

## ENHANCING CONTRACTUAL TIME PERFORMANCE MANAGEMENT: A HYPERLEDGER FABRIC-BASED CONCEPTUAL FRAMEWORK

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### Abstract

Time performance management is a core contractual mechanism that contributes to the success of construction projects. However, its interdependent processes face underlying challenges. Hence, this paper aims to build a conceptual framework of how Hyperledger Fabric can contribute to addressing challenges encountered in practice. The results reveal that existing digital solutions implemented on construction projects can act as software oracles for Hyperledger Fabric blockchain and the contractual logic can be converted into smart contract functions at the process level. The paper acts as a point of departure to develop a proof-of-concept for practical adoption within the context of FIDIC Red Book 2017.

### Introduction

The delivery of large construction projects hinges on contractual governance (Zhang et al., 2023) and interdependent contractual mechanisms (Chen et al., 2018). The logical execution of those contractual mechanisms is operated by a construction contract administration (CCA) system. Among the various elements of the CCA system, time performance management is a core mechanism that contributes to the success of construction projects (Hetemi et al., 2020) and benefits all organisations involved (Maylor et al., 2023). Yet, time performance management continues to be perceived as fraught with challenges (Abdul-Malak and Mehdi, 2020). One main reason for this is that it is underpinned by interdependent processes with each process having its own underlying challenges (Farghaly et al., 2024).

To this effect, a host of research efforts have attempted to tackle an array of inherent challenges associated with each process through the adoption of advanced digital technologies. For example, some studies developed AI-based solutions to improve schedule generations (Soman and Molina-Solana, 2022). Another strand focused on enhancing progress reporting (El-Omari and Moselhi, 2011; Hamledari et al., 2017). In addition, attempts at improving the related claims management process were made (Palaneeswaran and Kumaraswamy, 2008; Ali et al., 2020). Furthermore, improving the analysis of schedule delays has occupied a considerable space in the extant literature (Bhii and Hegazy, 2021; Guévremont and Hammad, 2018). Despite their empirically validated benefits, those research efforts tend to treat their respective process as independent from the other

processes. In addition, they tend to be rooted in the perspective of a single organisation (centralised) while overlooking the nexus of autonomous agents involved in the CCA process.

With the advent of Hyperledger Fabric (HLF, 2023), a permissioned blockchain, this overlooked perspective and its associated aspect can be tackled. A number of studies have proposed HLF-based solutions to tackle inherent challenges of contractual processes in construction projects while taking into account the inter-organisational perspective. Proof-of-concept-based studies have focused on financial management (Elghaish et al., 2022; Cheng et al., 2023), document and records management (Das et al., 2022), quality management (Sheng et al., 2020), and other relevant processes (Zhong et al., 2022). Yet, this emergent research line has not advanced the interplay between HLF and the processes associated with time performance management. In addition, while it encapsulates the inter-organisational perspective it tends to focus on developing the HLF-based solutions without rooting them in a defined contractual governance (Msawil et al., 2022). This is, of course, often due to a deliberately limited research scope. As a result, it can be argued that interested scholars and practitioners have remained uninformed of the practical and applicable alignment between this advanced technology and current contractual practices, on the one hand, and existing digital solutions implemented on construction projects, on the other hand. This argument is echoed by Çıdık and Boyd (2022).

Hence, this paper proposes an HLF-based conceptual framework for enhancing contractual time performance management. The framework attempts to integrate existing digital solutions of relevant processes into a single digital platform, while grounding the framework within the context of the FIDIC Red Book (RB) 2017 (FIDIC, 2017) - a standard contract model devised by the International Federation for Consulting Engineers (FIDIC) and it is widely adopted worldwide for infrastructure projects procured through the design-bid-build route.

### Conceptual background

The conceptual background first formulates the research problem in the form of challenges. Subsequently, it summarises existing HLF-based solutions developed for various CCA processes before justifying the research need.

## Challenges facing time performance management

Both scholars and practitioners continue to regard time performance management mechanisms to be fraught with challenges regardless of the form of contractual governance adopted. Table 1 consolidates relevant identified challenges based on analysing literature against the various processes associated with this contractual mechanism. From an inter-organisational perspective, it can be inferred that the persistence of such current challenges hinders efficient and effective management of time performance, which can result in financial losses to all involved organisations (Elazouni et al., 2023). In addition, such challenges damage the business relationship to varying degrees (e.g., due to unsettled time extension claims, legal disputes) (Jelodar et al., 2016). These challenges highlight the need for developing an innovative solution to achieve an efficient and effective time performance management from an inter-organisational perspective while respecting contractual governance. In this paper, it is argued that such an innovative solution can be realised through the adoption of Hyperledger Fabric (HLF), a permissioned blockchain protocol, and its associated smart contract technical functionality.

Table 1: Summary of analysed challenges against the relevant processes

Process	Reference (indicative)	Challenge
Programme production	Hong et al. (2021)	Ch-1: Incompleteness of programme
	Koc and Gurgun (2022)	Ch-2: Misapplication of related sub-clauses
	Hegazy and Kamarah (2022)	Ch-3: Unoptimised programmes
Progress reporting	al Qady and Kandil (2015)	Ch-4: Unspecified types of records
	Fan et al. (2015)	Ch-5: Absence of records collection tools
	Carson (2006)	Ch-6: Distortion of information
Programme update	Ibbs et al. (2017)	Ch-7: Lack of mitigation efforts records
	Carson (2006)	Ch-8: Concealment of schedule delays
	Demirel et al. (2019)	Ch-9: Lack of defined communication channels
Time extension claims management	Seo and Kang (2020)	Ch-10: Information asymmetry at inter-organisational level
	Bhiih and Hegazy (2021)	Ch-11: Inaccurate schedule and resource updates
	Seo et al. (2021)	Ch-12: Missing contractual obligations
	Abdul-Malak and Mehdi (2020)	Ch-13: Inaction due to optimism bias
	Seneviratne and Michael (2020)	Ch-14: Missed time-bar
	Jelodar et al. (2016)	Ch-15: Avoidance of discussion and poor communication
	Francis et al. (2022)	Ch-16: Non-finality of decisions

Process	Reference (indicative)	Challenge
Delay analysis	el Nemr (2021)	Ch-17: Inaccessibility to information records
	Palaneeswaran and Kumaraswamy (2008)	Ch-18: Insufficient and contradictory information
	Guévremont and Hammad (2021)	Ch-19: Difficulty with establishing continuous reasoned causation
	el Nemr (2021)	Ch-20: Polarisation of views on delay analysis method selection

## Hyperledger Fabric-based applications for CCA

HLF is a digital implementation protocol that was specifically devised to execute permissioned blockchain-based business processes. Accordingly, studies have justified the suitability/applicability of HLF as a permissioned blockchain to the managerial and contractual processes of construction projects (Tao et al., 2021; Elghaish et al., 2020). HLF blockchain-governed transactions are executed through a ‘chaincode’ that contains ‘smart contract’ functions (HLF, 2023). At its core, a blockchain-based ‘smart contract’ can be described as a logical structure of a programming code that implements the business logic of a contractual process (Mason, 2021). Feeding the required input data into smart contract functions can be achieved by several methods: it may be from previous transactions immutably stored in the HLF blockchain (Sheng et al. et al., 2020); from so-called ‘oracles’ based on hardware, software, or human agents (Lu et al., 2021); or a combination of these methods (Mason, 2021).

In the research stream that concentrates on blockchain applications in the construction project management (CPM) sphere, a broad range of HLF-based solutions has emerged. Among this growing stream, only a limited number of studies can be mapped to the particular contractual processes/mechanisms of CCA (Msawil et al., 2022). These are presented in Table 2.

Table 2 is evidence that these identified CCA process challenges can be resolved by the HLF-based application’s unique features (authorised accessibility, symmetric information, digital security, immutability, process streamlining, and simultaneous traceability of performed contractual obligations). Yet, the potential applicability of HLF to improve processes involved in the contractual time performance management in particular has not been unearthed, at least in the context of a defined contractual governance. In general, it is recognised that contextualising innovative digital solutions within existing practices can act as an enabler to their possible adoption in construction (Çıdık and Boyd, 2022).

Table 2: Relevant Hyperledger Fabric-based applications for CCA

Contractual Mechanism	Ref.	Focus of study	Oracle
Financial management	Cheng et al. (2023)	Developing a framework to facilitate construction cost management.	Human
	Wu et al. (2022)	Developing an HLF-based smart contract system for smart payment.	Human
	Elghaish et al. (2020)	Developing a financial system for Integrated Project Delivery procurement.	Software (BIM-based tools)
	Elghaish et al. (2022)	Developing a financial management solution for traditional procurement routes.	Software (BIM-based tools)
Performance reporting	Wang et al. (2020)	Building a framework for information sharing.	Human
Quality and acceptance management	Sheng et al. (2020)	Presenting a framework to support the management of quality information.	Human
	Lu et al. (2022)	Developing a technical solution to support remote E-inspection of building projects.	Human
Document and record management	Tao et al. (2021)	Proposing a framework for distributed common data environment	Human
	Das et al. (2022)	Developing a secure document management system to integrate project participants and document/record silos.	Human
Project 'legal' governance	Zhong et al. (2022)	Proposing an HLF framework to automatically monitor and record environmental pollution.	Hardware (Internet of Things (IoT) sensors)

Hence, this paper attempts to tackle the preceding formulated problematisation through the development of a conceptual framework. To this effect, it is conceptualised by converting the processes associated with time performance management under FIDIC RB 2017 into HLF-based technical architecture (on-chain) linked with available software implemented on construction projects (off-chain). Together with the analysed studies, the proposed conceptual framework paves the way forward to advancing the understanding of the potential applicability of HLF to improving time performance management as a practical/ particular instance of the wider CCA system.

### Contractual derivation of the framework

This section derives the various processes and subprocesses associated with contractual time performance management. The derivation is based on analysing relevant contractual sub-clauses of FIDIC RB 2017 as an application context. Figure 1 shows the resulting analysis of the processes and subprocesses along

with three forms of their contractual interdependencies: explicit, implicit, and absent. Due to limited space, the illustrated processes and subprocesses are briefly explained herein as deduced from their corresponding sub-clauses at the contractual process level.

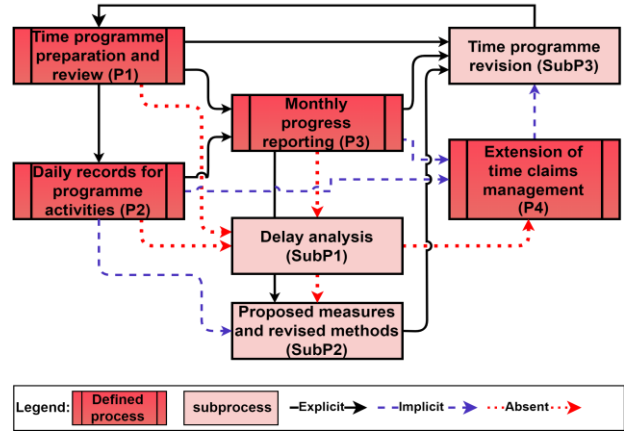


Figure 1: Key processes and subprocesses and their interdependencies

**Time programme preparation and review (P1):** this is derived from sub-clause 8.3 [Programme]. It places an obligation on the Contractor to prepare and submit the time programme to the Engineer, taking into account a wide range of factors and aspects.

**Daily records for programme activities (P2):** this is based on sub-clauses 6.10 [Contractor's Records] and 4.4.2 [As-Built Records]. It places an obligation on the Contractor to prepare and keep daily progress and as-built records for each activity shown in the programme to feed data into P3.

**Monthly progress reports (P3):** this is extracted from sub-clause 4.20 [Progress Reports] wherein a relatively long list of requirements is placed on the Contractor to prepare the monthly progress reports and submit them to the Engineer. Among other aspects, the requirements include a comparison of the actual and planned progress based on the programme update.

Under both P2 and P3, if a delay event that impacts the time performance occurs due to the Contractor's own cause, then the Contractor needs to propose [mitigation] measures to recover such time impacts. Such a Contractor's delay can be detected from the daily and monthly records and can be achieved through subprocess 1 (SubP1).

**Delay analysis (SubP1):** the contractual analysis of FIDIC RB 2017 did not reveal an explicit method of delay analysis. It recommends seeking advice from legal experts on the selection of an appropriate delay analysis method in line with the governing law of the Contract [project] and including it in the particular conditions.

**Proposed measures and revised methods (SubP2):** this can be considered as an undefined subprocess and it is inferred from sub-clauses 4.20 [Progress Reports] and 8.7 [Rate of Progress]. Any such measures and methods should be immediately incorporated into the programme to enable instant fulfilment of obligations and protection

of rights of all involved organisations. Hence, it is logical to include this contractually inferred subprocess therein to place an emphasis on its role in closing the interdependence loop and linking the earlier processes to SubP3.

**Time programme revision (SubP3):** as a result of any changes to the initial programme that may result from (P3) and/or the adoption of measures/ methods under (SubP2), the Contractor shall revise the programme accordingly as a self-performed contractual obligation based on sub-clause 8.3 [Programme] or Engineer's instructions under 8.7 [Rate of Progress]. The revised programme becomes the programme for the subsequent period.

Under the aforementioned relevant processes and subprocesses, if a delay event occurs which is not a Contractor's responsibility, then the Contractor is entitled to an Extension of Time (EoT) as a contractual remedy.

**Extension of time claims management (P4):** this process is derived from sub-clauses 8.5 [Extension of Time for Completion], 20.2 [Claims for Payment and/or EoT], and 3.7 [Agreement or Determination]. It involves multi-sequential stages that hinge on the coordination and control-related obligations performed mainly by the Engineer and Contractor (with a minor involvement on the Employer's part). As evident in Figure 1, this process is contractually disconnected from the other processes, despite the very practical fact that its successful execution is influenced by information contained in (P1, P2, P3, SubP1, Sub2, and SubP3) and its outcome necessitates revising the programme. The authors emphasise here that this apparent 'disconnect' has been disregarded, as a critical review of the drafting of FIDIC RB 2017 is beyond the scope of this paper.

Based on the analysis above, it is self-evident that the means of improving contractual time performance management of FIDIC RB 2017 rests in addressing these processes and subprocesses. Yet, integrating them simultaneously while providing trust at an inter-organisational level and respecting the contractual governance is argued to have remained elusive. The following section presents an attempt to tackle this elusiveness.

### The proposed HLF-based chained time performance management framework

This section presents the proposed conceptual framework by drawing on the tabulated HLF-based studies summarised in Table 2. As Figure 2 shows, the proposed concept connects the three involved organisations represented by human agents in a distributed manner around the notion of 'chained time performance management'. According to HLF design philosophy, each organisation is represented as a digital node and authorises its own human agents and software to act as peers on HLF network.

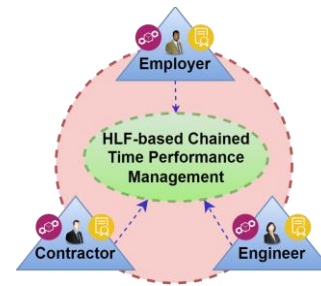


Figure 2: The multi-organisations connected to chained time management performance

Figure 3 shows the three key components of the framework and their digital relationships. In what follows, the key components along with their digital flow are described.

**Off-chain:** this component represents a construction contract environment where scheduled activities take place at a construction site, human agents perform contractual tasks, and software-based tools are implemented to aid human agents. In addition, it includes the defined contractual governance that regulates the interactions among the involved organisations. Of particular relevance to the current conceptual framework are human agents (human oracles) entrusted with performing a variety of contractual tasks and digital solutions (software oracles) implemented at the project level. The former includes project managers, project controls engineers, and quantity surveyors. The latter can include scheduling software (e.g., Microsoft Project and Oracle Primavera P6), BIM-based solutions, AI-based tools, and electronic document management systems. Both oracles interact with each other in a dynamic manner with human agents entrusted with data inputs while digital solutions entrusted with generating outputs. In this conceptual framework, it is proposed that both oracle types can act as dynamic data pipeline that feed required data variables of blockchain-based smart contracts through middleware.

**Middleware:** this component acts as a digital bridge between the off-chain oracles and the on-chain side. It performs a range of digital operations including invocation, queries, and updates. This component hinges on database servers and Application Programming Interfaces (APIs). It serves multiple technical functions. First, it enables human agents to interact with the HLF blockchain. This interaction can be to invoke a smart contract function by entering the required data variables or to query the blockchain ledger. Second, it enables available digital solutions (software oracles) to trigger a smart contract function in response to the occurrence of an event or query the blockchain ledger at regular coded intervals (e.g., each 24 hours) or invoke a specific function when pre-defined conditions are met based on programmed conditional statements. In addition, this set of middleware serves to return results retrieved from the ledger (on-chain) to human agents at both the project and inter-organisational levels. Furthermore, the database

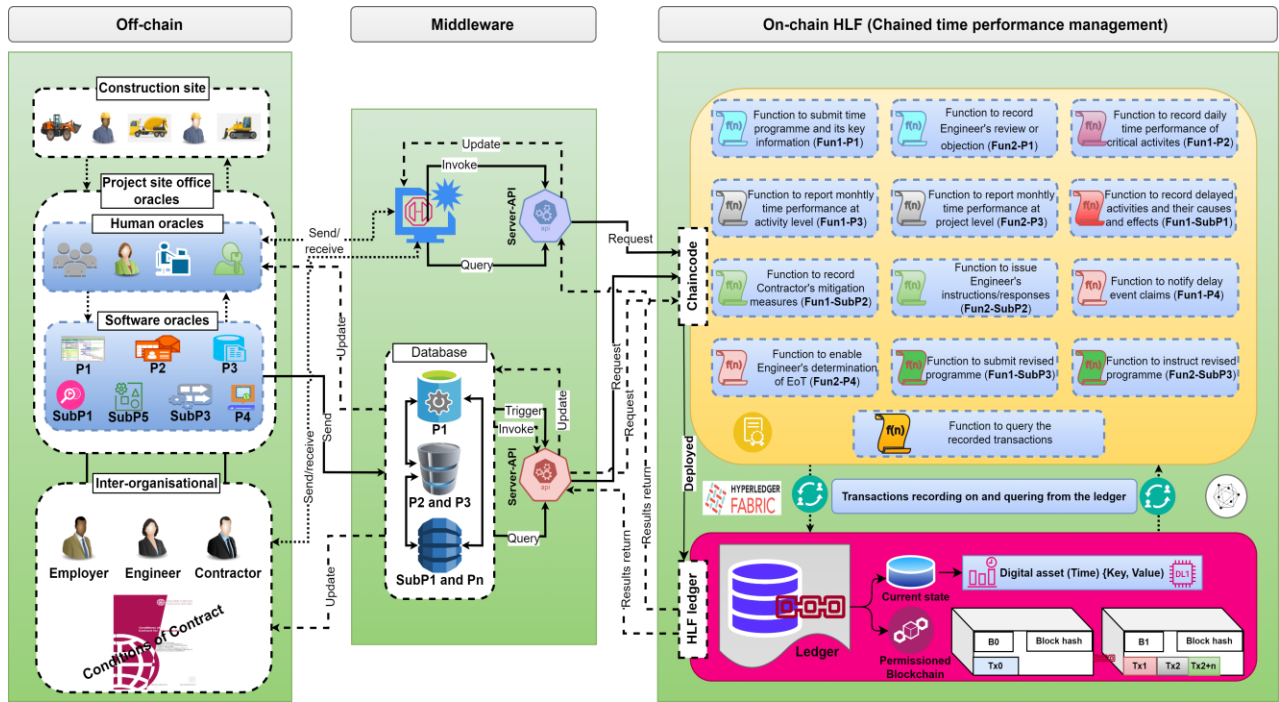


Figure 3: HLF-based chained time performance management framework

updates itself for subsequent digital operations (e.g., automatic invocation). Due to limited space, the solid and dotted arrows shown in Figure 3 conceptually show those digital operations. The detailed rules of the conceptualised operations and their interdependencies along with the server selection are currently under development.

**On-chain HLF:** the design of this component follows the HLF design philosophy. It includes a single channel that represents ‘chained time performance management’. Authorised peer nodes at both the project and inter-organisational levels as well authorised software oracles are given access to the channel. On each authorised peer node, both the ledger and chaincode are deployed.

- **The chaincode:** the chaincode contains a set of the application-based smart contract functions coded to represent the contractual logic (see the previous contractual derivation of the framework) under each process or subprocess. In this paper, this set is called application-based smart contract functions which differs from system-based smart contract functions (e.g., initialise the ledger). Currently, the parameters that reflect the contractual logic of the relevant sub-clauses of FIDIC RB 2017 are being defined and analysed. To automatically execute a coded contractual task, the coded parameters inside a given smart contract function will receive data variables either from human agents or software agents or both, through middleware. If the received data variables meet the coded conditions, then the smart contract function executes a transaction that is immutably recorded on the blockchain. Subsequently, the various cumulative transactions can be queried by human agents or software agents to monitor the time performance and to automatically trigger specific action as coded.

- **The ledger:** the ledger consists of two interconnected parts: the blockchain and the current [world] state. The blockchain stores and processes all valid transactions whereas the current state shows the latest value of the defined asset (see the explanation below).

In addition to the preceding chaincode and ledger, the conceptual framework recognises the other digital HLF components (e.g., certificate authorities, endorsement policy, system-based chaincode, and identifying an ordering service for validating transactions and ordering blocks). For clarity and simplicity, those digital components are not shown in Figure 3.

### Conceptual explanation of the proposed framework

This paper proposes a novel approach to managing time performance of construction projects in line with the objective ontology of FIDIC RB 2017. The proposed framework argues that time can be represented as a single digital asset in line with the philosophy of blockchain technology. To this effect, the contractual time is argued to be an asset owned by the Employer and it is allocated to the Contractor with the aim of using it to complete the construction project. The Engineer has a dual role in managing this asset: to monitor the Contractor's contractual state of time at defined intervals as stipulated in the Contract [project] data and to determine when the Contractor needs an increase in the allocated time (e.g., in case of a delay event which is not a Contractor's responsibility). This establishes an interdependent proactive approach to time performance management whereby all the processes and subprocesses are digitally connected through the adoption of an HLF-based solution.

Accordingly, this proposed approach chains and integrates the peers and their respective organisations enabling them to have complete status of time

performance at any given moment with a history of fulfilled and remaining contractual obligations.

In addition, the human and software oracles providing input data are both identified in the recorded transactions based on HLF certificate authorities. On the part of human oracles, this increases the level of due-diligence and accountability in respect of data inputs. The need for increased due-diligence assessment fundamentally stems from the prospective awareness that a 'smart contract' function cannot be invoked without the input of all required data variables while taking into account that there will be neither an opportunity to change any input data nor to revoke recorded resultant transactions due to immutability. This awareness will substantially reduce erroneous data inputs and, hence, increase the likelihood of keeping the permissioned blockchain input error free. With this in mind, the data variables can be obtained from available digital solutions as software oracles.

It is envisaged that existing digital solutions can act as software oracles to feed smart contract functions with required data variables. However, an unintended limitation of current available digital solutions is that they tend to treat their digitalised processes as being independent which are in fact interdependent. Hence the proposed framework integrates those solutions (deployed off-chain) with their corresponding channel (on-chain ledger and smart contract functions) through APIs and databases that can technically be developed. In turn, smart contract functions are interconnected on the HLF platform with the capability of calling each other as well as calling APIs to obtain and feed data from the relevant processes of the 'chained time performance management'.

The logical flow of this proposed approach follows contractual processes described in FIDIC RB 2017 with slight adjustments in terms of interdependence. This logical flow chains the entire associated processes from the commencement date of the Contract (i.e., project) to the date of completion in the form of a defined digital asset that represents the contractual time. The state changes of the defined asset are automatically and immutability recorded on the ledger through a series of digital transactions. As an example, the progress reporting process (**P3**) can be linked to the EoT claims management (**P4**) process through their respective smart contract functions supported by blockchain-governed API servers. With this linkage, as soon as the update of a given activity on the programme shows a negative float (i.e., delay) of a pre-defined numeric value while following a programmed delay analysis (**SubP1**) to detect the allocated delay responsibility, the 'notice' of EoT claim can be triggered through a smart contract function. As a result, the EoT claim management process automatically starts if that activity is not the Contractor's responsibility. If, on the other hand, the delay is the Contractor's responsibility then **SubP2** (see above) is invoked. With those interdependent processes and subprocesses being digitally executed, the relevant information flow coupled with the contractual obligations are captured and recorded in HLF-based transactions while being visible and immutably traceable at the inter-organisational level.

## Discussion

In developing the notion and its conceptual framework, a number of findings emerged. In contrast with earlier HLF-studies, the conceptual framework highlights the possibility of enhancing the management of time performance by capitalising on HLF capabilities and connecting them with human and software oracles. It proposes a set of smart contract functions to enable the execution of various contractual processes and subprocesses as derived from FIDIC RB 2017.

Deploying and operating those prospective smart contract functions on an HLF-based platform can mitigate a number of inherent challenges. With reference to Table 1 above, examples at the project level include misapplication of related sub-clauses (Ch-2), missing contractual obligations (Ch-12), inaction due to optimism bias (Ch-13), and missed time-bar (Ch-14). Challenges addressed at the inter-organisational level include distortion of information (Ch-6), information asymmetry (Ch-10), avoidance of discussion and poor communication (Ch-15), and difficulty with establishing continuous reasoned causation (Ch-19). For both levels, it can be posited that the net foreseeable result is enhanced control and coordination of contractual obligations and information in respect of time performance management.

Evidently, with minor adjustments to the existing contractual logic of FIDIC RB 2017 at the contractual process level in terms of connection, the notion of 'chained time performance management' can be realised. For example, such adjustments may involve explicitly connecting the EoT claims management process with the other processes while defining a delay analysis protocol in the particular conditions of a construction contract. Yet, these adjustments should be coordinated and cross checked across the whole Contract to avoid unintended consequences. Prospective adopters can seek contractual and legal advice to verify and validate such adjustments before scaling the proposed framework into technical development and production.

## Conclusions

This paper presents a conceptual framework for enhancing contractual time performance management from an inter-organisational perspective while respecting contractual governance. With available digital solutions linked to HLF as a digital core coupled with minor adjustments to contractual logic, a way to enhancing contractual time performance management can be built in a single digital environment.

This paper has implications for practice and research. In practical terms, it establishes an adaptable conversion path from practical problems associated with contractual time performance management to an HLF-based framework. This path may help interested practitioners adapt the approaches presented herein to other mechanisms of FIDIC RB 2017 and other standard contract models. Along the same line, it highlights the possibility of using existing digital solutions, implemented in practice, as software oracles to leverage advanced HLF-based solutions. Theoretical contribution

to the body of knowledge was realised in two ways. First, in advancing the case of blockchain in CCA and construction at large by proposing an adaptable HLF-based framework for time performance management. Second, by offering an application reference within a defined contractual context that can be further validated by academic researchers.

Further work is currently being carried out to develop and refine the application framework. This includes: (i) defining the parameters of the proposed smart contract functions, (ii) coding the smart contract functions using a suitable programming language, and (iii) developing API rules and their technical requirements. Accordingly, the framework will be instantiated through the demonstration of a proof-of-concept on an infrastructure project to realise the notion of 'chained time performance management' for large construction projects.

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