent years, several alternative platforms that support development of smart contracts are proposed. However, very limited publications evaluated the technical maturity, popularity, performance, and transactions costs of these new blockchain platforms. Hence, only Ethereum, Cardano, and EOSIO public blockchain platforms are considered in this research.

Among the top public blockchain platforms Ethereum has been the only choice for all of the four public use cases, as shown in Table 3. This dominance is mainly due to the maturity and popularity of the Ethereum as being the first blockchain platform enabling smart contracts (Li et al. 2021) and also due to the fact that it provides a powerful smart contract engine which has been designed very generically and leaves many application options open and that can basically be used as a universal platform for any type of application (Valenta and Sandner 2017; Keller et al. 2018; Mor et al. 2021; Fang et al. 2021). The popularity of the Ethereum blockchain also provides availability and diversity of the development resources and community support (Ahmadisheykhsarmast and Sonmez 2020; Mokdad and Hewahi 2020). Ethereum has the biggest market capitalization among the three blockchains, which is particularly important for applications requiring large payments. The current market capitalization of Ethereum is $398.3 Billion (Etherscan 2021), Cardano (ADA coin) is $72.4 Billion (Cardanoscan 2021), and EOS (cryptocurrency of EOSIO) is $4.5 Billion (Eoslflare 2021). Market capitalization is an important factor for applications requiring large payments. For example, for a smart contract system that requires cryptocurrency payments for multi-billion mega construction projects, if market capitalization of the cryptocurrency is not sufficient, a large amount of buying demand of cryptocurrency by the project owner may lead to rapid appreciation of the cryptocurrency against fiat currencies, similarly a large amount of selling demand of cryptocurrency by the contractor may result in a rapid depreciation of the cryptocurrency against fiat currencies (Ahmadisheykhsarmast and Sonmez 2020).

Despite its several advantages Ethereum platform has few disadvantages. The confirmation time (the time that a transaction is appended to the blockchain) and transactions cost for the Ethereum blockchain is reported to be significantly higher than those of the EOSIO blockchain (Garriga et al. 2020, Mokdad and Hewahi 2020). Cardano blockchain presents an alternative to Ethereum blockchain, however the confirmation time and transaction costs for Cardano is also higher than those of EOSIO (Garriga et al. 2020). Hence, particularly for applications requiring fast and low cost transactions, EOSIO platform may provide a better solution, although it is not as mature and popular as the Ethereum platform.

4.2.2 Private, consortium and hybrid blockchain platforms

In recent years, Hyperledger Fabric has been the common choice for development of private and consortium blockchain applications, which can also be observed in the use cases reviewed. All of the use cases, which consisted of five consortium and two private blockchains, adopted or recommended Hyperledger Fabric. Nanayakkara et al. (2021) performed a comparison of seven blockchain platforms (which did not include Ethereum) that support permissioned networks, and recommended Hyperledger Fabric for developing an enterprise system. One of the main advantages of

Hyperledger Fabric is that is utilizes general-purpose commonly used programming languages, such as Java. However, this advantage comes with the disadvantage that these languages were not originally designed for coding smart contracts and may present risks that developers do not need to consider when using specific smart contract languages, such as Solidity of the Ethereum platform (Yamashita et al. 2019). While the original Ethereum blockchain is a public blockchain, it is possible to create private or consortium blockchains using the Ethereum platform (Buterin 2015). Ethereum platform also enables development of hybrid platforms in which a private or consortium blockchain is integrated with a public blockchain (Desai et al. 2019). In this research only the Hyperledger Fabric and Ethereum platforms are considered for private and consortium blockchains as literature includes numerous studies on the limitations and advantages of these two popular blockchain platforms (Pongnumkul et al. 2017; Hao et al. 2018; Yamashita et al. 2019; Monrat et al. 2020; Panwar and Bhatnagar 2020).

The main limitation of the Ethereum platform for private and consortium blockchain applications is its performance against Hyperledger Fabric (Pongnumkul et al. 2017; Hao et al. 2018; Monrat et al. 2020; Panwar and Bhatnagar 2020). The experiments conducted by Pongnumkul et al. (2017) revealed that Hyperledger Fabric consistently outperforms Ethereum across three performance metrics which are execution time, latency and throughput. Hao et al. (2018) assessed the performance of consensus algorithms of Ethereum and Hyperledger Fabric and made the conclusion that Hyperledger's consensus algorithm outperforms Ethereum's algorithm in terms of average throughput and average delay. The performance analysis results of Monrat et al. (2020) which was based on the throughput and latency evaluation metrics, illustrate that Hyperledger Fabric performs better than Ethereum in permissioned platform. Similarly, Panwar and Bhatnagar (2020) performed performance analysis of Ethereum and Hyperledger Fabric private blockchain platforms with changing amount of transactions and revealed that Hyperledger Fabric achieves higher throughput and a low-level latency as compared to Ethereum and also, Hyperledger provides a less execution time than Ethereum as the number of transactions increase. Despite the fact that Hyperledger Fabric enables a higher efficiency, its diversity and availability of the development resources and as well as its powerful smart contracts engine makes Ethereum an adequate alternative also for private and consortium smart contract blockchain applications, particularly for the applications that are not seeking a high performance.

4.3 Decision framework

A decision framework is developed based on the findings of the review. The main objective of the framework is to maximize the benefits of the blockchain while minimizing its disadvantages for a specific project management application. The perceived properties and advantages of the blockchain along with its contributions to the project management are considered in the proposed framework. The framework considers the decisions related to decentralization, privacy, flexibility, transparency, efficiency, transaction costs, use of common programming languages, maturity of the blockchain platform, market capitalization of the cryptocurrency used, and the need for a powerful smart contract engine. The framework identifies the main category of the project management application and considers the decisions related to a particular category namely; information management, payments, and contract management.

The framework starts with the determination of whether the application requires cryptocurrency transactions, as shown in Fig. 5. If the application requires cryptocurrency transactions, the main domain category is determined as payments. In the payments category, only public blockchain and hybrid blockchain platforms are considered, as only public platforms enable cryptocurrency transactions currently. The first decision for the payments category is made according to privacy requirement. If privacy is required, Hybrid-Ethereum platform is selected. If privacy is not required, the next decision of the payments category is about the size of the transactions. If the application will be used to make large cryptocurrency transactions, Public-Ethereum platform is recommended due to its large market capitalization of Ether. If the application will not be used to make large transactions, a selection is made between the Public-EOSIO (efficiency and low transaction costs) or Public-Ethereum (maturity and powerful smart contract engine) platforms.

The framework next considers guaranteed execution of contract conditions. Although smart contracts can also be coded with private and consortium blockchains, only public blockchains guarantee execution of smart contracts, as the company or consortium running the blockchain can easily modify the smart contracts. However, in public blockchains, once a smart contract is deployed on the blockchain it cannot be modified and execution of smart contracts are guaranteed. If the application requires guaranteed execution of contract conditions, the main domain category is determined as the contract management. In the contract management category, the first decision is made on the privacy requirement. If the contract management application requires privacy, a Hybrid-Ethereum platform is recommended as this hybrid option could guarantee execution smart contracts along with privacy. If privacy is not required a selection is made among the properties of efficiency and low transaction costs (Public-EOSIO), or maturity and the need for a powerful smart contract engine (Public-Ethereum).

In the proposed framework, if the application does not require cryptocurrency transactions or guaranteed execution

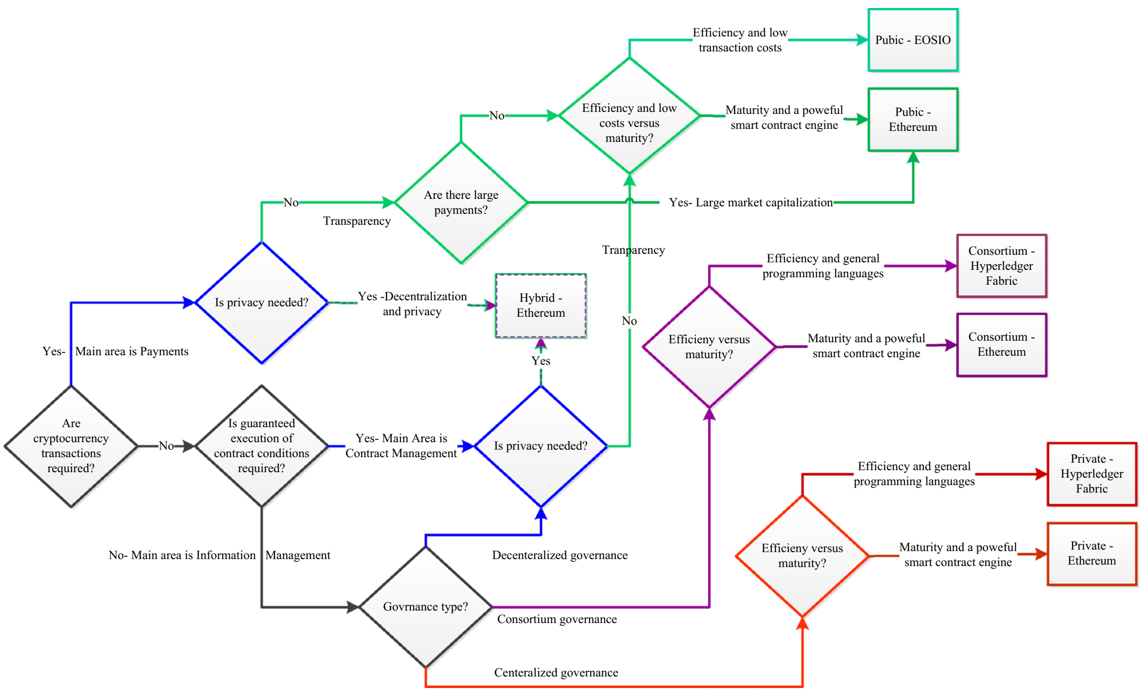

Fig. 5 Blockchain decision framework for project management applications

of contract conditions, the main domain category is identified as information management. The first decision for the information management category is made based on the level of decentralization required for the application. If full decentralization is required to guarantee transparency, reliability, immutability, traceability, authenticity, and self- execution properties; decentralized governance should be selected. The next decision for an information management application that requires decentralized governance is on the level of privacy. The proposed framework includes a hybrid blockchain alternative which enables fine tuning of the decentralization and privacy properties for a specific application. Hence, if a part of the application requires fully decentralization and privacy is also needed, Hybrid-Ethereum platform should be used. When full transparency is preferred together with full decentralization, a selection is made between the Public-EOSIO or Public-Ethereum. If consortium level governance is more suitable for the information management application, the decision is made based on the properties of consortium platforms. Consortium- Hyperledger should be used when efficiency and use of general programming languages are required. Consortium-Ethereum should be selected when a mature platform with a powerful smart contract engine is required. In some blockchain applications in information management, central control and full flexibility may be preferred instead of decentralization, hence a selection should be made among Private-Hyperledger and Private-Ethereum platforms.

5 Conclusions and future research directions

The contribution of this paper for research and practice is two-fold. The paper first provides a systematic literature review, develops a taxonomy of blockchain application domains, and identifies major contributions of blockchain in project management. Based on the findings the paper than presents a blockchain decision framework for maximizing the benefits of blockchain applications for project management.

The analysis of the use cases indicate that the unique and novel properties of blockchain enables a major potential for building trust, enhancing communications, reducing disputes and claims, and preventing fraud in project management particularly in the information management, payments, and contract management application domains. However, the properties and advantages of blockchain for a particular application depend on the technical decisions. A framework is presented based on the review results for making the optimal blockchain and platform selection decisions during development of project management applications. The proposed framework can guide implementers and researchers on technical design decisions including privacy, transparency, decentralization, blockchain type, and platform selection decisions in development of blockchain systems for a particular domain.

Despite the fact that blockchain present numerous properties simultaneously and has an unique potential for contributing to management of projects in different aspects, the review results reveal that blockchain applications in project management is at its early stages. The current blockchain applications mainly focus on the information management, with few emphasis in payments and contract management domains. Majority of the blockchain publications in project management research consist of conceptual studies, case studies, and frameworks, only very few has developed systems. Hence, there is a major gap in research focusing development of blockchain systems in project management, particularly in the area of decentralized applications.

Decentralized project bidding systems that are controlled by the blockchains is a potential area for future research. The whole project bidding process could be presented as a smart contract deployed on a decentralized public blockchain, which will eliminate human interference during bidding. Decentralized project bidding systems would provide full transparency, build trust among the bidding participants, and could eliminate or reduce fraud in project bidding.

Integration of blockchain with artificial intelligence is another potential area for future research in project management. Decentralized decision support systems that are based on blockchain and artificial intelligence would provide a trusted and transparent alternative for improving the decision making process in different domains of project management. One particular example is a decentralized application for dispute resolution. The application could include an artificial intelligence part which is coded as a smart contract and deployed on the public blockchain. The autonomous and independent decentralized application for dispute resolution would provide an efficient, trusted and transparent alternative and could enable stakeholders to resolve disputes before going for expensive and inefficient alternatives.

Blockchain applications in project management is at its very early stages, however it is receiving increasing attention. The review results reveal that a wide range of sectors in project management domain is showing interest for adopting the blockchain for different purposes. Blockchain not only provides a novel technology for enabling major contributions to management practice, but also presents a new and interesting research area for achieving decentralized project management.

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