INTEGRATED PROJECT DELIVERY WITH BLOCKCHAIN: AN AUTOMATED FINANCIAL SYSTEM

Faris Ali Khairy Elghaish, Sepehr Abrishami & M. Reza Hosseini

ABSTRACT

Integrated project delivery (IPD) in the architecture, engineering and construction (AEC) industry relies on risk/reward sharing and deferral of parties' profit payments until all project activities are completed. A decentralised, automated and secured financial platform is needed to enable all parties to control and track financial transactions, with no unauthorised changes allowed. The new technology, blockchain, enables data to be recorded, has no network participant with dominant power and manages data using specific functions, in line with smart contracts. The present study is the first to develop a framework proposing blockchain technology utilisation in IPD projects. The framework would enable core project team members to automatically execute all financial transactions, through coding the three main transactions of IPD projects: reimbursed costs, profit and cost saving, as functions of the IPD smart contract. To demonstrate the proposed framework's applicability, a "proof of concept" is developed and validated through an IPD case project. The practicality of the built-up hyperledger network (IBM® Blockchain Cloud Beta 2) and the advantages of the proposed smart contract functions are examined. The user-friendliness of the proposed financial system and its efficiency in automating all transactions are demonstrated. No deficiency is found in the blockchain network components. The study's findings, applied in a favourable external context, would facilitate IPD adoption and use across the AEC industry by providing a workable solution to existing financial barriers. The findings extend the horizon for further research on exploring blockchain's capabilities to solve comparable deficiencies to those affecting the AEC industry.

Keywords: Distributed ledger technology (DLT); Smart contract; Hyperledger fabric; Building Information Modelling (BIM); Alliancing; 5D BIM; Financial transactions.

1. INTRODUCTION

Integrated project delivery (IPD) is a delivery approach characterised by: (1) early involvement of project participants [1 ,2]; (2) sharing risks/rewards [2 ,3]; (3) replacing the tender stage by the buy-out stage, without traditional bidding [1]; and (4) deferring payment of profits until all project works are completed [4]. Therefore, IPD requires a distinctive financial management approach, as well as a collaboration platform [2 ,4]. A review of the literature indicates that the financial system and collaboration platform required for IPD projects must satisfy several requirements [5]. These are: (1) a readable/consistent accounting system is needed [4]; (2) all project participants can check all cost records including those of other project participants [2]; (3) all recorded data should be immutable to achieve the desired trust environment [2 ,4]; and (4) the collaboration platform should be inaccessible to any third party [6].

To enable parties to interact and share sensitive data [7], IPD requires the adoption of high levels of information and communications technology (ICT). Blockchain can be an ideal solution for the following reasons: it is defined as a distributed ledger that has the advantage of decentralising the operation across the network through a specific consensus mechanism (i.e. peer to peer) [8]; all data are presented as blocks which will be immutable once joined to the chain; and self-authentication is required for all new recorded data [9].

Recently, researchers and practitioners have focused on exploring the various ways in which blockchain can be used in the AEC industry. The use of smart contracts to automate payments without appointing a third party and the sharing of data through a decentralised platform [9 ,10] have been particular areas of interest in construction management. The AEC

industry is therefore exploring blockchain opportunities in the following functions: creating immutable financial systems [9 ,11]; sharing information through a highly secured platform [10 ,11]; and using smart contracts to automate payments [9 ,11].

Another advanced methodology in the AEC industry, Building Information Modelling (BIM) is designed to enhance project delivery [12]. That said, some deficiencies are apparent, such as the lack of integration methods that foster BIM adoption [13]. The most advanced form of BIM implementation, BIM level 3, relies on a delivery approach that facilitates collaboration and shares risks/rewards among project parties [14]. Furthermore, the recent wave of research in the AEC industry presents the feasibility of integrating blockchain into construction processes to accelerate collaboration, maximise trust and cut costs by minimising third-party involvement in legal/financial tasks [15]. With these points in mind, taking advantage of the interrelationship between BIM and IPD is highly recommended [2 ,16]. The integration of BIM with blockchain is also encouraged [10 ,11], with various researchers having acknowledged the capabilities of blockchain in offering solutions for the deficiencies of existing financial systems. For instance, Abrishami and Elghaish [8] present some generic cases of blockchain application in the AEC industry, and Turk and Klinc [9], Wang et al. [17] discuss blockchain's potential to enhance construction management processes and tools. Other studies have investigated the integration of blockchain and BIM, such as the work of Mathews et al. [18], in which the authors present the various ways that blockchain could enhance collaboration when BIM is being used.

However, none of the available studies go beyond the theoretical realm; in other words, their contribution remains confined to proposing conceptual frameworks or theoretical models. The present study provides a background for responding to the widespread consensus on the capabilities of blockchain in construction management, in practical terms. It extends existing research studies by moving beyond theoretical models to develop a workable solution.

The objectives of this study are pursued through: (1) developing a framework to build an automated financial system using blockchain (hyperledger fabric), while considering BIM throughout the process; (2) building blockchain network components and a smart contract – including all IPD transactions, such as reimbursed costs, profit and cost saving – for an IPD project; and (3) testing the proposed IPD-based blockchain framework through developing a proof of concept, using the IBM® Blockchain Platform Cloud Beta 2.

This paper is structured as several sections. The theoretical background is presented next in order to provide insight into the topic's essence and to establish the gap in the literature. This is followed by descriptions of the development of the framework and the validation process for the case project. The paper concludes by setting out several recommendations for practitioners and by clarifying the study's implications, from a broad perspective.

2. THEORETICAL BACKGROUND

2.1. Distributed ledger technology (DLT)

Tapscott and Tapscott [19] define blockchain as a distributed ledger that records all data shared among different members in a network. Each transaction represents a block in the network and, subsequently, new blocks are linked to the previous ones, in order to create a chain [20]. The interrelationships among all blocks maximise the opportunity for security [21]; that is, each block carries data and a hash (i.e. a code) for previous blocks to reduce the chance of hacking [22]. Mason and Escott [20] define two categories of blockchain networks (BCNs). The first category, the public BCN, can be accessed publicly under the generic consensus mechanism. However, it remains secure due to its cryptography power mechanisms, like Bitcoin [23]. The second category is the private BCN, characterised by having pre-identified users, in which the mechanism for obtaining users' consensus must be clearly identified [24]. The private BCN represents a single BCN platform for a certain organisation, with the data

centralised in that organisation; however, the data are decentralised between network users [23].

Kumar and Mallick [25] define the BCN as a tamper-proof technology that makes it fit for multifunctioning and, therefore, a promising technology through which to avoid a wide range of bad practices across various industries. Similarly, the BCN provides high levels of security, as the block recorder can check all the recorded data, in terms of the sequence and the interrelationships of data in the network [26]. In the BCN, this prevents the likelihood of tampering with data [25]. In addition, BCNs are efficient in supporting computing solutions [9,11]. The cost of implementing blockchain is justified, when compared to the cost of using third parties to implement financial tasks [27]. The price of conducting a transaction relies on the size and load of the BCN; the cost can also be optimised by adding specific provisions to the smart contract. [28].

Blockchain networks (BCNs) comprise two categories of nodes: (1) the network member nodes and (2), to direct information inside the BCN, the orderer peer nodes. For sending any new data to the BCN, smart contracts include a set of functions which can be invoked at any time to send data within the BCN, as described in the next section.

2.2. Smart contracts

The development of smart contracts dates back to 1994, with “a smart contract” defined as an automated system to perform contract terms, such as payment transactions, through an automated/agreed protocol [19,29]. Due to contract terms being executed based on pre-identified consensus mechanisms [30], a traditional trusted third party is not needed. Meanwhile, Peters and Panayi [31] propose the following comprehensive definition of a smart contract: a platform for enforcing and monitoring the data entered by trusted sources, to be stored in a BCN, based on pre-identified contract terms. These pre-identified terms should be

121 coded/written using a program language like Go (see Donovan and Kernighan [32] for details).
122 This is one of the blockchain features and its ability to transfer cryptocurrency/data over
123 blockchain is a result of the evolving BCN throughout the last decade [29]. Andoni et al. [23]
124 state that smart contracts use peer-to-peer (PTP) networks that enable multi-trusted parties to
125 manage data simultaneously, so that each chain in the BCN carries its own data and,
126 subsequently, all data are stored in the ledger, according to the agreed consensus mechanism
127 [33]. Smart contracts also reduce dependency on lawyers/third parties in executing and
128 monitoring contract terms, such as financial transactions, hence the accuracy and
129 transparency of data can be enhanced [20]. In fact, as Christidis and Devetsikiotis [29] point out,
130 smart contracts benefit users by providing an automatic audit of the transferred data. Once the
131 validity of the data has been shown, the data can be immutable to enhance transparency and
132 security.

133 Smart contracts have a close affinity with the chaincode in the hyperledger fabric, given that
134 the chaincode ensures that all transactions are linked and properly sequenced. A discussion of
135 the origin of smart contracts and how they work relies on explaining the structure of the
136 hyperledger fabric as a blockchain platform and the way that the chaincode operates.

137 Klaokliang et al. [34] describe the structure of the hyperledger as follows:

- 138 • **Ledger:** a set of blocks that records multiple transactions.
- 139 • **Peer:** a pool that contains ledgers and smart contracts.
- 140 • **Chaincode:** the smart contract that performs transactions according to the
141 hyperledger concept.
- 142 • **Channel:** the path taken by the transaction and blocks, to be allocated among
143 different peers.

- **Endorsement policy:** a set of instructions providing specific metrics to the peer to decide if the transaction received is valid or invalid [35].
- **Ordering service:** the ordering service node (OSN) that is utilised to order transactions and blocks based on the agreed consensus mechanism, such as Kafka (see Javaid et al. [36]). This node should include specific information regarding the size of blocks, maximum time and number of transactions allowed for each block, before assigning it to the peer through the channel [35 ,37].
- **Consensus mechanism:** a set of protocols designed to ensure that all the network's nodes work according to the agreed conditions and defined steps to endorse transactions [23 ,38].

2.3. Blockchain/smart contracts in construction

Blockchain has not been widely adopted across the construction industry; however, several attempts to use blockchain have been made by developing business models [15]. As an example, BIMCHAIN is a proof of concept to integrate BIM into blockchain in the form of a plug-in for BIM platforms [11 ,39]. Fox [40] reports on several cases of adopting smart contracts in the construction industry, such as: delivering the agreed contracts automatically with enabling parties to update any variations; enhancing copyright for project documentation; and making automated payments among project parties, adding that it can also work as a claim submission platform [11 ,15]. As a result, smart contracts will be valuable in the automation of some construction processes that traditionally rely on multi-interactions and contributions from project participants in making decisions [20 ,30].

Cardeira [41] states that late payments and insolvencies in the construction industry lead to several claims, but the adoption of smart contracts can significantly reduce the negative consequences [40]. Therefore, (ICE) [10],Lamb [11] contend that a smart contract is a simple

and quick executable solution, making it promising for business developments. In fact, complex transactions are relatively expensive; therefore, adopting smart contracts will reduce these accumulative costs [42].

Uncertainties in construction payments are a challenge in developing a reliable cash flow, subsequently leading to claims that affect business growth [43]. With the recommended construction trust account [41], smart contracts can work as trust accounts that hold the money to be transferred automatically to the party who is to receive it [41]. Project participants will trust smart contract outputs, given that all the embedded data are immutable and decentralised [11,20].

Koutsogiannis and Berntsen [44] argue that digital construction is an integrated process. With the growth of digitalisation across the AEC industry, smart contracts can be implemented for a wide range of activities. The utilisation of smart contracts with cryptocurrencies can provide a draft contract that specifies where particular funds can be kept to avoid common insolvency issues or late payments [41]. In addition, cross-verification by several references leads to the acquisition of an efficient, robust, secure and reliable system, thus building a trust environment among project parties [20,30].

2.4. Integration of BIM, IPD and smart contracts

Turk and Klinc [9] state that blockchain platforms (e.g. Ethereum and hyperledger) can be integrated with BIM to add new features. These features can record all the changes in three-dimensional (3D) BIM models throughout the design and construction stages, subsequently enabling stakeholders to easily track these changes [45]. Mason and Escott [20] assert that BIM integrated with smart contracts will be attainable by 2020, due to the foreseeable increase (up to almost 25 billion) in the number of sensors in devices. The promise of BIM level 2 is the minimisation of paper-based communications and exchange [46]; therefore, a platform is

much needed that shares information among project parties with high levels of transparency and tracks all possible changes [47]. Moreover, Parn and Edwards [6] recommend the utilisation of blockchain with the common data environment (CDE) to enable the recorded data to be tracked with displaying recorders, as the data will be stored as a set of nodes.

Cousins [48] argues that BIM processes require a 3D contractual model that includes all the data needed for validation and authorisation of all possible tasks. BIMCHAIN, as discussed, can minimise the gap between 3D BIM models and paper-based legal documentation [39]. It can be seen as an attempt to manage BIM by using smart contracts that enable automated payments, insurance and project information tracking [11 ,39]. Smart contracts can therefore be coded for integration into BIM processes/platforms, enabling traditional provisions to be executed in an automated way. This will facilitate the access of all stakeholders to all available data in a secure way, managing project funds and releasing the owed payments based on a set of agreed-upon rules [40 ,41]. Additionally, blockchain can provide a secure and collaborative environment for BIM processes [7 ,8], in which all project parties can obtain the same benefits in accessing all the information. Stakeholders will also have the chance to control project changes, due to the main blockchain principle regarding neutrality [8].

Mathews et al. [18] contend that IPD requires a high level of trust and a collaboration network among core team members: all IPD team members are supposed to be ‘all for one and one for all’ [49]. Blockchain, due its capabilities in terms of transparency, immutability and automated data validation, will be able to create a new proposition [8 ,33]. Therefore, all sorts of rewards can be extracted, be they tangible or intangible [43 ,50]. Moreover, blockchain allows several participants to work collaboratively in a single project and supports a data-driven digital environment for better project delivery [8 ,44]. Some researchers, such as BIMCHAIN [39], Cousins [48], assert that the combination of BIM and blockchain can provide an

incorruptible, reliable and transparent system to record, update and maintain the project database. Blockchain and smart contracts not only enhance collaboration in the construction industry [51], but also keep all participants informed of the project status and all changes, such as 3D BIM design, construction site procedures and the flow of supply materials [18].

2.5. Decision criteria for selecting a suitable blockchain platform for IPD

A major hallmark of IPD is its compensation system for allocating gain and pain ratios among project participants [52]. This necessitates a cooperative contracting relationship that ties the individual success of participants to success in achieving the project objectives [1]. All participants must agree on a suitable compensation scheme [50], with this scheme determining the proportions of cost overrun, cost underrun and any other fees within the total budget and under the agreed cost [50, 52]. The cost scheme must comprise direct, indirect and overhead costs and capture the risk/reward proportions based on the degree of achievement during project delivery [50, 53]. In IPD, three components or limbs can be defined: Limb 1 represents the reimbursement of project costs and captures all project implementation costs (guaranteed); Limb 2 refers to the overhead costs for all participants, in addition to the profit (at-risk); and Limb 3 is the pain or gain ratios (the contractual agreement) [53].

Table 1 shows the IPD characteristics in terms of financial processes, illustrating the five common permissioned blockchain platforms. The suitable platform is the one with characteristics matching the corresponding IPD characteristics. The five platforms can be summarised as follows:

- Hyperledger fabric, as discussed.
- Ethereum, an open and programmable blockchain platform: (1) enables anyone to sign up and create an Ethereum account; (2) enables decentralised applications to be

built, as well as smart contracts to be deployed; and (3) uses a cryptocurrency called Ether and has a consensus mechanism that is not fabricated [54].

- R3 Corda is designed as a specialised distributed ledger platform for the financial industry: it is classified as a permissioned blockchain platform, with a token able to be sent using a smart contract [55].
- Ripple is an open payment system: as well as a digital currency called ‘XRP’, it has a consensus mechanism called Ripple Consensus Algorithm (RPCA) that is not fabricated. It has its open source project for smart contracts [56].
- Quorum is designed to provide security and maintain a desired level of privacy for financial and banking services. Interested readers are referred to Baliga et al. [57] for details.

The consensus mechanism should be modular and flexible to enable IPD parties to develop a suitable mechanism, according to the team and project environment; therefore, Ethereum, Ripple and Quorum cannot be used to develop an IPD financial system.

The consensus mechanism, privacy, sending transactions as fiat currency or by tokens and the functionality of smart contracts are the main distinctions among the five listed platforms. Of these platforms, the Ethereum platform is a private blockchain; hence, any interested entity can join based on agreed algorithms [58,59]. It is, however, not designed for business networks. Regarding the consensus mechanism, Ripple and Quorum use probabilistic and major voting techniques, respectively [60]. Accordingly, these two platforms are not sufficiently flexible to enable the design of a consensus mechanism based on agreement among an IPD’s core team members. The R3 Corda permissioned blockchain platform enables a network’s participants to modularise the consensus mechanism, with transactions able to be sent and recorded as fiat currencies [55,59].

264 The hyperledger fabric has a consensus mechanism that is modular and can be fabricated
265 according to terms agreed among network (project) participants [37]. Regarding the
266 applicability of permissioned blockchain platforms, several commercial packages are
267 available, for example, the IBM® Blockchain Cloud, the Oracle Blockchain platform and the
268 SAP Cloud, among others [61], with these able to work in cooperation with the hyperledger
269 platform to facilitate its implementation. It can therefore be inferred that the hyperledger
270 platform is the most appropriate for IPD projects, as shown in Table 1.

271

Table 1. Permissioned blockchain platforms and IPD financial characteristics

No	IPD characteristics	References	Blockchain platforms					References for blockchain platforms
			Hyperledger fabric	Ethereum	R3 Corda	Ripple	Quorum	
1	IPD core team members are pre-identified entities; all members should acquire the same information at the same time as it is released.	[2 ,53]	✓	✗	✓	✓	✓	[58 ,60]
2	Risks/rewards are shared among parties; this requires all parties to be able to track project progress (cost and schedule) and having access to all data, regardless of their location.	[3 ,50]	✓	✗	✓	✓	✓	[60]
3	A new party can join at any time after the core team members are formulated.	[43 ,49]	✓	✗	✓	✓	✓	[37 ,60]
4	Three financial transactions should be invoked in each payment milestone (reimbursed cost, profit and cost saving).	[3 ,4]	✓	✓	✓	✗	✓	[60 ,62]

5	The consensus mechanism should be flexible, so it can be changed based on agreed conditions.	[7]	✓	✗	✓	✗	✗	[38 ,62]
6	As IPD core team members come from different backgrounds, the financial system should be friendly for various users, understandable and flexible: a platform that uses commercial packages is preferred.	[2 ,16]	✓	✗	✗	✗	✗	[61 ,63]
7	Financial transactions should be invoked and recorded in specific tokens (fiat currencies such as dollars).	[2 ,4]	✓	✗	✓	✗	✓	[35 ,58 ,60]

3. RESEARCH GAP AND JUSTIFICATION

Research on blockchain has received much attention in recent years [7 ,9]. Some researchers have demonstrated the importance of implementing specific features of blockchain, such as smart contracts in automating payments in the construction industry [20 ,30]. Evidence in the literature acknowledges the wide applicability of blockchain and smart contracts. For example, Mathews et al. [18] argued that the integration of BIM and blockchain can maximise trust among project participants in the AEC industry, while Abrishami and Elghaish [8] proposed that blockchain can be useful in enhancing supply chain management. However, to date, the available research studies on the topic have not gone beyond conceptual proposals and recommendations. Research on the topic has therefore been limited to the theoretical conceptualisation of possible applications of blockchain in the AEC industry.

The above gap can be a major issue across the AEC industry. With the growth in adoption of BIM level 2 and the move in BIM level 3 towards the full integration of all dimensions [64], the need to use IPD [50] is increasing. The integration of BIM and IPD [14] also requires much more research. Moreover, some aspects of IPD implementation, particularly financial management, act as major barriers. To be specific, sharing risks/rewards requires an automated/immutable system to record the achieved profit, cost saving and reimbursed monetary values for each member, as the IPD core team members cannot receive their profits and rewards until all project works are delivered [3 ,4 ,50].

Through a comparison of the requirements of an efficient IPD financial system and blockchain capabilities, specifically hyperledger fabric, building an IPD financial system using hyperledger fabric is conceptually confirmed in this study. This

confirmation builds on the capabilities proven in previous studies, such as the works of Abrishami and Elghaish [8], Nawari and Ravindran [65], Li et al. [66]. It also provides a response to widespread recommendations to utilise blockchain and BIM in an integrated way. The present study's outcome is intended to enhance the financial process in the AEC industry, particularly for IPD projects, as recommended in the literature [11, 39].

4. RESEARCH METHOD, DESIGN AND TOOLS

The objective here is to present and then test a workable solution through developing a proof of concept, using the permissioned blockchain (hyperledger fabric platform). The blockchain approach is used as it can provide a secure platform for the transferral of data of a sensitive nature, as previously discussed.

The present study uses an experiment as the principal method for testing assumptions on the effectiveness and workability of the proposed automated financial system for the IPD approach. The reason is that experiments are effective in revealing whether real data either support or rebut the conceptualisations of a study's researchers. According to Zellmer-Bruhn et al. [67] "experiments isolate causal variables and enable a strong test of the robustness of a theory: they provide convincing evidence for theories". In other words, the validity of assumptions in the present study on causes and effects, in which a match between data and theory is observed, is demonstrated through experiments [68, 69]. Figure 1 illustrates the logic of the research and its design.

Figure 1. Research design and tools

As shown in Figure 1, the created framework proposes a solution that addresses the deficiencies of IPD financial management, through integrating the merits of blockchain and smart contracts (with a hyperledger fabric platform). The proof of concept is then developed, using the following tools, to test the applicability of the framework:

- IBM® Blockchain Cloud Beta 2 platform, as it is user-friendly [8] and does not require skilled operators or high levels of competency. Therefore, this easy-to-use tool is applicable for practitioners across the AEC industry, even junior and novice users [35].
- IBM® VSCode extension for blockchain, as it facilitates the writing of the smart contract by providing templates to help novice users to correctly write the functions.

5. FRAMEWORK

The framework is divided into three main sections, in line with the three main IPD phases, as previously discussed. The first section focuses on preparing the BCN before its deployment. This should be implemented throughout the IPD pre-construction stage. The second section develops a mechanism to manage all IPD transactions within the IPD construction stage: it also enables those parties who finish their agreed works at earlier stages of the project timeline to follow other contractors without needing to attend all meetings (see Figure 1). The third section, the close-out stage, is different to that used in traditional approaches as it determines the profit proportions owed to owners and non-owner parties.

The presented framework is designed to integrate the three processes of IPD, blockchain and BIM in order to visualise the flow of information. For BIM, the framework provides details of which BIM dimensions are to be utilised. This provides information that feeds into the proposed IPD–blockchain system, using 4D to inform the payment schedule for all IPD core team members and 5D to provide cost data (see Figure 2).

Figure 2 shows the entire process of implementing the permissioned blockchain and the hyperledger fabric with the IPD stages. Different types of information and different tasks are involved in every IPD stage. Therefore, the framework aims to enable potential users to implement it easily. It can be used to inform users of the input and outcome of each IPD stage, along with the progress achieved in developing or utilising the blockchain network (BCN). Each set of IPD stages has different levels of information and distinct characteristics; therefore, the BCN should be developed and used according to the characteristics of the IPD stages, as discussed next.

5.1. Conceptualisation to buy-out stage

Three major sections form the conceptualisation to buy-out stage. Firstly, in building the network components, each party in the IPD core team represents a peer node in the blockchain network (BCN). This peer node carries its own ledgers in the deployment stage, while there is a peer node to order transactions is called the orderer peer.

Secondly, the endorsement policy includes the path of a transaction from one party to others for endorsement, that is, defining who should endorse transactions proposed by one of the parties. This requires the development of mathematical equations to enable determination of the value of each transaction and the proposal of new terms consistent with blockchain technology. The third section covers the ordering policies and is concerned with the path of the transaction to be recorded, including by which peer (project party) and through which channel.

Core team members in IPD should have the same level of information/details; therefore, any transaction by non-owner parties (including contractors and the consultant team) should be endorsed by owner parties and consultant peers. Given that not all contractors finish their tasks at the same time, the time stamp is part of the endorsement policy.

Each contractor is limited to acting within a specific period, with this extracted from the project timeline (4D BIM). Any proposed transaction (e.g. sent by a contractor) beyond the specified ranges will be invalid. The IPD compensation approach relies on reimbursing all costs below the specified profit-at-risk percentage (Limb 3). This value is coded for each party individually, so no party can exceed its coded value. Equation 1 below shows how reimbursed costs in IPD are calculated:

$$RMVoT_i = \sum Limbs (1,2 \text{ and } 3) \leq PMVoLimbs \quad (1)$$

where $RMVoT_i$ is the reimbursed monetary value of the transaction for contractor i and $PMVoLimbs$ is the planned monetary value of limbs for contractor i .

Other transactions must also be invoked by any non-owner party: these transactions should be profit/risk values and the achieved cost saving value. Equations 2 and 3 show the calculation mechanism of these two transactions when the total planned value of the compensation structure is greater than the reimbursed costs:

$$T_{2p} = PMVoLimbs - RMVoT1 = \begin{cases} (+)Profit \\ (+)(Profit + Cost\ saving) \\ (-)Monetary\ value\ of\ risks \end{cases} \quad (2)$$

$$T_{3CS} = T_{2p} - Limb3 \quad (3)$$

where T_{2p} is the second transaction for the profit values and the T_{3CS} is the third transaction for the cost saving values.

If the value of $RMVoT_i$ exceeds that of $PMVoLimbs$, the non-owner party should split the value into two transactions. Equation 4 presents the reimbursed costs as the whole compensation structure:

$$T_{1R} = PMVoLimbs \quad (4)$$

Another transaction (T_{2R}) should be implemented by the same contractor i and endorsed by the client: this represents the direct costs of all works that exceed the planned values (see Equation 5 below):

$$T_{2R} = \sum DCALimb3 \quad (5)$$

The value of transaction (T_{2R}) should be assigned to all other peer nodes carrying the time stamp which identifies the trigger of the transaction and the time.

The interrelationships among project parties on the BCN should be drawn to identify the endorsement path. The proposed framework assumes that the owner is committed to

endorsing any transaction invoked by any non-owner party. For mistakes made by the client in any previous transaction, the client can invoke a retrieved payment to receive their money back; however, this should be endorsed only by the payer non-owner party.

The IPD smart contract should include specific functions to record the proposed financial transactions, with three IPD financial functions to be coded: (1) reimbursed costs pool, (2) profit pool and (3) cost saving pool. Each function should include identifier parameters, such as sender, value, milestone and nature of trade package.

Given that the IPD agreement accepts the addition of new members at any time during the project stages, the smart contract can include a function for this purpose with specific parameters, such as name, nature of trade package and contacts. To maximise transparency and security for IPD parties, the profit pool can be capped at a certain monetary value for each milestone, as well as accumulatively. The profit thus will be checked/endorsed automatically for any new transaction.

The ordering process presents a main part of the hyperledger fabric network component. In the IPD context, the ordering policy refers to the management and control of relationships among project parties. To be specific, the movement of endorsed transactions should be pre-identified through nominating the channel for transferring the transaction data.

The ordering process in the present study is designed to follow the sequence of the project timeline and the distinctive relationships among IPD project team members. To extend IPD characteristics by sharing all acquired data among all participants, the genotype of each transaction should show: (1) the transaction number (i.e. 1, 2, etc.); (2) the identity of the respondent (i.e. owner or non-owner parties); (3) the endorsement status (i.e. which peer has accepted the transaction); this last aspect is based on who

invoked the transaction, with the endorsement policy defining which peers should endorse the transaction (see Figure 2).

Figure 2. Framework: IPD-based hyperledger fabric

At each payment milestone, all non-owner parties who are supposed to implement works based on the project timeline (4D BIM) should invoke three transactions according to the agreed endorsement policy. Once all the invoked transactions have been endorsed, the total reimbursed cost transaction should be gathered in a block (e.g. Block 1 for the May payment milestone). Accordingly, this block should be shared with the peers of all parties through a channel. Subsequently, the other two transactions that carry profit and cost saving should be transferred to the peers of all parties. This ensures that all IPD core team members have the same amount of information, enabling them to make the decision needed (see Figure 2). Therefore, any IPD project requires two channels: the main channel to transfer transactions among all parties and another individual channel among all non-owner parties and the owner, in case an error is revealed, so adverse transactions can be invoked by the owner to restore the amounts paid.

5.2. Construction stage (processing and reflection)

The processing of a transaction in hyperledger fabric comprises four major stages, with these stages tailored to fit the BIM and IPD contexts. Therefore, all the information needed from BIM models is identified, taking into consideration the IPD characteristics. In addition, tasks related to the hyperledger fabric are presented. These four stages are described below and highlighted in Figure 2 (using numerical indications from 1 to 5):

- **Sending a transaction proposal to specific peer nodes:** in accordance with the project timeline (4D BIM), non-owner parties who have implemented works should initiate request transactions using the application programming interface (API) to invoke the chaincode function. The framework relies on IBM blockchain, while the IBM cloud offers the API screen that can manage the

BCN nodes, channels and peers. Every network member can use this API screen to log in and invoke any function to record new data in the hyperledger. As stated in the endorsement policy, the transaction should be sent for endorsement to pre-identified peers (see Figure 2, ‘processing’ and ‘reflection’ sections).

- **Endorsing proposed transactions:** all transactions should meet the mentioned endorsement policy requirements, such as the maximum value of each transaction and the planned time in which to invoke the transaction (see Figure 2, ‘processing’ and ‘reflection’ sections). Once a transaction has been endorsed, it returns to the transaction sender to begin the ordering process.
- **Ordering the endorsed transaction:** all endorsed transactions should be transferred to the ordering peer node so their signature can be double-checked. Subsequently, transactions will be ordered chronologically; that is, an interrelationship exists between the transactions and the precedence for each transaction (as planned in 4D BIM) based on the ordering policy agreed in the pre-deployment stage. Hence, the chaincode architecture represents the number of transactions, the transaction sender, value of the transaction and the trade package name (i.e. T1, ceiling package trade contractor, £500, ceiling package) (see Figure 2, ‘processing’ and ‘reflection’ sections). Accordingly, based on the timestamp, the transactions are packaged into a block to be sent to peers for their commitment. The chaincode architecture for the proposed three transactions (reimbursed costs, profit and cost saving) should be arranged, as illustrated in Figure 3, and coded as function parameters in the IPD smart contract.

Figure 3. Architecture of the IPD-based smart contract transaction

- **Committing the transaction:** all ordered and packaged transactions should be broadcast to the peer nodes pre-identified in the ordering policy, as stated in Figure 2 ('processing' and 'reflection' sections). To illustrate, all ordered transactions proposed by non-owner parties should be broadcast to all peer nodes through a channel using the application programming interface (API). In addition, a transaction coming from the owner party, to correct any issue revealed in a previous financial statement (an adverse transaction), should be transferred to all peers (project parties), to make them aware of any change in the final statements of the three main IPD transactions.

5.3. Close-out stage

At each milestone, the same process should be repeated; however, the accumulative value of project profit should be checked through the ordering service. All profit transactions for each milestone should be gathered in a ledger; hence, the profit node (profit pool) includes a bundle of ledgers. The summation of the profit requested by all non-owner parties should be presented in the ledger. Each profit ledger must be linked to the previous one to achieve the conditions, as formulated in Equation 7:

$$VAPT = \sum AVoPT_{(Ln, Pn)} \leq PLimb3_{(Mn, Ln)} \quad (7)$$

where $VAPT$ is the valid accumulative profit transaction; $AVOPT_{(Ln, Pn)}$ is the accumulative value of profit transactions, stated in ledger (n) for party (p) ; $PLimb3_{(Mn, Ln)}$ is the planned monetary value of *Limb 3* for payment milestone (n) , stated in ledger (n) . As discussed, IPD supports sustainable relationships among owner parties and non-owner parties. Accordingly, a financial evaluation for all parties should be retrieved from the hyperledger fabric network, with evaluation parameters as presented in Equation 8:

$$f(AFP_{ij}) = \begin{cases} C = ARC_{ij} - Planned\ Limbs\ (1\ \&\ 2) & (-) = C \geq 0 \\ P = APP_{ij} - Planned\ Limb\ 3 & P \leq 0 \\ CS = ACS_{ij}/Planned\ Limbs\ (1\ \&\ 2) & CS \geq 0 \end{cases} \quad (8)$$

where C represents the paid cost; AFP_{ij} refers to the accumulative financial parameters for party I which is appointed to implement trade package j (in £); P represents the profit parameter; ARC_{ij} is the accumulative reimbursed cost (in £); APP_{ij} is the accumulative paid profit (in £); CS represents the cost saving; and ACS_{ij} is the accumulative cost saving (in £).

As discussed, three parameters can articulate a performance indicator for the entire IPD financial progress. Table 2 below illustrates how these parameters can be understood by IPD core team members.

Table 2. Evaluation of financial parameters during IPD close-out stage

Parameter	Value	Indication
C	Zero	The package has been implemented as planned and no cost saving has been achieved.
	(+)	A cost overrun has occurred and part of the profit proportion has been consumed.
	(-)	A cost saving has occurred equal to the estimated value from this parameter.
P	Zero	The estimated profit is achieved.
	(-)	A cost overrun has occurred and a proportion of the profit has been consumed as a cost.
CS	Zero	No cost saving has been achieved. This case is accompanied by the C equals zero parameter.
	>Zero	A cost underrun has been achieved and the profit percentage has been completely achieved.

Note: C = cost; CS = cost saving; P = profit

Therefore, an inquiry function needs to be coded into the IPD smart contract to support the collection of the information needed to undertake the proposed financial evaluation.

5.4. Interoperability between BIM, IPD and blockchain

Figure 4 illustrates the interrelationships between BIM tools and the chaincode hyperledger fabric within the IPD implementation stages. During the IPD pre-construction stage, and particularly during the documentation and buy-out stages, the BIM dimensions – 3D, 4D (Scheduling) and 5D (Cost) – provide the information needed to develop the chaincode system. The information needed from BIM should be the starting and finishing dates of each trade package, so these can be coded into endorsement and ordering policies; the total cost for each package; and the maximum estimated profits for each non-owner party, to be used in validating the profit transactions per payment milestone and accumulatively at further milestones (see Figure 2, the ‘endorsement policy’ section). Simultaneously, the chaincode hyperledger fabric should be designed using the BIM data, such as defining the number of peers

(peer per party) and the functions that need to be written into the IPD smart contract format, as discussed next.

Figure 4. Interoperability among BIM, IPD and the chaincode system

As shown in Figure 4, once the construction stage begins, the non-owner parties who have implemented works should invoke smart contract functions by the retrieved values (from 5D BIM). These are the financial resources spent to implement the agreed works, counting the remaining profit-at-risk percentage based on agreed values in the IPD buy-out stage and determining, through API, whether or not a cost saving has been achieved. This process is reiterated to reach the close-out stage. As all risks/rewards should be shared during the close-out stage, all parties can request the net amount of total profit, cost saving and reimbursed costs. Subsequently, based on the agreed risk/reward

proportions during the buy-out stage, each party can receive the proportion owed in each term: profit, cost saving and risks [49]. The performance of each party is then assessed using 5D BIM, by comparing the planned profit to the achieved profit.

In contrast to traditional accounting systems that record owed profit, cost saving and profits for each party, the chaincode hyperledger fabric prevents any party from amending the achieved percentages. This is particularly the case as some parties leave the construction site at early stages, creating a lack of trust among the remaining parties.

6. PROOF OF CONCEPT

6.1. Blockchain (permissioned) web-based IPD

In developing the proof of concept, 10 main steps are undertaken to create a blockchain network using the recently released IBM® Blockchain Beta 2 platform, as illustrated in Figure 5. This IBM Beta platform can enable enterprises to develop and extend their networks when these enterprises intend to use the network as an ongoing practice. The IPD-based blockchain proof of concept is developed based on the hyperledger fabric, as discussed in the ‘development of the framework’ section. The hyperledger fabric includes specific components: Certificate Authorisation (CA), Member Service Provider (MSP), peers and channels, with each peer (project party) needing to have a CA as well as being an MSP to identify its presence in the network. The channel role is to move the information (transaction) to a set of peers (project parties), in accordance with an agreed endorsement policy. For instance, a client should have all the information regarding reimbursed cost, profit and cost saving for all participants. The client peer should also be selected when instantiating the smart contract. The architect team is responsible for developing the network and all other participants (i.e. contractors and trade contractors) can then join the network. Figure 5 presents a map which directs the development of a

blockchain network (BCN) to automate financial transactions in the construction industry. As can be seen, all processes are accompanied by adequate details to clarify the nature of each step and show who is the responsible party for each step.

Smart contracts should be written in specific algorithms. The IBM® VSCode extension for blockchain is used to write all the proposed functions. Therefore, each party should invoke the three transactions and each payment milestone to update the hyperledger fabric network.

Figure 5. Logic of the proposed “Proof of Concept” blockchain based IPD framework

6.2. Case project

This section describes the case project. A property development company decides to build a compound of 100 identical houses. The specification of each house is as follows:

(1) the gross floor area is about 192 m²; (2) the house has a single floor; and (3) from reviewing the Revit architectural plan, the spaces are a master bedroom with its own

bathroom and robe room facilities, three bedrooms, large living room, kitchen, dining room, another bathroom, family room and utility room.

The project works are categorised into five trade packages: (1) general works; (2) ceilings: (2) lighting fixtures; (3) finishing; (5) doors and windows. The client intends to use IPD to deliver the project. An architectural firm and five trade contractors are appointed to build the project's core group, as well as involving trade contractors to obtain the required information during kick-off meetings. The blockchain network (BCN) should include all IPD core team members (client, five contractors and the consultant).

6.3. Blockchain network (BCN): IBM® Blockchain Beta 2 Platform

As illustrated in Figure 6, seven participants are involved in the case project as BCN members; consequently, each party should be represented by a peer. In creating a peer, two main components should be created beforehand, these components being the Certification Authority (CA) and Member Service Provider (MSP). Figure 6 shows a CA for each party and one for the orderer peer. This network is developed for a project that comprises seven members in its core team: client, architect, main contractor and the other four trade contractors (doors and windows, finishing works, ceiling works and lighting fixture works).

Figure 6. Developed blockchain network based on IPD

Figure 7 illustrates the IPD core team's organisations with each participant identified by a distinct Member Service Provider (MSP). This is also used to validate the identity of network members; that is, when data are sent from any party to other parties, the receivers are identified through their MSPs (as shown in Figure 7 for the presented case project). The orderer here works as a node in the network; therefore, their MSP should be presented in the organisation list (see Figure 7).

Figure 7. MSP for the organisation members

As previously discussed, the channel is a main part in the BCN, and is used to move data between network parties. Figure 8 shows the channel for an IPD project case, which is called “ipdchannel”, with members provided in order to identify the path of the data when any function is invoked to record any new data on the network and specifying which parties should receive the data. In IPD projects, all core team members should receive the same amount of data in the same sequence. Therefore, all parties should be listed, as illustrated in Figure 9.

Figure 8. Creating a channel to assign the data to the network participants

6.4. Smart contract based on IPD financial terms

As previously discussed, the IBM® VSCode extension is used to build the functions of the smart contract (the chaincode), packaging it and, subsequently, installing and instantiating it to the specific channel and peer. As proposed in the framework (see Figure 4), the chaincode should include substantial functions, such as the ‘instantiate’ and ‘query’ functions. The user can add more functions to govern the purpose of the chaincode.

In the prototype presented here, four functions are added to perform the proposed purpose of the framework, that is, recording all project transactions and preventing any possible amendments. Figure 9 shows the functions used: (1) adding participants; (2) cost saving; (3) reimbursed costs; and (4) profit.

All financial transactions are defined through specific parameters: who the sender is, the trade package, payment milestone and the value of the transaction (see Figure 9).

```

project1 > lib > JS my-contract.js > ...
1  'use strict';
2
3  const { Contract } = require('fabric-contract-api');
4
5  class MyContract extends Contract {
6
7      //update ledger with a greeting
8      async instantiate(ctx) {
9          let greeting = { text: 'Instantiate was called!' };
10         await ctx.stub.putState('GREETING', Buffer.from(JSON.stringify(greeting)));
11     }
12
13     //add a member along with their email, name, address, and number
14     async addMember(ctx, email, name, address, phoneNumber) {
15         let member = {
16             name: name,
17             address: address,
18             number: phoneNumber,
19             email: email
20         };
21         await ctx.stub.putState(email, Buffer.from(JSON.stringify(member)));
22         return JSON.stringify(member);
23     }
24
25     async Reimbursedcosts(ctx, sender, milestone, value, package) {
26         let member = {
27             sender: sender,
28             milestone: milestone,
29             value: value,
30             package: package
31         };
32         await ctx.stub.putState(sender, Buffer.from(JSON.stringify(member)));
33         return JSON.stringify(member);
34     }
35
36     async profit(ctx, sender, milestone, value, package) {
37         let member = {
38             sender: sender,
39             milestone: milestone,
40             value: value,
41             package: package
42         };
43         await ctx.stub.putState(sender, Buffer.from(JSON.stringify(member)));
44         return JSON.stringify(member);
45     }
46     // look up data by key
47     async costsaving(ctx, sender, milestone, value, package) {
48         let member = {
49             sender: sender,
50             milestone: milestone,
51             value: value,
52             package: package
53         };
54         await ctx.stub.putState(sender, Buffer.from(JSON.stringify(member)));
55         return JSON.stringify(member);
56     }
57
58     // look up data by key
59     async query(ctx, key) {
60         console.info('querying for key: ' + key );
61         let returnAsBytes = await ctx.stub.getState(key);
62         let result = JSON.parse(returnAsBytes);
63         return JSON.stringify(result);
64     }
65 }
66
67 module.exports = MyContract;

```

Figure 9. Snapshot of the developed chaincode based on IPD financial transactions

6.5. Smart contract on blockchain network (BCN)

After developing the chaincode, any party can invoke one of the transactions in accordance with the agreed endorsement policy (see Figure 2). Figure 10 illustrates the installed smart contract that includes the proposed functions. The smart contract should be uploaded to the smart contract panel in the network and to the endorsement policy as stated in the ‘development of framework’ section. The uploaded smart contract should then be installed and instantiated in all peers (project parties). Subsequently, project parties can invoke the four main functions (reimbursed costs, profit, cost saving and query) at each payment milestone. Invoking can be executed through a web-based application, thus providing easy access for all participants regardless of their technical skills and capabilities.

Figure 10. Snapshot of installing and instantiating smart contracts on blockchain-IPD network

At the completion of the IPD project, any party can invoke the ‘query’ function in order to estimate the recorded amount of money in each pool (reimbursed cost, profit and cost saving). This can increase the rate of IPD adoption, given that the main barrier is the lack of trust in sharing risks/rewards. This can be addressed by implementing

blockchain, particularly hyperledger fabric – the blockchain for business networks. With blockchain (hyperledger fabric), all participants have an equal opportunity to track all financial transactions, regardless of their geographical location.

7. DISCUSSION

The proof of concept provided here presents a workable procedure for addressing a major barrier to the adoption of IPD in the construction industry, namely, the management of financial transactions among project parties under the distinctive nature of IPD characteristics [5 ,70]. This is accomplished through proposing a methodology that offers a practicable and viable solution to the documented financial deficiencies of IPD, as discussed below.

- The issue of profit pooling – paying profits after all project works are completed, regardless of the timeline of trade packages [4] – has been solved as all profit transactions are received by the profit pool after passing the automated endorsement and validation processes. Subsequently, all recorded values are immutable, with any potential amendment causing a problem for the entire blockchain network (BCN).
- Another endemic financial issue revealed by IPD is the inconsistency of accounting between owner parties and non-owner parties [71] that can lead to misunderstandings. This is contrary to the main purpose of IPD which is to create a sustainable relationship. Therefore, the hyperledger fabric has a single/consistent electronic format to record the data and all parties receive the necessary data in the same sequence, with the same amounts and tokens (i.e. currencies).
- The promise of IPD is about management by decentralised teams, with there being no dominant party. This necessitates repetitive meetings to make all required decisions [4 ,49]. The proposed utilisation of the IPD-based blockchain can reduce the need for such repetitive meetings, with all financial issues being managed through the hyperledger fabric network.

- Another advantage is the facilitation of decision making among IPD core team members through the endorsement policy that includes rigorous algorithms to define the decision paths, This comprises the identity of decision makers and the effectiveness of previous decisions (i.e. the consultant party should validate all financial data; therefore, this party, as a vital decision maker, should be mentioned in all decision paths).
- According to Pishdad-Bozorgi and Srivastava [50], IPD targets create sustainable relationships among parties in the AEC industry. This requires performance evaluation by the end of the project, in terms of the achieved rewards against the risks for each party. To conduct this, the hyperledger fabric network, through the ‘query’ function, can provide all recorded accumulative risk/reward values for each node (party) in the network. The owner can therefore determine the parties who achieved their targets, thus assisting with informed decision making on future collaboration.
- A blockchain network that uses cryptocurrencies instead of fiat currencies [72] and the contradiction between the private ledger in the bank and the distributed ledger in the blockchain have been managed through utilising the hyperledger fabric which depends on tokens in sending transactions to build the network, as well as deploying the smart contract. The IPD approach requires that the three main transactions (profit, cost saving and reimbursed costs) merely be recorded, while the actual money can be sent through normal bank accounts.
- Contractual challenges exist, such as the necessity of coding unstraightforward legal concepts and other practical challenges [70]. With this in mind, the present study succeeds in developing a smart contract that includes all the needed

functions. Non-coded expressions and elements will not affect the efficiency of the entire financial process.

- The proposed methodology is invaluable for IPD adopters, given the simplicity and user-friendliness of the proposed financial system in relation to IPD goals and benefits. Blockchain, IPD and BIM are aligned in a dynamic process to allow IPD users to utilise all available capabilities and noting that, in IPD, BIM is highly recommended. Therefore, all input data for the endorsement policy are designed to be derived particularly from 4D BIM and 5D BIM models.

8. LIMITATIONS AND FUTURE STUDIES

The present study develops a platform from which to deal with the financial challenges of implementing IPD projects; hence, this research can be extended horizontally. To be specific, the proposed financial system is validated by developing a “proof of concept”. Therefore, a fully integrated prototype that includes an automated way to retrieve data from BIM models for the blockchain network (BCN), in order to develop the endorsement policy, can be investigated in future research.

Much more can be done to improve the proposed prototype and to extend it vertically by adding more functions, such as contingency costs. This would assist each party in invoking the recording of incurred values, where “unneeded proportion” and other legal terms could be coded to automate the entire process and reduce the impact of a third party on the smart contract. Subsequently, these functions could be invoked and add new features to the network. Moreover, the present study presents a generic methodology for developing a BCN and a smart contract for IPD; therefore, the same methodology used with the IBM® Blockchain platform could be used with other platforms, such as Oracle.

Integrated project delivery (IPD) has a sophisticated financial process, with the developed framework system showing its applicability for providing reliable solutions. Therefore, this framework could be extended to work with different procurement approaches, including the design-build (DB) approach. In this case, some changes should be considered including: (1) the endorsement policy and the ordering policy would need to be amended as the risk/reward sharing mechanism is not utilised; (2) the functions in the smart contract would need to be adjusted as only a single payment should be invoked in the DB approach; and (3) the BCN members would be different as subcontractors cannot be participants as no contractual relationships exist between owner parties and themselves.

Even though the applicability and practicability of the framework are validated using a case project, further validation is required. This could be achieved by conducting case study research to observe the attitudes of project stakeholders regarding the applicability of the proposed financial system.

9. CONCLUSION

Apart from the contributions of the present study to the world of practice, as discussed above, the study opens new horizons for promoting the adoption of blockchain in the AEC industry. The study's primary added value to the body of knowledge is to go beyond the conceptual stage of existing studies by initiating the empirical and real-life application of blockchain through exploring a case project. This provides a stepping-stone from which to direct future research studies.

With reference to the literature on IPD, not only does this study provide a solution to IPD challenges, but it also offers the potential for generalisability to other procurement approaches, addressing the financial aspects of each approach. In this regard, the present

study is one of the first to showcase the potential of blockchain and smart contract technologies in addressing IPD's financial management deficiencies. In particular, the capabilities of hyperledger fabric are demonstrated, with the study's findings pointing to the alignment of its characteristics with IPD features.

In broader terms, the present study creates a point of departure to move beyond the sophisticated financial management systems required by IPD, by showcasing the capabilities of blockchain technology and its applicability as a future element of IPD projects.

From a wider theoretical perspective, the study attempts to promote the use of IPD and to foster its adoption by addressing the sociotechnical barriers that are seen as hindering its implementation. Although the study provides a technical solution, the peripheral impacts improve the people side. To be specific, the presented automated financial system enhances trust and transparency among IPD core team members, offering them the assurance that all endorsed transactions are immutable and enabling each team member to check the accumulative values of reimbursed cost, profit and cost saving.

From this vantage point, the study provides a springboard for revolutionising contractual arrangements. These smart contracts must target the fostering of collaboration and facilitation of the exchange of data and information among IPD core team members through virtual interfaces, replacing the traditional big rooms. The other fertile ground for extension would be revolutionising the structure of traditional procurement methods, such as the design-build (DB) approach while considering its distinctive characteristics. Furthermore, overcoming the limitation due to the semi-automated links of BIM data with blockchain networks (BCNs) for endorsement purposes is another area ripe for future research studies, with the aim being the full automation of existing arrangements.

In the present study, the IPD financial terms/processes are revolutionised to be consistent with IPD financial characteristics, and mathematical models are developed for each scenario. Hence, the proposed financial system considers all the distinctive IPD characteristics. Operational flexibility is taken into consideration regarding scalability, to enable any party to join the network (project) after the network is built up. Security and privacy merits have been incorporated, as the hyperledger fabric is permissioned blockchain; therefore, specific details, such as CA and MSP, are needed by all parties.

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