Summary for CIFE Seed Proposals for Academic Year 2020-21

Proposal number:	2020-09
Proposal title:	**Blockchain-Enabled Smart Contracts for Autonomous Construction Progress Payments**
Principal investigator(s)[1] and department(s):	Martin Fischer (Professor), Civil & Environmental Engineering
Research staff:	Hesam Hamledari (PhD Candidate), Civil & Environmental Engineering
Total funds requested:	**60,647$**
Project URL for continuation proposals	**http://**
Broad Category Addressed in this Research[2]	**fosters business & economy / experience improved for all stakeholders**
Project focus area addressed by proposal[3]	**Automation/ Payments**
Stakeholders' benefitted by the research[4]	**Owners, Builders, Financiers, and Operators/Facility Managers**
Expected time horizon to impact the industry	**2 to 5 years**
Type of research[5]	**Exploration**
Industry Involvement	

[1] The PI(s) must be academic council member(s) at Stanford.
[2] Remove the categories that do not apply to this research proposal.
[3] Remove the focus areas that do not apply to this research proposal.
[4] Remove stakeholders that you do not anticipate to primarily benefit from this research.
[5] **Exploitation -** "refinement, choice, production, efficiency, selection, implementation, and execution;" **Exploration** - "search, variation, risk taking, experimentation, play, flexibility, discovery, innovation." For more information please take a look at the following article.

Abstract (up to 150 words)	Construction progress payments are crucial to projects' successful delivery. Traditional payment applications are time consuming to prepare, and they cannot take advantage of the myriad of digitized progress data, available thanks to the recent advancements in on-site reality capture. This research explores the use of blockchain-based smart contracts to automate and decentralize the administration of progress payments, conditioning cash flow on job site observations without reliance on heavily intermediated and time-consuming payment applications. The proposed method will be tested in two real-life case studies of robotic data capture and BIM-based progress documentation. The blockchain-based payment system will be compared with current payment applications in terms of supply chain visibility, the level of payment granularity, and the level of effort.

1- Engineering or Business Problem

Construction progress payments are crucial to a project's successful delivery and the financial wellbeing of its stakeholders. The construction industry still relies on the use of traditional contracts and payment applications that hugely rely on human-centered workflows and are time consuming and costly to prepare, review, approve, and execute (Fig. 1). As a result, project stakeholders commonly suffer from late- or non-payments, making the architectural, engineering, and construction (AEC) industry credit heavy and cash poor. A 2019 survey of 1138 firms reveals that it takes engineering and construction companies 85 days to receive payment (PwC 2019), a 10-day increase compared to previous year (PwC 2018). The McKinsey Global Institute identified traditional contracts as one of the seven major barriers to increased productivity in the construction industry (McKinsey 2017); improvement in contracting practices was estimated to increase productivity and cost savings by 8-10% and 6-7%, respectively (McKinsey 2017).

Recently, there has been an ever-growing interest in automated means of tracking the construction progress via remote capture technology and model-driven communication of captured data; as a result, industry practitioners now have easier, more frequent, and more affordable access to a myriad of data regarding the as-built status and the progress of work at jobsites. However, practitioners still need to capture and communicate the progress of the work using forms such the American institute of architects (AIA) documents (e.g., G702 and G703) or customized forms specific to each firm.

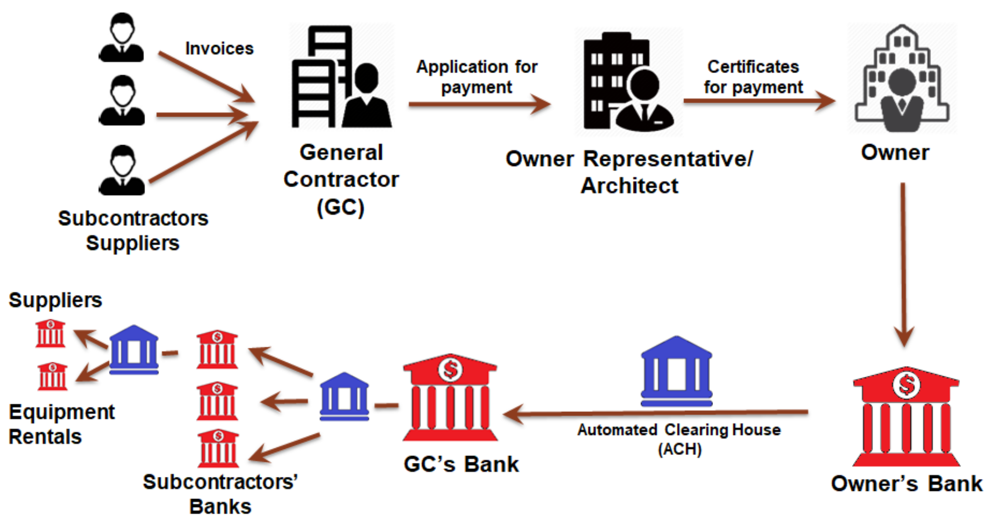

Fig. 1. Current payment application workflows are heavily intermediated and time consuming

Despite the availability of digitized progress data, the industry lacks methods to fully utilize the captured jobsite reality for administering progress payments.

2- Theoretical and Practical Points of Departure

The industry uses a myriad of remote capture technologies to document the state of progress at job sites. Most commonly, these include laser scanners or digital cameras, either mounted on robotic platforms (e.g., unmanned aerial vehicles) or operated manually. Artificial intelligence-based solutions are then used to analyze the collected data, captured in the form of images, videos, and point clouds, to quantify the progress of construction work performed by various trades.

At CIFE, we have investigated both the computer vision-based detection of construction progress and its automatic integration into 3D and 4D building Information models (Fischer et al. 2018; Fischer et al. 2017; Hamledari et al. 2017a; Hamledari and Fischer 2020; Hamledari et al. 2017b); however, as discussed in the previous section, current payment applications are not designed to support the use of this data for payments. The utilization of progress data for payments necessitates the use of computerized contracts that can automatically condition the status of payments on observed job site reality and without reliance on manual workflows.

With this regard, the concept of 'smart contract', first proposed by Nick Szabo (Szabo 1994), is the primary point of departure for this work. Szabo introduced smart contract as "a computerized transaction protocol that executes the terms of a contract". He proposed an automated *protocol* that 1) satisfies contractual agreements, 2) minimizes malicious and unintentional errors, and 3) eliminates the role of intermediaries in contract administration.

The latter objective, the decentralized administration of contract, became a possibility with the advent of blockchain technology in 2008 (Nakamoto 2008). Blockchain made it possible for 'smart contract' to see real-world implementation and gain traction in the computer science community. Blockchain is one of the building blocks of the Fintech (Hileman and Rauchs 2017) and a primary reason behind the recent successes of cryptocurrencies such as Bitcoin (Nakamoto 2008). Blockchain technology introduces a temper-proof and distributed shared ledger as a means of record keeping in a peer-to-peer (P2P) network. In the Bitcoin domain, blockchain is used to maintain an immutable record of transactions without the need for a centralized authority such as banks (Swan 2015). Bitcoin's decentralization eliminates the need for trust between parties involved in a transaction and in P2P networks; this is considered by many to be the key factor differentiating cryptocurrencies from their unsuccessful predecessors such as b-money and bit gold

(Swan 2015; Vigna and Casey 2016); this decentralization is key to real-world implementation of ‘smart contracts’.

The blockchain’s consensus mechanism enables the execution of computerized contracts without reliance on centralized intermediaries; this decentralization enables a trustless network of peers to administer terms of contract autonomously; this decentralized contract execution was proposed by the Ethereum protocol (Buterin 2014; Wood 2014). Ethereum has its own blockchain and native cryptocurrency (Ether); however, it goes beyond decentralized exchange of money and can be thought of as “Blockchain 2.0” (Diedrich 2016). Its protocol and its nearly Turing-complete language allow for the execution of programs on a decentralized world computer, the Ethereum Virtual Machine (EVM).

Research Methods and Work Plan

This research focuses on designing a blockchain-based payment system, its real-world implementation, and a comparison of its performance with current payment applications. Fig. 2 illustrates the envisioned blockchain-based system which translates each on-site data capture to a series of payments to the trades performing the job and without reliance on traditional payment applications.

In the first step and early on in the project, stakeholders transform the contractual agreements, as materialized in contract documents, into smart contracts (Fig. 2a); this requires clear formalization of rules, the underlying agreements, and the payment terms in relationship with the scope of work, schedule of values, and other project information. The smart contract is then deployed on the blockchain (e.g., Ethereum) and can be executed throughout the project. Please note that this process (Fig. 2a) is carried out in the beginning of the project, but also every time there is an update to the agreements or project information that govern the payment administration. For example, if there is a change in the evaluation of work, the updated schedule of values needs to be incorporated into a new smart contract and deployed on the blockchain. The previous smart contract will still exist on the blockchain, but the project participants will only interact with the new instance consisting of the updated information.

Throughout the project (Fig. 2b), the status of job sites is captured using a myriad of remote capture technologies, and the data is published to the blockchain, resulting in a series of automated payments to the responsible trades (Fig. 2c) and based on terms of contract as documented in the smart contract script. The computerized code will condition the payments based on the observed site status. This process is independent of individual stakeholders, and it is executed in a decentralized manner; this decentralization is the key role of blockchain and smart contract in automating progress payments (Hamledari and Fischer 2020). This is because centralized control over the maintenance and execution of the contract code reduces the trust in the outputs and resulting payments; it reduces the reliability.

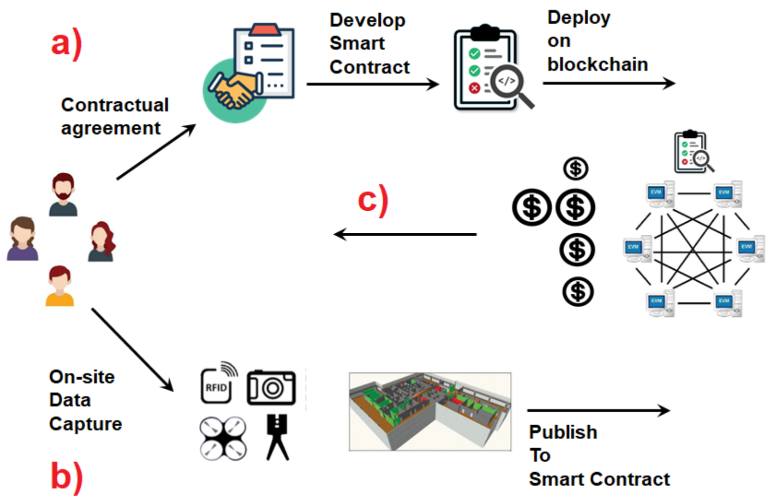

Fig. 2. The envisioned blockchain-based payment system, translating each progress report into payments without reliance on time-consuming and manual payment applications

The research objectives are twofold: 1) the real-world testing and feasibility analysis of blockchain-based payment systems; and 2) a comparison of current payment applications and the innovative solution.

Real-world testing: blockchain-based systems have not yet seen real-world implementation. Therefore, as part of the research project, we will implement a blockchain-based system and use it to execute payments within two case studies (Fig. 3). The first is a collaboration with CIFE partner, Swinerton, where Boston Dynamics robots will be used to capture the status of progress at job sites. The second case study uses a camera-mounted drone platform to document the status of work at an indoor site. The progress for both cases will be analyzed using artificial intelligence and incorporated into building information models. The first case study provides us with laser scan data for mechanical, electrical, and plumbing (MEP) components, while the latter comprises of digital images for finishing work on indoor partitions.

Comparison of current payment systems and the proposed solution: a series of metrics will be tracked in both systems, and they will be compared to understand the impact of blockchain-based payment systems on the stakeholders involved in the progress payment workflows; these include the level of effort involved in payment processing, the payment granularity (the scope of work, the frequency), and the supply chain visibility (the accuracy, timeliness, and completeness of information retrieved regarding the status of payments).

Data capture	SPOT robot (Boston Dynamics)	Manual	Drone	Manual
Progress data	Laser scans		Images	
Scope of work	MEP		Partitions/indoor finishing	

Fig. 3. The two case studies used for real-world testing and comparing the blockchain-based systems with current payment applications (image courtesy of Swinerton)

Expected Results: Findings, Contributions, and Impact on Practice

The proposed research provides the industry practitioners with a method for automated progress payment using data captured at job sites; it further provides a clearer understanding of the impact of blockchain and its benefits for the stakeholders involved in the payment chain.

It must be noted that this research builds on the previous two CIFE seeds by the authors that respectively investigated the automated incorporation of progress data into building information models (Fischer et al. 2017) and the secure and immutable recording of project data on blockchain (Fischer et al. 2018). The former provides an automated, objective, consistent, and reliable means of accessing a shared understanding of job site reality. The developed solution is independent of remote capture technology, so it provides support for various data types including digital images and laser scans, among others. The latter project is crucial to successful implementation of blockchain-based payment system because project data, including payment terms, need to be secured and collectively maintained over time. A centralized control over such data reduces the trust in resulting payments and decreases the reliability of the system; the automation of payments and the elimination of the gated workflows necessitates that such transition from progress data to payment remains under control of no single party.

The proposed research is expected to impact the industry in a number of ways including: 1) increasing the efficiencies of payment systems; 2) increase visibility, in turn increasing the accuracy of cash flow predictions, especially crucial to sub and prime contractors; and 3) reducing the late- and non-payment risks for trades completing the work and the lien risks for owners.

Industry Involvement

This research project is exploring the first real-world implementation of blockchain and smart contract technology for progress payment; for this to be successful the method must be designed in close collaboration with industry partners and with complete understanding of the needs and challenges for all stakeholders involved in the payment workflow including owners, prime and sub-contractors, suppliers, and project financiers.

Through these partnerships, the researchers also aim to develop a clear understanding of current payment workflows; this helps identify a baseline for comparing the blockchain-based system with conventional payment applications. CIFE partners can also become involved in the method's testing by providing case study data.

Next Steps

Not all types of construction payments are addressed in this research, and the work is focused on progress payments; future work needs to study how other types of payment can be incorporated into this system; these include payment for services or material that is stored on site but not directly captured in progress data.

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Sponsor:	CIFE
Submission Type:	New
Budget Preparation Date:	21/4/2020
Budget Start Date:	21/4/2020
Project Name:	Title: TBD
Department:	Civil Engineering
Principal Investigator:	Martin Fischer
Administrator:	Blanca Rebuelta

			Period 1	All Periods
		From	9/30/2020	9/30/2020
		To	6/30/2021	6/30/2021
Personnel Salaries				
Graduate Students				
Research Assistant	Academic	50.0%	30,348	30,348
	Summer	50.0%	10,116	10,116
Total Graduate Student Salaries			40,464	40,464
Total Salaries			40,464	40,464
Benefits				
Graduate			2,023	2,023
Total Benefits			2,023	2,023
Total Salaries and Benefits			42,487	42,487
Other Direct Costs				
Tuition				
Research Assistant	Academic	50.0%	20,358	20,358
	Summer	50.0%	6,786	6,786
Total Tuition			27,144	27,144
Domestic Travel			2,000	2,000
Total Other Direct Costs			29,144	29,144
Total Direct Costs			60,647	60,647
Total Amount Requested			60,647	60,647

Rates Used in Budget Calculations

Benefit Rates

Graduate: FY 1 05.00%; FY 2 05.00%; FY 3+ 05.00%;

Indirect Cost Rates