Integrating Advanced Technologies to Uphold Security of Payment: Data Flow Diagram

Heap-Yih Chong[1]; Alexander Diamantopoulos[2*]

[1]School of Design and the Built Environment, Curtin University, GPO Box U1987, Perth, WA 6845, Australia. E-mail: heap-yih.chong@curtin.edu.au

[2]School of Design and the Built Environment, Curtin University, GPO Box U1987, Perth, WA 6845, Australia. E-mail: ajdiamantopoulos@hotmail.com *corresponding author

Abstract

Security of payment (SOP) issues still persist in the construction industry despite numerous investigations and incremental reforms. Various solutions and policies have been proposed and analysed in-depth in previous studies. However, limited studies have focused on the integration of advanced technologies to address SOP issues. The aim of this research is to develop a comprehensive framework that integrates practical advanced technologies to address SOP issues in the construction industry. A concurrent mixed-method design was adopted to (a) identify the industry's perspective on what advanced technologies can be accepted to address SOP issues through a questionnaire survey, and (b) identify the use of advanced technologies through a live construction project as a case study. Subsequently, a data flow diagram framework was developed to articulate the whole process flow of how the system delivers automatic payments to subcontractors upon the completion of their contractual obligations and work done. This research contributes new and practical insights into the application and integration of smart sensors, oracles, BIM, blockchain technology and smart contracts in addressing SOP issues in the construction industry.

Keywords: Security of Payment; Advanced Technologies; Subcontractors; Building Information Modelling; BIM; Blockchain Technology, Smart Contracts; Smart Sensors; Oracles; Data Flow Diagram; DFD.

1. Introduction

Payment problems are caused by multiple, complex interconnected factors; therefore, there is no single, catch-all panacea to address security of payment (SOP) issues. The causes, effects and solutions to SOP issues have been analysed in depth in previous studies, therefore it is not within the scope of this paper to analyse these in-depth, only to highlight and briefly explain them to create context and grounds for this research. SOP issues can be caused by the following: the structure of the industry, thin profit margins, low capitalisation, deferred payments, the holding of retention money, competition within the construction industry, risk allocation, the cyclical nature of the construction industry, the lack of business acumen, and insolvencies [1-5]. These causes have magnitude of effects include but are not limited to: cash flow problems, contractual disputes, insolvency, and construction delays [3].

Various solutions have evolved over time and they seek to address the underlying causes and effects of the problem. Notably, the most "impactful" solutions to date include: the implementation of Adjudication Acts, administrative solutions, and trusts as solutions. Related studies [3, 4, 6,7] conclude that while there have been minimal complaints and the effects of the solutions are generally perceived as positive, there are multiple factors from an industry point of view that prevent them from being influential in solving SOP issues entirely, including: (a) the fear of reprisal from contractors if subcontractors exercise their rights; (b) the ability for parties to forward awards from adjudicators and third parties to arbitration and/or litigation for final determination; (c) a lack of awareness and understanding of rights with the "critical need" for widespread education; and (d) the lack of incentives for all parties within the contractual chain; for example, project banks accounts (a type of trust) will prevent head contractors from strategically managing their cash flow, this is because payment is made simultaneously to both the head contractor and subcontractors. Head contractors will therefore be reluctant to adopt trusts as solutions because they will need to reduce their cash position and bargaining power as a result. These reasons reduce the likelihood of private sector adoption unless trusts are legislated. Concluding that despite the various solutions to-date (each of which do not consider advanced technologies) SOP issue still persists. The research argue that the capabilities of advanced technologies, such as smart contracts, blockchain technology, BIM, and smart sensors could be integrated and implemented to address the long-lasting SOP issues within in the construction industry, as the capabilities that these technologies display are highly beneficial and applicable to the issue at hand. Although the application of blockchain technology and smart contracts have been proposed in certain domains, such as Internet of Things [8,9], Artificial Intelligence [10] , Deepfake [11], and 5G [12,13], these concepts are still at their infancy stage in the construction industry. There is a lack of awareness amongst industry members and the body of knowledge surrounding how these advanced technologies can be integrated to address SOP issues.

Hence, the aim of this research is to develop a comprehensive framework that integrates practical advanced technologies in addressing SOP issues in the construction industry, particularly from subcontractors' perspective. Two underpinning objectives have been designed to achieve the aim, namely, (a) identify the industry's perception in adopting advanced technologies as potential solutions to SOP issues, and (b) conduct an empirical study to outline the use advanced technologies in a live construction project. A concurrent mixed-method design was conducted through the questionnaire survey and case study to achieve the first and second objectives. Data flow diagram method was used to develop the framework. This research is of significance in improving the industry's poor image in payment issues through the use and integration of advanced technologies.

2. Theoretical Foundation

2.1 Background of Study

Quantifying the full extent of SOP issues is challenging, however, there is statistical evidence indicating that the construction industry has one of the highest rates of payment delinquency and insolvency of all business sectors [3,14-16]. Notably, in Australia, the Small Business and Family Enterprise Ombudsman's [17] highlighted small-medium enterprises claimed to have experienced late payment and received the payment more than 30 days. In the New Zealand construction industry, out of 99 respondents, 63 per cent were exposed to payment delays and 53 per cent were exposed to payment losses [3]. While in China, the total unpaid arrears totalled to RMB30.4 billion in 2003 within the Chinese construction industry [1].

The underlying causes and effects of the problem are important to address, because unquestionably, productive performance of all parties within the construction industry is dependent on uninterrupted cash flow during the contractual period [3]. The regularity of cash flow for subcontractors and suppliers alike is crucial, because typically, these parties assume an inequitable amount of risk and generally have low start-up capital, which means they have to fund labour, materials, and other resources in order to meet their obligations under the contract [5]. The inequitable transfer of risk is a result of the subcontracting nature of the industry, in which, the industry has evolved from directly hired workforces and is now characterised by a pyramid structure [18]. This structure creates silos; the head contractor is engaged and subsequently paid by the client, while the subcontractors and suppliers are engaged and subsequently paid by the head contractor [19]. As a result, the money has to travel through multiple layers before reaching the subcontractors who are directly funding and undertaking the works, additionally, traditional payment terms only give subcontractors the right to make a payment claim once per month for works completed to date. For example, the requirement for payment being no more than 42 days after submitting the payment claim [20]. The combination of low capitalisation, harsh allocation of risk and lengthy payment terms put subcontractors in a situation where if payment issues do arise, it may prevent them from making repayments, resulting in the inability to fund future projects and causing them to stop outright due to insolvency, while at the same time preventing the subcontractor from paying employees [3]. Subcontractors should be protected through the implementation of feasible, long-lasting payment solutions.

Overall, the causes of non-payment and late payment for subcontractors or as a whole in the industry are said to be complex and multifaceted [5]. Causes of payment default and late payment are different internationally and are influenced by many factors such as legislation, governance culture and so on. Table 1 summarizes the causes of payment defaults from subcontractors' perspective.

Table 1: Causes of payment defaults from subcontractors' perspective

Causes	Non-Payment	Late Payment	Comments	References
Local and cultural attitude towards payment	Yes	Yes	Purposeful delay in assessing and certification of progress claims and purposeful non payment	[2,3,21]
Client and contractors fail to implement appropriate governance	Yes	Yes	Multilayering of subcontractors and the contractual governance of 'pay-when-paid' or 'back-to-back' arrangements	[2,21]
Fragmentation of the construction process/ hierarchical structure	Yes	Yes	Increased number of layers in which money has to pass, increasing likeliness of non-payment and delay and causing subcontract to finance for longer periods	[1-3,5]
Competition within the construction industry	Yes	Yes	Lack of work for large amount of contractors causing thin profit margins and susceptibility to financial shock.	[1,2,5]

Changes in market and economic conditions	Yes	Yes	Result in high volatility for demand for goods and services in uptrend. In the downtrend the bust causes increased competition and lower margins.	[1,3,5])
Low capitalisation of a business (poor financial management/ stability) and poor business acumen.	Yes	Yes	More capital results in better response to financial shock, lower capital can cause contractors to strategically hold onto money and do not pay subcontractors (due to cashflow difficulties as a result of low start up capital).	[2-5]
Bankruptcy, liquidation, insolvencies and receivership	Yes	Yes	Companies may not need to pay retention held or money owing.	[3,5]

2.2 Related Works

Multiple solutions have evolved over time and they seek to mitigate the underlying causes and effects of the problem. Notably, the most "impactful" solutions to date include: the implementation of legislation, administrative solutions, and project bank accounts. Although these solutions are beneficial, they are also generally perceived as ineffective from an industry point of view [2,3,6,7].

This research argues that SoP issues can be addressed through effective use of advanced technologies. However, utilising advanced technologies to address SOP issues is a new concept that has not been a topic of empirical studies to date, therefore, the purpose of the related works section is to (a) identify the capabilities of the advanced technologies as expressed through practical uses cases and literature to determine how advanced technologies can be combined and/or used to address SOP issues and (b) to get an understanding of the current development and adoption levels of each advanced technology.

2.2.1 Advanced technologies in addressing security of payment issues

Blockchain (BC) is a distributed ledger technology; a chronological database of transactions recorded and managed across a network of decentralised nodes [22]. The phrase "blockchain" refers to these transactions being clustered together in blocks, and the chain that links the blocks is the approved history of transactions since inception of the block itself, creating provenance and transparency while also providing a trusted immutable record [23]. In order to record transactions on a block and subsequently add the block to the BC, each node on the network must reach consensus through a consensus mechanism. In a general sense, this mechanism involves each node completing a cryptographic algorithm which in turn validates transactions and adds new blocks to the BC; enhancing data security and decentralisation [24]. Furthermore, it is possible that a BC network can be private, meaning that (a) permission is required to join the network, and, (b) the authority to perform the consensus mechanism and subsequently upload transactions is limited; creating data privacy and legal accountability [25]. BCs capabilities could prove to be useful in addressing SOP issues. As the availability of funds could be displayed to a predetermined project team on the private BC network, reducing concerns surrounding future non-payment scenarios due to lack of availability of funds. Additionally, there is potential to store retention monies on the private BC network, ensuring that retention monies would be protected and accessible upon a contractor becoming insolvent, preventing non-payment of subcontractors [19]. Last, there is potential for the private BC network to store project updates as transactions on the ledger after consensus is reached. This consensus confirms that contractual obligations have been met subsequently uploading this transaction to the ledger, triggering a blockchain-enabled contract (smart contract).

The concept of smart contracts surfaced in 1997 [26]. Smart contracts serve as a software module that is developed by the BC owners on the private BC network and, installed into the BC itself as a transaction [26]. The practical use of smart contracts came to light in 2015 with the creation of a cryptocurrency called Ethereum [24]. smart contracts have the ability to automatically execute and release funds that are stored on the BC network when certain obligations or instructions in the form of computer code are met [23,24]. This is because smart contracts can "read" information on the BC network and as a result when a transaction that is specific to the conditions of the agreement is sent, validated and subsequently stored on the BC network the smart contracts will execute [27]. Furthermore, smart contracts can be linked together, allowing simultaneous payment of parties when certain obligations are met [28]. A company called Ujo Music is currently leveraging smart contracts to pay musicians automatically via a digital payment system when a particular musicians' song is streamed [25]. Whereas several other industries are currently developing frameworks for smart contracts ecosystems. The ability of the smart contracts to release the stored funds on the BC network upon certain conditions being met, automatically, would prove to be useful in the construction industry [29]. smart contracts would prevent the strategic management of cash flow from higher contractual counterparts and reduce the likelihood of late and/ or non-payment because the smart contracts would trigger automatically and release funds simultaneously (from the client, to the contractor to the supplier/ subcontractor) upon certain obligations being met under the smart contracts agreement, for example, upon the delivery of materials.

In order to execute a particular condition automatically as described above, the smart contracts will require feedback from the external environment that is relevant to the performance requirements within the digital agreement [30]. There is potential that this can be achieved by smart sensors. A sensor is a device that provides signals from physical processes in a measurable way, whereas a smart sensor is an advanced platform with added technologies that transform these traditional signals into digital insights [31]. These technologies consist of radio frequency identification, global positioning systems, wireless network sensors, Bluetooth, and hybrid versions (a combination of tracking devices). Tracking technology has been examined, applied, and reviewed through studies, trials, and real-life applications for the past two decades, for example: Harley Davidson utilise smart sensors to track each step of production, uploading information to a performance management system progressively [31], RFID tags are being used to track pipe spool delivery and receipt [32], sensors are being used to identify the travel patterns of workers [33], GPS technology is being utilised for long-range tracking of asset movement from manufacture to delivery [34], and lastly, RFID readers and GPS receivers are being used to localise building components in an industrial setting [35]. Whereas recently, frameworks have been produced proposing the integration of different tracking technologies for all stages of materials tracking; off-site manufacturing, transportation, and site logistics [34].

Sensors have the ability to supply data from the outside world occurrences directly to smart contracts, these are referred to as oracles [24]. There are several different types of oracles; hardware, software and consensus oracles [30]. Hardware oracles supply information directly from the physical world and consist of, but are not limited to, RFID tags, Bluetooth sensors and GPS technology, whereas software oracles extract specific information that is required from online sources to the smart contracts [30]. Software oracles can retrieve and submit website data automatically to a relying smart contracts on the BC network [36,37]. However, there is a lack of literature identifying the practical use-case of hardware oracles. Nevertheless, the combination of smart sensors and smart contracts capabilities could prove to be useful in addressing SOP issues. The smart sensors could communicate the location of the materials along the supply-chain and confirm location in the form of a transaction on the BC network (also providing provenance) in real-time and upon validation of this transaction from the nodes on the BC network the smart contracts would self-execute, causing the BC to release payments to the supplier and/or subcontractor. Figure 1 illustrates the smart contracts transactions for suppliers or subcontractors.

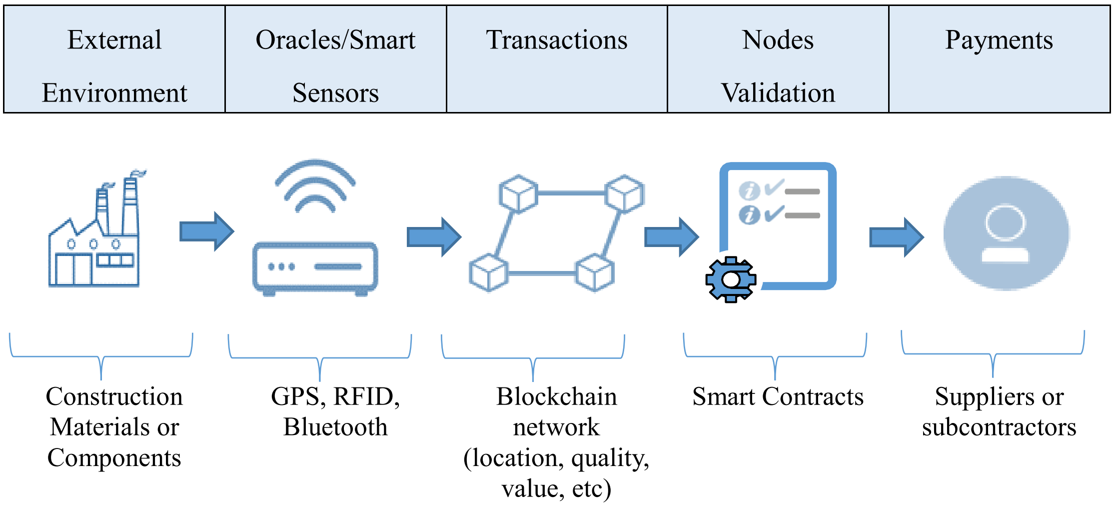

Figure 1: An illustration of smart contracts transactions for suppliers or subcontractors

Studies conducted by several researchers have explored the possibility of integration between BIM and smart sensors, as well as the integration between BIM and BC technology. Frameworks have been proposed to integrate smart sensors with BIM [38-40]. Smart sensors can integrate with BIM by leveraging a software engineering [41]. For example, bcBIM has been proposed and this system can be utilised as a method to trace and authenticate BIM data [42].Although development and implementation is required when considering the integration of smart sensors and BIM and subsequently BIM and BC, the concept could prove to be very useful addressing SOP issues. The smart sensors could transfer information surrounding material location and performance from the external environment to the BIM model, allowing the BIM model to display live as-built information for certification purposes. After certification, the data could be transferred directly to the BC network. This data or 'status information' could then undergo a second certification process via the consensus mechanism, allowing a transaction to be uploaded to the BC network, triggering the smart contracts, automatically releasing payment for works completed. Potentially reducing the likelihood of non-payment and late-payment.

The capabilities of the advanced technologies, singularly, as well as when integrated have been identified as summarised in Table 2. The combined capabilities are considered as highly applicable in addressing SOP issues. However, it is noted that the concept is new and lacks perspective within the construction industry, suggesting that there is a lack of literature indicating how and why these technologies should be combined for the purpose of addressing SOP issues.

Table 2: Advanced technology applications (BC: blockchain, SC: smart contracts, SS: smart sensor, OR: oracle, and BIM: building information modelling)

Papers	BC	SC	SS	OR	BIM	SUMMARY
[25]	Y	Y	-	-	-	Description of SC Frameworks and current use cases, description of BC use for storage of sensitive information and storage/ transfer of funds.
[31-35]	-	-	Y	-	-	SS applications: traceability of products during supply-chain process, analysis of wireless SS for real-time resource tracking, drafting of framework allowing SS to provide tracking information for all stages supply-chain process
[36,37]	Y	Y	-	Y	-	Analysis of software OR systems.
[38-40]	-	-	Y	-	Y	Framework that proposes integration of SS and BIM.
[41]	-	-	Y	-	Y	Analysis of software that allows integration of real-time sensor data with BIM.
[42]	Y	Y	-	-	Y	Model to guide the architectural design of a system that allows the integration of BIM and BC.

2.2.2 The research gap

The literature analysis explains the current managerial solutions or policies do not adequately ensure payment or speed up cash flow through the construction industry's contractual chain. Althoughthe practical use-cases of blockchain technology, smart contracts, smart sensors, oracle and BIM that may be applicable in addressing SOP issues, each of these advanced technologies has different levels of adoption and development. Table 2 shows only three out of five technologies above have been integrated in the previous studies. This reveals an obvious technical gap for a complete and effective integration of those technologies in addressing SOP issues. The connections among the technologies requires further investigations and adjustments from construction practices in terms of assessing completed works and releasing payments for subcontractors. The related workflow and integration processes remain undeveloped from the theoretical perspective.

3. Research methodology

3.1 Concurrent mixed-method approach

As depicted in Figure 2, a concurrent mixed-method approach was adopted to satisfy the overarching research aims and objectives. The design consisted of two research approaches occurring simultaneously: a factor analysis of questionnaire results, with the outcome satisfying research objective one and a content analysis of semi-structured interviews, documents, and information from an onsite observation, with the outcome resulting in the development of a case study, satisfying research objective two. Subsequently, the outcomes of the two approaches were used as the basis to develop a practical and comprehensive DFD framework. This framework can potentially act as a guide for IT developers to design and implement an automated payment system that will allow advanced technologies to be adopted and used as solutions to SOP issues.

The main reason behind the research is predominantly due to the fact that SOP issues persist worldwide despite the various solutions and frequent investigations, however, Australia was chosen as the scope of the research, because Australia's construction industry is currently facing the highest rate of payment delinquency and insolvency compared to other business sectors [5]). This has led to the release of the Fiocco report [5] in late 2018. This report is symbolic, further substantiating that SOP issues still persist within Australia. Therefore, the questionnaire seeks to understand what advanced technologies are accepted as feasible and practical in addressing SOP issues from an Australian construction industry perspective while also outlining what advanced technologies are being used on a live construction project within Australia.

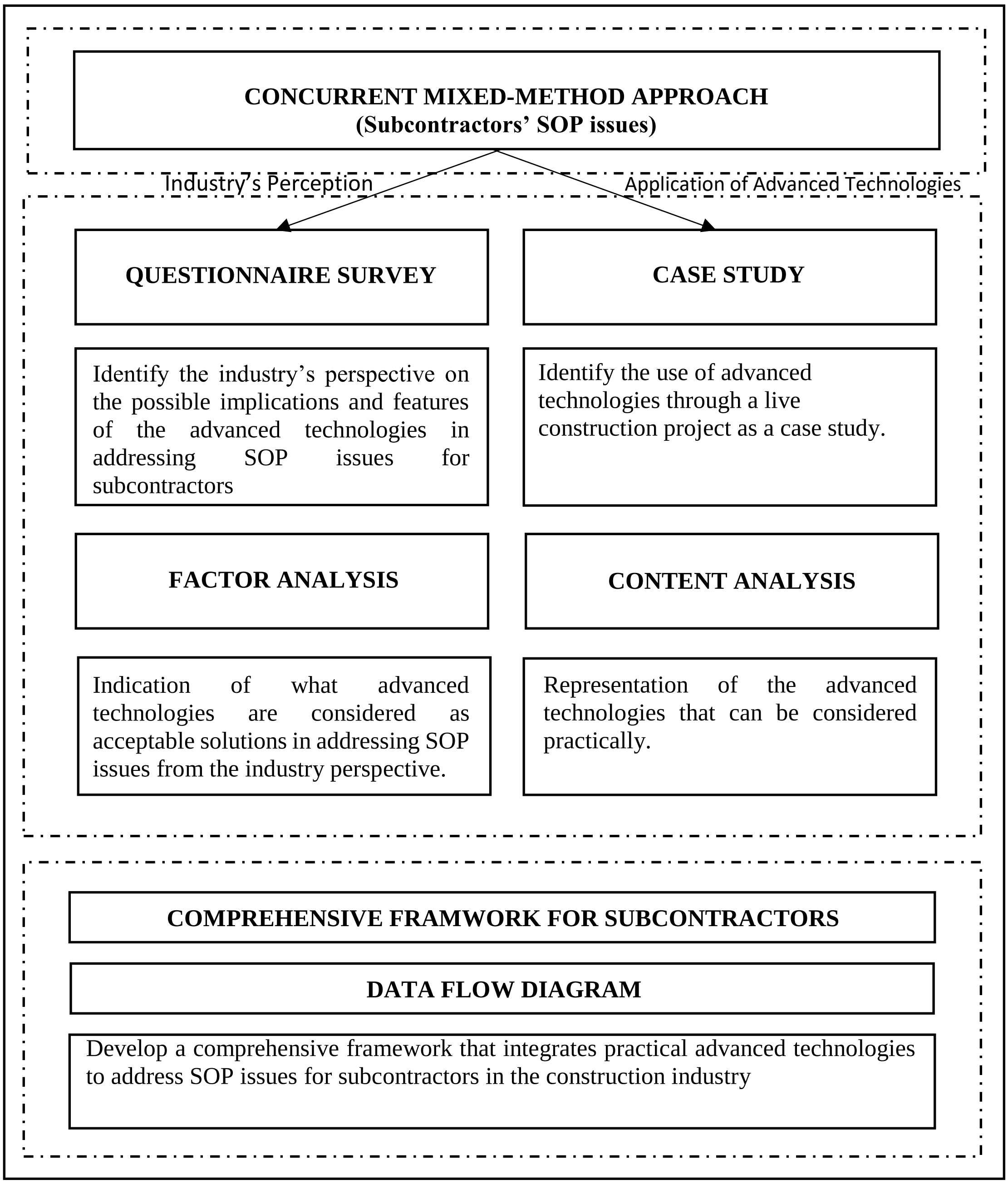

Figure 2: Research framework

The first stage of the data collection was facilitated by a questionnaire survey. A purposive approach was undertaken meaning that information rich respondents with a high level of commercial acumen were targeted, as these individuals administer payments and are therefore more likely to have had some exposure to SOP problems, thus providing better responses [43]. The survey included two sections: Section A, which consisted of questions that elicited demographic information from the respondents. While section B, the main section of the questionnaire, consisted of statements that were established using the findings from the literature review, such as:

- Smart contracts can execute payment, automatically, using the funds that are embedded on the blockchain network upon works being completed. This will provide surety of payment throughout the project (B1) [25,36],
- Smart contracts self-executing clauses allowing automatic payment upon completion of works will result in less accounts of non-payment (B2) [25,37],
- Smart contracts and blockchain allowing embedment of funds and self-executing conditions will reduce the level of bargaining power amongst supply chain members (B3)[25,36,37],
- A comparison of the BIM model and the as-built structure via the project team can be an effective means of ensuring works is complete (B4) [38-41],
- Smart contracts have the ability to be linked together allowing simultaneous payment and therefore faster payment of contractual counterparts, reducing cash flow difficulties (B5) [25,36,37],
- If every payment, transaction, business interaction and execution can be registered on the blockchain and viewable by authorised stakeholders the construction process will be more transparent and therefore less disputes will arise (B6) [25,36,37],
- Instructions can be incorporated into payment transactions and follow through between smart contracts, safeguarding subcontractors from late and non-payment i.e. funds released to SC before Contractor can accesses funds (B7) [25,36,37],
- Smart contracts having the ability to embed funds and therefore allowing retention monies to be protected will prevent contractors, subcontractors and other supply chain members from becoming insolvent in the event of insolvency of contractual parties higher in the contractual chain (B8) ([25,36,37],
- Tendering on a project that utilises smart contracts which use computer protocols to enforce obligations and verify negotiations would not be a deference from the tender proc cess (B9) [25,36,37],
- Smart contracts having the ability to embed funds will provide evidence of availability of financing, pre-construction, making the project more attractive to tender on (B10) [25,36,37],
- Smart contracts can register and manage inputs from different sensors, making payment instantaneous upon works being completed, reducing the likelihood of late payment (B11) [25,36,37],

- A BIM model would prove to be a reliable source of information for works actually completed if updated by a project team member (B12)[42],
- Transactions should be made public amongst all supply chain members to increase collaboration and therefore allow effective project delivery (B13[32,33], and
- There are no perceived disadvantages with using advanced technology to solve payment problems (B14) [33].

The second stage of the data collection was to showcase the use of advanced technologies for addressing SOP issues in the construction project. This would help justify what advanced technologies can be considered and eventually incorporated within the DFD framework. The data used to develop the case study was gathered from three sources: interviews, documents, and an on-site observation. The interviews were a well-suited method of data collection, as this method allowed the researcher to continuously probe for more information and further explanations of responses. This can ensure validity of responses, and therefore, providing a case study that only included trustworthy information [44]. The interviewees were technology experts with vast experience, they have been influential in the implementation of technologies such as blockchain, smart sensors and BIM on some of Australia's largest high-rise construction projects. Furthermore, an onsite observation was also used as a data source for the development of the case study. During the course of the site-visit, photos were taken to provide photo evidence of the technology in-use and to validate information from the other data collection methods. Additionally, a document analysis was conducted; the documents analysed were provided by the experts, this allowed the researcher to substantiate the capabilities of the technologies and to confirm that the information from the interviews were perceived correctly by the researcher.

Content analysis was used to analyse the data collected from the interviews, the document analysis and the onsite observations. This analysis refined the large amount of information to into a concise and trustworthy case study. Further, verification and validation of the information within the case study was achieved through extensive revision by the experts from the case study project.

3.2 Framework

Data flow diagram (DFD) was the tool used to develop the framework. DFD is a graphical modelling tool that breaks down complex systems into a network of functional processes [45]. Generally, DFD uses four symbols to provide a graphical representation of information flow through a process, these symbols represent: the process, data flow, an external entity, and the data store[46]. There are three separate levels of DFD included within this paper, the context diagram (the highest level), level-0 DFD and level-1 DFD. Subsequent levels are merely a further breakdown of a particular processes function as shown in Figure 3. For example, the level-0 DFD comprises of the processes that make up the main process within the context diagram. The DFD framework in this research paper has been developed using the outcomes of the questionnaire survey and case study. Furthermore, upon completion, the DFD was reviewed by the technology experts from the case study project.

4. Data analysis and findings

4.1 Questionnaire survey

Table 3 provides a summary of the demographic profile of the respondents, confirming that information rich candidates were engaged, because, a total of 31 individuals provided responses, with 35.5 per cent of these respondents having 10-20 years of experience within the construction industry. Furthermore, 67.7 per cent of respondents were Contract Administrators and 12.9 per cent were Project Managers. It is also noted that 74.2 per cent of respondents have a Bachelor's degree or higher.

Table 3: Respondent demographic information

Demographic Information		Number of Individuals	Percentage
Years of experience in the construction industry	12 Months or Less	1	3.2
	1-2 Years	3	9.7
	3-5 Years	8	25.8
	6-9 Years	8	25.8
	10-20 Years	11	35.5
Occupation within the construction industry	Project Manager	4	12.9
	Contract Administrator	21	67.7
	BIM Consultant	2	6.5
	Other	4	12.9
	Secondary School Graduate	2	6.5

Education level	Graduate Diploma	3	9.7
	Graduate Certificate	1	3.2
	Bachelor's Degree	19	61.3
	Master's Degree	4	12.9
	Doctorate	1	3.2
	Other	1	3.2

Fourteen variables of the potential advanced technologies were identified from the literature and used for the subsequent core part of the questionnaire. Factor analysis (FA) was used to reduce the variables into small groups of underlying factors. The groups were highly inter-correlated, indicating the acceptance of the advanced technologies and their capabilities by the industry as solutions to SOP issues. The variables were subjected to a principal component analysis (PCA) using SPSS version 25. Prior to performing the PCA for the FA, data suitability was assessed. A correlation matrix was produced and inspection of the matrix revealed many coefficients greater than 0.3 [47]. Table 4 shows the Kaiser-Meyer-Olkin (KMO) value was 0.682, exceeding the required value of 0.6 [48] and the Bartletts Test of Sphericity was 0.000 (<0.05), therefore, reaching statistical significance [49]. These results reinforce data suitability and the factorability of the correlation matrix.

Table 4: KMO measure of sampling and Bartletts Test of sphericity results

Statistical Tests		**Findings**
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.682
Bartlett's Test of Sphericity	Approx. Chi-Square	197.673
	df	105
	Sig.	0.000

The PCA identified the presence of five components (factors) with eigenvalues exceeding 1, explaining 36.812%, 11.116%, 9.338%, 8.111% and 6.695% of the variance respectively. However, the Scree Plot in Figure 3 reveals a clear change in shape at component 2. Using Catell's[50] Scree Test, it was decided to retain these two factors for further investigation using a parallel analysis.

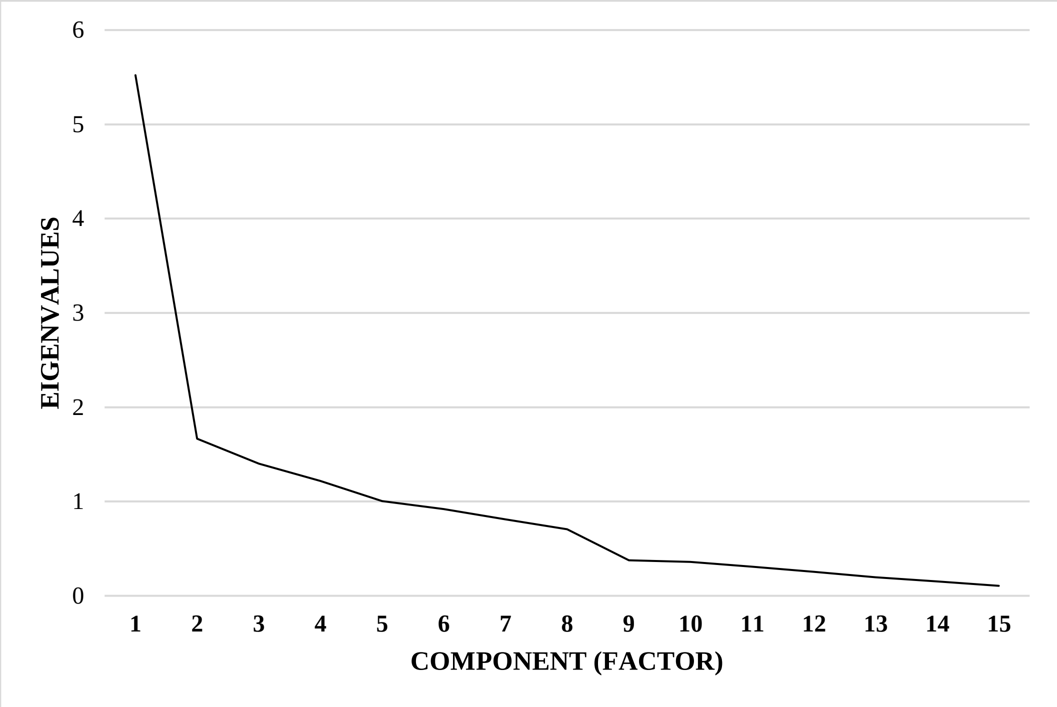

Figure 3: Scree plot

However, the parallel analysis identifies that only factor one has an eigenvalue exceeding the corresponding criterion values for a randomly produced matrix of a similar size (14 variables with 31 respondents) as shown in Table 5. Hence, this justifies that factor one should be the only factor to be retained in this analysis.

Table 5: Parallel analysis: actual eigenvalues vs criterion values

Component Number	Actual Eigenvalue	Criterion Value from Parallel Analysis	Decision
1	5.522	2.443	Accept
2	1.667	2.039	Reject

Factor one denotes 36.812% of the total variance. This factor contains five variables with strong rotated loadings (>0.3) as shown in Table 6. To aid in the interpretation of the factors, Oblimin rotation with Kaiser normalisation was performed. The high rotated loadings from the pattern matrix within factor one suggests that each variable is strongly related to the factor that contains it.

In relation to the research topic, factor one represents the advanced technology capabilities that are positively perceived by the construction industry as possible solutions to SOP issues. These capabilities are drawn from the outcomes of the literature review. It is shown that factor one contains various smart contract capabilities, therefore, factor one was named "smart contract capabilities as solutions to SOP issues" which consists of the following variables: B2, B5, B12, B7 and B1. Findings indicate that smart contracts are an accepted technology from an industry perspective; suggesting that smart contract capabilities within factor one can be considered for framework development.

Table 6: Variables within factor one

	Loadings
Perception of Advanced Technologies as Solutions to SOP Issues	**Factors**
	1
Factor 1: Smart Contract Capabilities as Solutions to SOP Issues (36.812% of variance)	
Smart contracts self-executing clauses allowing automatic payment upon completion of works will result in less accounts of non-payment (B2)	0.819
Smart contracts have the ability to be linked together allowing simultaneous payment and therefore faster payment of contractual counterparts, reducing cash flow difficulties (B5)	0.810
Smart contracts can register and manage inputs from different sensors, making payment instantaneous upon works being completed, reducing the likelihood of late payment (B12)	0.717
Instructions can be incorporated into payment transactions and follow through between smart contracts, safeguarding subcontractors from late and non-payment i.e. funds released to smart contracts before Contractor can accesses funds (B7)	0.675
Smart contracts can execute payment, automatically, using the funds that are embedded on the blockchain network upon works being completed. This will provide surety of payment throughout the project (B1)	0.562

Last but not least, a thematic analysis was used to analyse the responses from an open-ended question at the end of the questionnaire survey regarding their opinion on the implementation of those advanced technologies in addressing SOP issues. Table 7 outlines the main themes from responses as well as common explanations as to why the specific themes are perceived to be barriers. The main themes are: culture & resistance, cost, time, lack of knowledge & technical barriers and, confidentiality and trust.

Table 7: Thematic analysis of responses to an open-ended question

Themes:	Explanation:	Total Responses Confirming Barrier*:
Costs	**Costs associated with:** (1) The change in payment processes and procedures; (2) Training and development / upskilling; (3) Implementation into business practices; (4) Hardware and software; (5) Engagement of skilled third-party consultants.	18
Time	**Added duration associated with:** (1) Upskilling; (2) System and process overhaul.	11
Cultural and Resistance	**Cultural barriers:** (1) Operational overhaul / change in fragmented industry. **Resistance due to:** (1) Lack of incentives for contractors; (2) A reduction in bargaining power and not being able to strategically management cash flow.	20
Confidentiality / Trust	**Confidentiality and Trust barriers:** (1) Lack of trust due to reduced human interaction, for example, the system would be up for abuse i.e. purposefully installing faulty work for instant payment.	11
Technical barriers & Lack of knowledge	**Technical barriers & lack of knowledge:** (1) Lack of formal agreement prior to works commencing i.e. it is common for works to start as a result of a letter of intent - how will complete overhaul occur if there is no smart contract agreement in place; (2) How will variations and day works be considered? (3) Inability for contractor to hold money for non-conformances; (4) Early adopters are exposed to unknowns, unknowns = potential exposure to risk.	15

*Note: The total responses are greater than the number of respondents because each respondent has identified and confirmed more than one barrier each.

4.2 Case study

A case study has been carefully searched and selected to showcase the use of advanced technologies in upholding SOP for subcontractors. A large (+one billion AUD dollar) commercial construction project has been identified, which is currently under construction in Melbourne, Australia. It will consist of multiple towers, a combination of approximately 2,000+ apartments and hotel rooms, with each of the towers being 60 levels or more. The aim of this project is to completely automate the payment process for façade panel supply by utilising blockchain-enabled contracts (smart contracts). Yet, due to commercial sensitivity, certain information of the case study project could not be shared, as a result, alternative names and abbreviations are used.

All data from this case study were collected from the technology experts engaged in this project who work with multiple tier one contractors and currently have three live projects; all of which adopt advanced technologies to produce tangible outcomes for the head contractors. In this case study project, the technology used is referred to as Bluetooth low energy embedded sensor devices. These devices provide live location and status information at critical points/locations across the international supply-chain process starting in China as illustrated in Figure 4. The result, the entire façade panels package is automatically displayed on a 3D model depicting real-time status/location. The advanced technologies have automated manual labour-intensive tasks such as façade panel counting and status updating. They will be used for over 5000 façade panels throughout the course of the project for the following milestones: (1) façade panel fabrication complete, (2) panel in transit, (3) arrival of panel to the Australian warehouse, (4) dispatched to site, and (5) installation and payment automation of the façade panel for the subcontractor.

Figure 4: Fabrication location for facade panels

The following hardware and software components have been integrated to achieve the above milestones: smart sensors, Bluetooth beacon/s, Bluetooth gateways, mobile phone(s), a 3D building model and a cloud hosted data processing platform. Figure 5 shows a visual depiction of these hardware devices when they have been connected. The components have the following functions:

1. Mobile Phone: The application is deployed to assign tags to tracked items. The mobile phone can also act as a gateway or connect to the cloud.
2. Beacon: A small battery powered Bluetooth device has been used to communicate fixed-position to tags.
3. Tag: A small smart sensor can be attached to dynamic objects as illustrated in Figure 5.
4. Gateway: A router or collection device for the data released by the Beacons and Tags. The gateway has a Bluetooth listening component and a 4G backhaul component that senses the beacons or tags data and subsequently transfers this data to the database, automatically upon a tag passing.
5. A 3D model that provides visual conceptualizations of real-time information throughout the supply-chain process.

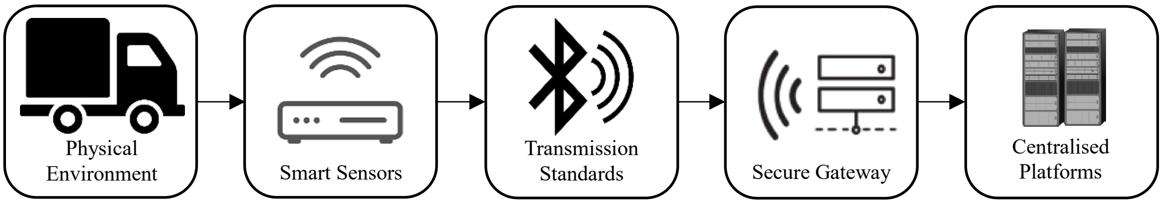

Figure 5: A visual depiction of the smart sensor ecosystem

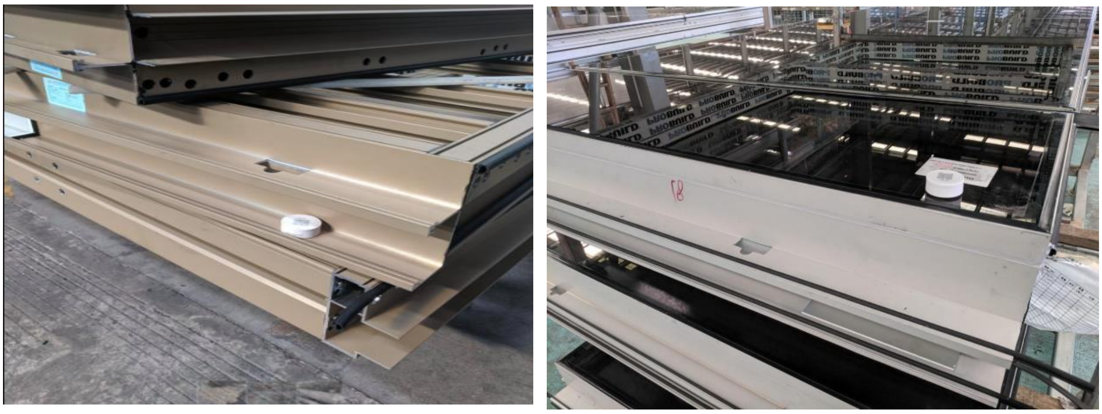

Figure 6: A smart sensor attached to a façade panel

The Bluetooth gateways are set up in some fixed locations. Each gateway is strategically located at multiple locations; each location along the supply-chain corresponds to a different milestone being achieved. For example, gateways are located at the manufacturer's factory in China at an exit point that each façade panel will move through when completed, this gateway signifies that façade panel fabrication has been completed. After each gateway has been set up, the façade panels must have Bluetooth sensors attached and assigned as shown in Figure 6. As described in the example above, location is inferred when the Façade panel moves past the gateways. This is achieved when the gateways receive the Bluetooth signals that are emitted from the sensors. These gateways are constantly powered and connected to the database via 4G, subsequently allowing the database to instantaneously collect and record information regarding the status and location of each façade panel as a 3D visualisation on the dashboard during movement. The 3D model uses colour mapping to signify a different status or milestone, as shown in Figure 7, i.e. blue indicates a façade panel. For the building information model (BIM) to be updated with "installed" the façade panel will be subjected to the head contractor's quality assurance methods and therefore each panel will need to be inspected. For example, a head contractor representative will inspect the façade panel and produce an inspection test plan, this confirms the works has been installed in accordance with the quality requirements, subsequently the smart sensor is removed by this project team representative signifying "Installed" automatically on the model. The dashboard that shows the 3D model is also smartphone friendly, allowing immediate status updates at any location on site – this is captured in Figure 8.

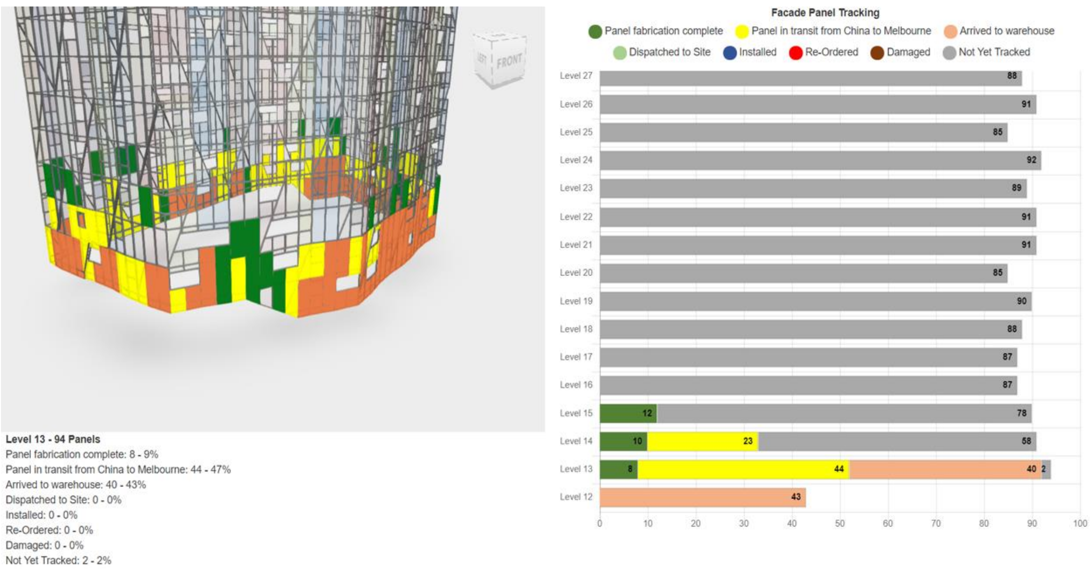

Figure 7: The project dashboard displaying real-time progress

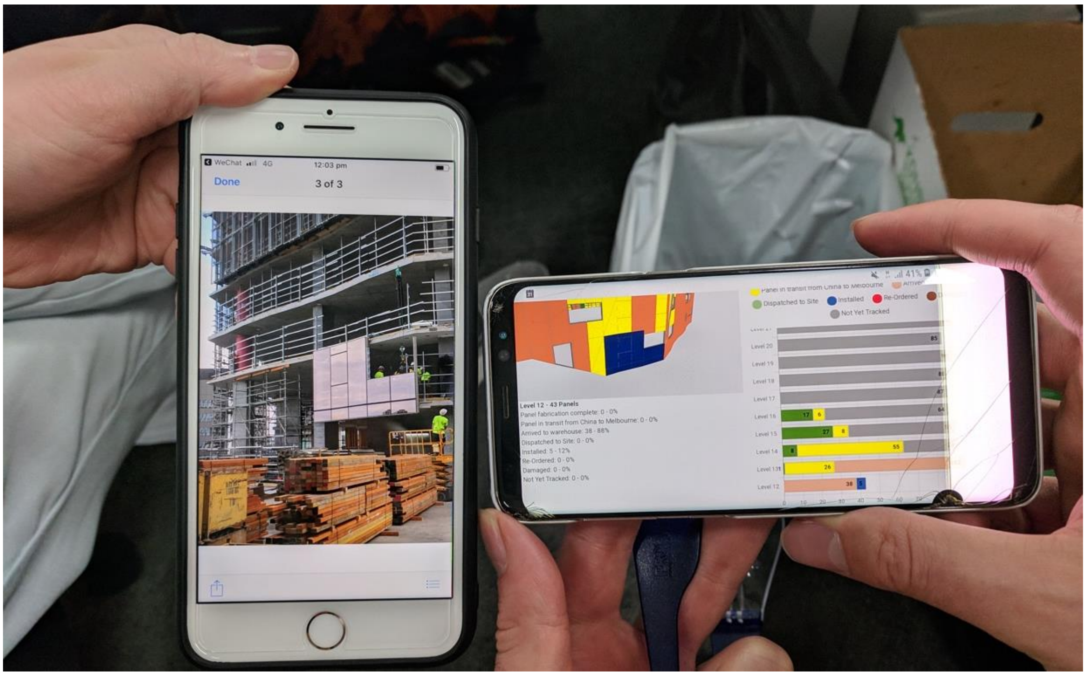

Figure 8: The project application displaying real-time progress

All location information is transferred and recorded onto a blockchain network (concurrently with the BIM model). To achieve this, the data flows from the sensors to the gateway, from the gateway to the database where the data is then recorded and transferred through an API to the blockchain network and the BIM model. Although the location information has been tracked and recorded separately in the blockchain network and the BIM model, the blockchain network will verify again the confirmed information from the BIM model before processing the transaction. This workflow seems having a double verification and will ensure the project to have a completely automation payment process for façade panel supply through blockchain-enabled contracts (smart contracts). The architecture of this blockchain network and smart contract ecosystem is designed and managed by a reputable blockchain company based in United States. A limitation of this particular aspect of the case study project was that the researchers were not able to assess the blockchain technology explicitly due to exclusivity agreements. However, a private or a partially private blockchain network seems to be adopted in the project, as this can serve the need to prevent commercially sensitive information from being shared. Additionally, through the observation of the data sources it can be ascertained that the consensus mechanism will not only be undertaken by a single entity but rather a selected team of the project to uphold decentralisation across the nodes.

Overall, a combination of the following advanced technologies are currently being adopted to deliver tangible outcomes: smart sensors (including oracles), BIM, blockchain and smart contracts.

These technologies will be incorporated into the DFD framework.

4.3 Framework development

DFD was selected as the tool to create the framework. The DFD breaks down the various interconnected functions within the automated payment system in a methodical and layman manner [45]. The DFD framework is derived from the outcomes of the questionnaire survey and the case study. For example, processes 1-4 within this framework have been heavily inferred from the case study, while process 5 has referred to the questionnaire results. Overall, the DFD framework provides a rich description of how each advanced technology functions within the automated payment system to address SOP issues. It has been verified by a technology expert from the case study project.

The context diagram, Figure 9, represents an overview of the systems major function, namely, “Automate payment using advanced technologies”. This is a high-level overview of how the system delivers automatic payment to subcontractors upon the completion of their contractual obligations (such as material delivery or material instalment) as determined by the advanced technologies within the major process.

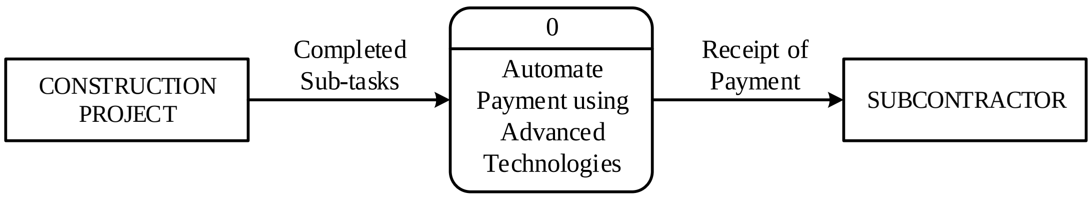

Figure 9: Context diagram of automated payment system

The child diagram, Figure 10, is a level-0 DFD which provides detailed information of all functions within the main process labelled “0” . The function of process “1.0” is to capture completed sub-tasks via smart sensors. This process receives two information inputs (identical to the case study): Input one is “completed sub-tasks” and represents the live-works that have been completed on the construction project. While the second input “Scope of Works” flows from data store one (D1). The SoW are drafted and stored within the subcontract agreement (D1). The SoW are important as they indicate the contractual obligations of the subcontractors and suppliers, therefore, influencing the type of information that the smart sensors need to capture.

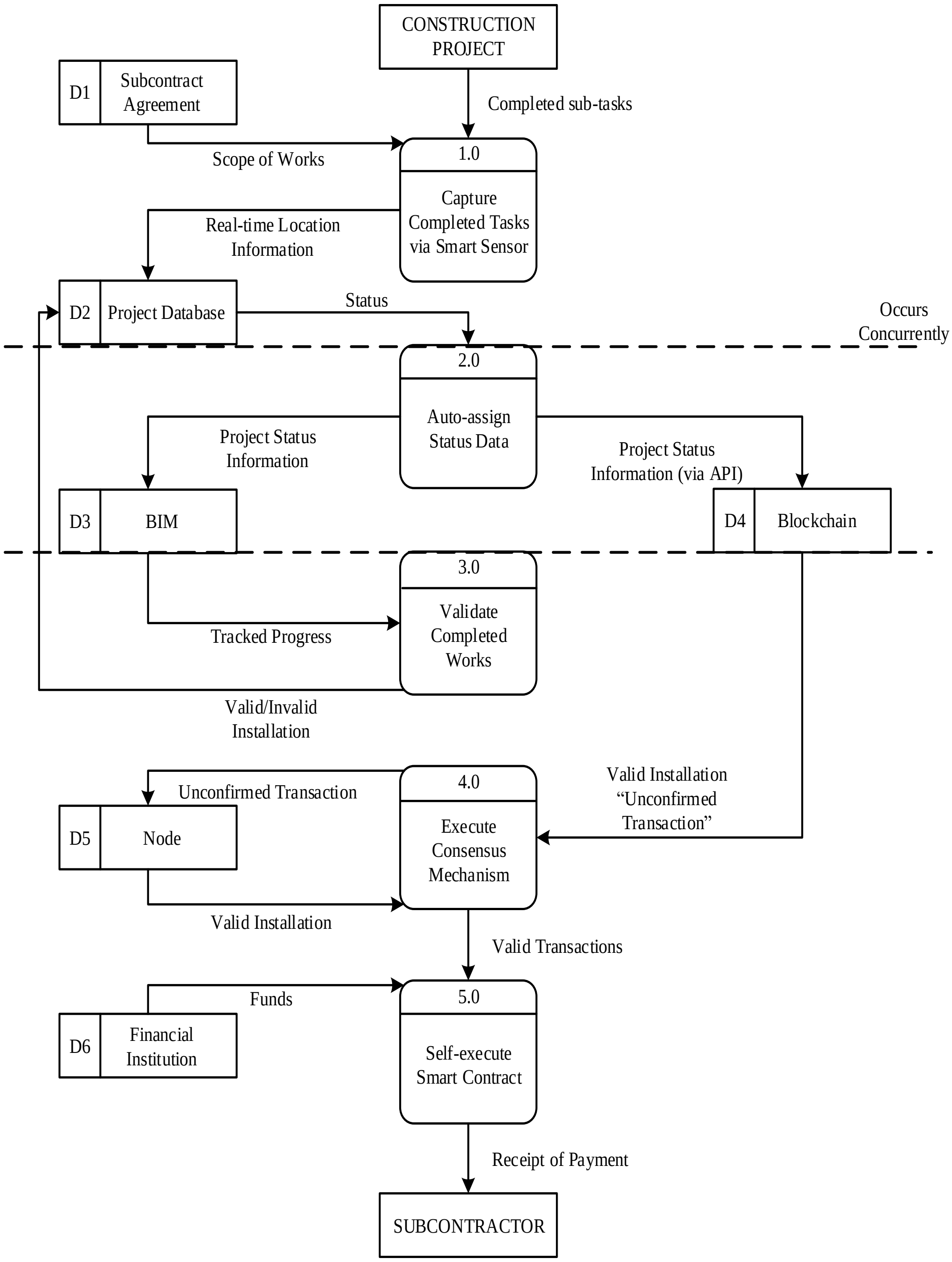

Figure 10: Level-0 DFD framework of automated payment system

As per case study project, process "2.0" auto-assigns up to date status information from the project database (D2) (also referred to as the "cloud hosted data processing platform") through to the BIM model (D3) and the blockchain network (D4) via an API. This process occurs automatically and concurrently. D2 receives and stores two sets of information; "Real-time Location Information" from process “1.0” and “Valid/ Invalid Installation” information from process “3.0”. The output of D2 is the “status” of the sub-tasks, representing the most up-to date installation information. The “status”, after passing through process “2.0” is updated on the BIM model as “Project Status Information”; similar to Figure 8 from the case study project. While, concurrently, process “2.0” transfers the “status” to the blockchain network via an API, with the “Project Status Information” representing the provenance of tasks.

Process “3.0” validates completed works. A level-1 DFD, Figure 11, has been created to describe the separate processes that occur within process “3.0” (identical to the case study project). The output; “Valid/Invalid Installation” from process “3.0” is integral to the system, as it is an added layer of verification for quality standards for installed works. For example, the BIM model can be updated using the “Real-time Location Information” from process “1.0”, however, this will not justify valid installation (works installed in accordance with quality requirements), therefore, process “3.0” will ensure the “Tracked Progress” information from D3 is marked and stored as a “Valid/Invalid Installation”. In Figure 11, the “Tracked Progress” within the BIM model is inspected by a human oracle (process “3.1”). As a result, an inspection test plan (“ITP”) is produced, certified and then validated (process “3.2”). If the ITP is certified the smart sensor will be removed (process “3.3”). Removal of the smart sensor signifies a “Valid Installation”. This “Valid Installation” information is then transferred to D2 and recirculated via process “2.0” to the BIM model and the blockchain network; ensuring the most reliable up-to-date “Project Status Information” is represented.

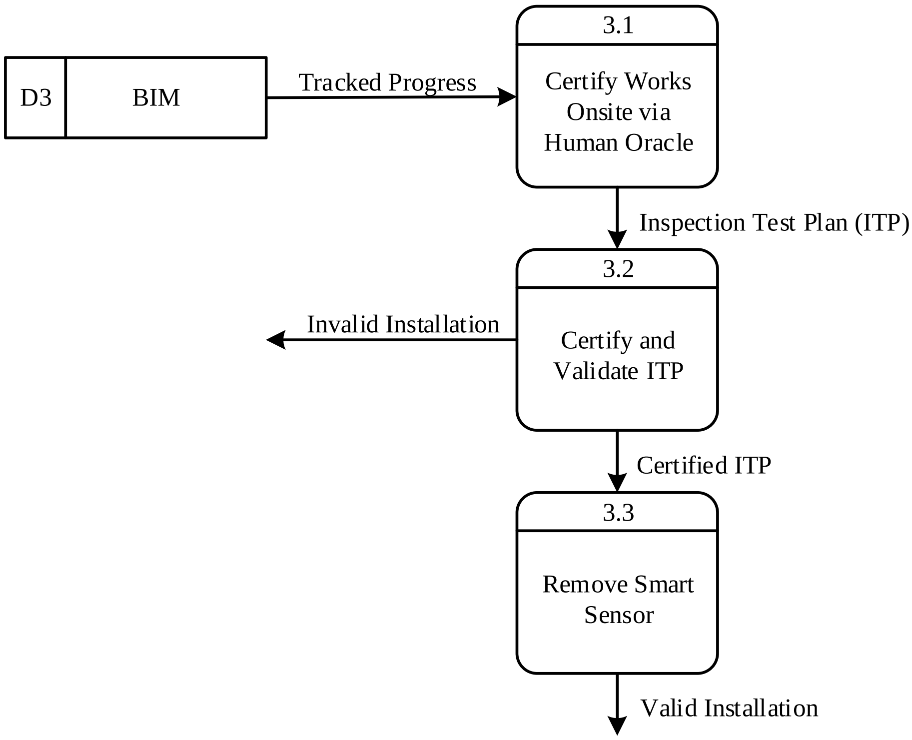

Figure 11: Level-1 DFD framework for process "3.0"

Before describing process "4.0", a consortium blockchain network is proposed in this system. This is because consortium networks (such as, Hyperledger) have levels of permission levied on the network; particular nodes such as the client and financiers are predetermined to verify as well as view particular transactions allowing confidentiality and privacy of commercially sensitive information [24,51]. Additionally, consortium blockchain networks can use smart contracts and select specific consensus mechanisms that are suited to the required business outcomes. An example Practical Byzantine Fault Tolerance (PBFT); this mechanism requires all participating nodes in the consensus to return a decision, making it a suitable method for a construction project where trust and security is required [24] .

The function of process "4.0" is to execute the consensus mechanism. Initially, the input of D4 is the same tracked information for D3. Yet, the output of D4 will only refer to the processed and confirmed information from process "3.0", namely, "Valid Installation(s)". This is to uphold another layer of verification for the completed works. Although the works have been marked as "Valid Installation" as the input of process "4.0", it is still an unconfirmed transaction on the blockchain network. Therefore, "Unconfirmed Transaction(s)" are constantly assigned to the predetermined nodes (these nodes represent parties to the contract that have authority to certify payments) on the consortium blockchain network (process 4.1). These previously "Unconfirmed Transaction(s)" are validated by the predetermined network using the consensus mechanism (say, PBFT) (process

"4.2"). This is another layer of security within the blockchain network in the private blockhain to constraint the nodes (users) to access and add transactions to the ledger (process "4.3"). In which, multiple validated transactions will be committed to the ledger by the nodes, creating a block that will be added to the blockchain as "Valid Transactions(s)".

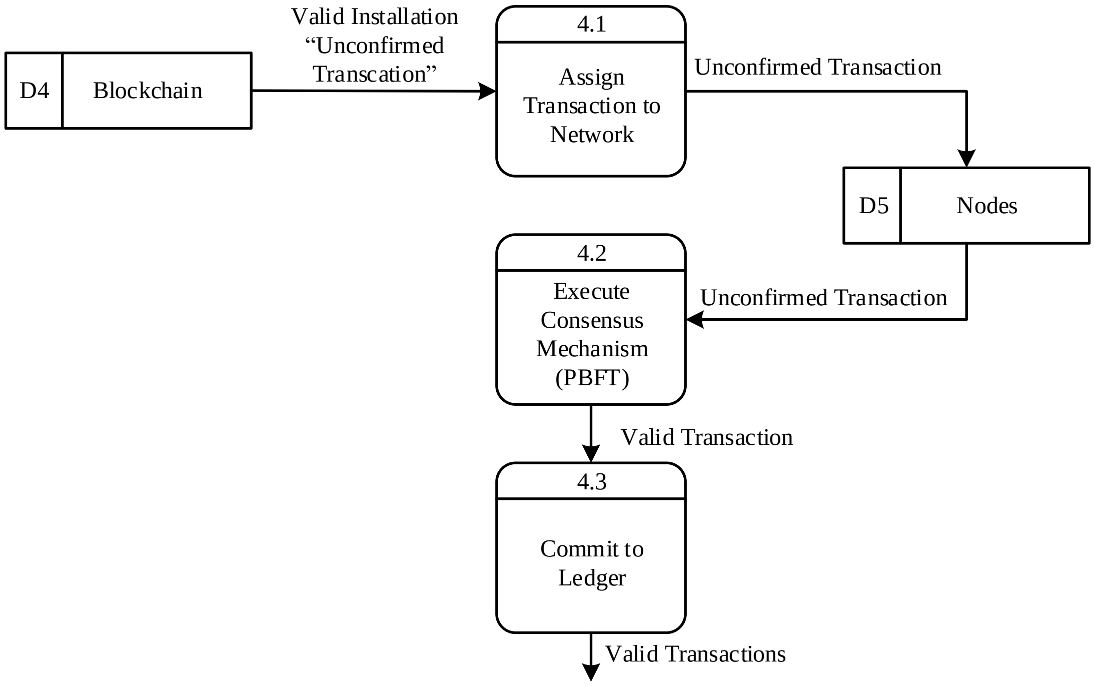

Figure 12: Level-1 DFD framework for process "4.0"

Process "5.0" self-executes the smart contract. The "valid transactions" signify that the works have been completed (a "transaction" could include material location information, material codes and/or ITP codes), this input is what triggers the smart contract; (refer to the variable B2 of the factor analysis), this is because, one of the capabilities of a smart contract is that payment instructions can be coded within the smart contract as computer code (refer to the variable B7), and in this circumstance, the smart contracts are coded to execute upon specific "valid transactions" being uploaded to the blockchain network. Furthermore, the smart contract has the ability to read information (in this case transactions) that are specific to a particular condition/ obligation. The financial institution and client (D6) are integral to this system as they are responsible for embedding the funds on the blockchain network, upfront, allowing the smart contract to withdraw payment upon works being completed/ installed by the subcontractor and suppliers, automatically (refer to the variable B1 & B5). After execution of the smart contract, the subcontractor and supplier will receive the payment almost instantaneously, with receipt of payment being sent automatically to the required parties (refer to the variable B12).

5. Discussion and Contributions

5.1 Knowledge contributions

The main contribution or innovation of the paper lies within the proposed DFD framework for new application of blockchain technology with other advanced technologies in the construction industry. The framework has revealed how blockchain technology, smart sensors (including oracles), blockchain technology, smart contracts and BIM can be integrated to facilitate the implementation of an automated payment system in upholding SOP for all parties, even though the overall process flow is meant for subcontractors in this research. It has articulated a new workflow from integrating the advanced technologies. Some new and important insights have been discussed in the framework, namely, (a) the location and sequence of the operation for the six databases in supporting of the five main processes, (b) the need for having another layer of security in recording status of the work completed (separating BIM and blockchain network individually), (c) the detailed descriptions and processes for self-executing smart contracts and the early involvement and commitment of the financial institution and client (D6) for embedding the funds on the blockchain network. This new application of the advanced technologies together and its related workflow are new to the current body of knowledge. Certain modifications need to be made to the existing payment clauses, allowing automatic payment for subcontractors under smart contracts. Meanwhile, sensors need to be linked with the blockchain network. The funds also should be kept in advance under smart contracts to avoid late or non-payment, or even allowing simultaneous payment upon works being completed. Overall, the new implementation of this payment system would serve as the first foundation of knowledge in contract administration from both technical and managerial perspectives.

Furthermore, the case study is one of few practical blockchain technology-enabled examples in construction projects. To the best knowledge of the authors, this could be even the first documented academic case study in using various advanced technologies including blockchain technology, smart sensors and BIM for upholding SOP for subcontractors. It has identified the practical capabilities of the advanced technologies in tracking, recording, installing and paying of the façade panel. The smart sensors and BIM are being utilised together on this project to provide live location and status information at critical points/ locations across the entire supply-chain, automatically, onto a BIM model. While the same smart sensors are also feeding the same data directly to the blockchain network to be stored. The capabilities of these particular advanced technologies, when combined, have not been identified or discussed within literature using a live construction project as an example. Furthermore, it is noted that a major ambition of the case study project is to have payment 100 percent automated by the end of the project, through combining the capabilities of smart sensors and smart contracts for all components. This could a new theoretical perspective in embracing current e-payment deployment for progress claims in the construction industry.

Last but not least, the third contribution lies within the proposed DFD framework for new application of blockchain technology in the construction industry. The framework has revealed how blockchain technology, smart sensors (including oracles), smart contracts and BIM can be integrated to facilitate the implementation of an automated payment system in upholding SOP for all parties, even though the overall process flow is meant for subcontractors in this research. It has articulated a new workflow from integrating the advanced technologies been designed based on a logical flow of upholding SOP through,

which can be used as a practical guide for a whole system development in the future. Some new and important insights have been discussed in the framework, namely, (a) the location and sequence of the operation for the six databases in supporting of the five main processes, (b) the need for having another layer of security in recording status of the work completed (separating BIM and blockchain network individually), (c) the detailed descriptions and processes for self-executing smart contracts and the early involvement and commitment of the financial institution and client (D6) for embedding the funds on the blockchain network. These ideas are non-existent in the construction industry, as the current body of knowledge merely discusses the benefits and capabilities of each of these technologies, independently, for different use-cases.

5.2 Practical contributions

There are various practical contributions that result from the development of the DFD framework. The practicality of the DFD has provided stakeholders with some reassurance and a new perspective surrounding the adoption and implementation of this alternative payment system. Additionally, implementation of this automated payment system would enable contractors and clients to uphold professionalism, transparency and reputation by ensuring that all parties on their projects get paid on-time and in-full. Other stakeholders can also benefit from this automated payment system, for example, subcontractors and suppliers will be provided with surety of payment throughout the project, preventing the likelihood of cash flow difficulties and insolvencies. While, for clients and financiers, it will provide a robust mechanism for certifying works completed to date, as all supply-chain and installation information is live across the entire supply chain.

6. Conclusion

The objectives within this study have been achieved, as the factor analysis has indicated that smart contracts are an accepted advanced technology in addressing SOP problems, concluding that the industry's perception on using advanced technologies to address SOP is favourable (objective one). While the case study provided an explanation and overview of how smart sensors, BIM and blockchain technology are currently being used together on a live construction project, indicating that smart sensors, blockchain technology and BIM can be integrated and used practically (objective two). The outcomes of the factor analysis and case study both assisted in the development of the practical and comprehensive DFD framework. This DFD framework can be used as a guide when developing a fully functional automated payment system (objective 3). The framework breaks down the complex processes and functions within the system methodically while identifying all interfaces between the technologies making it easy to interpret. It is posited that the DFD framework when implemented can enable the integration of advanced technologies providing an alternative payment solution that will allow automated payment of subcontractors and suppliers upon their contractual obligations being met, addressing late-payment and non-payment (SOP) issues. Suggesting that integrating advanced technologies is a feasible and practical solution in addressing SOP issues.

Certain limitations and recommendations need to be considered in interpreting the research findings. First, in theory, it is evident that there are clear advantages to using this system, however, it is possible that disadvantages and nuances will arise upon development and subsequent implementation in construction projects. Therefore, future research should consider tracking the scheduling processes say, work packaging within the automated payment system [52], which will subsequently assist in the development and implementation of the framework efficiently. Second, the development of this DFD framework has not considered the impact that human factors can have on the operation of the system. Human factors may influence the current research findings, because, there is potential for suppliers to commit fraud during the process. For example, the smart sensor may be physically moved by a human past a specific gateway, signifying that a milestone has been met when it hasn't. It is therefore recommended that future research consider fraud or any other related human factors that may influence the systems operation. These human factors should be also considered together with the potential security breaches or financial losses from the smart contracts vulnerabilities [53]. The researcher should then analyse additional security layers and/or network security techniques that may be able to be integrated within the system to combat the impact of these human factors. Third, although the DFD framework has briefly discussed one of blockchain platforms in the DFD framework, namely, Hyperledger, there are many blockchain platforms that could be adopted in upholding SOP, such as Ethereum, IBM Blockchain, Ripple, EOS, IOTA, Multichain, Corda, and so on. The selection of the right platform is still a key barrier against its adoption. Fourth, the success of this whole process relies heavily on the financial institution and/or client providing cash up front. This is because funds need to be available upon the works being completed to allow automatic payment. This may hinder the industry from adopting this system. Future research should consider how to balance the risk associated with these upfront capital costs. Last but not least, the proposed DFD framework has not incorporated any mathematical algorithms or coding samples as it still requires substantial programming efforts for the full system development.

Acknowledgment

The authors would like to thank Ynomia, particularly, Matthew Lickwar and Matthew Barbuto for their kind assistance, time and patience during the case study development and framework validation.

Data availability statement

Certain data of the paper are confidential. Yet, the questionnaire data are available upon request.

References

[1] J. Wu, M. Kumaraswamy, G. Soo, Payment Problems and Regulatory Responses in The Construction Industry: Mainland China Perspective. Journal of Professional Issues in Engineering Education & Practice, 134(4) (2008). doi:10.1061/(ASCE)1052-3928(2008)134:4(399).

[2] T. Cheng, G. Soo, M. Kumaraswamy, W. Jin, Security of Payment for the Hong Kong Construction Industry. Journal of Management, Procurement and Law. 163(1) (2010), pp. 17-28. doi: 10.1680/mpal.2010.163.1.17.

[3] T. Ramachandra, Exploring Feasible Solutions to Payment Problems in The Construction Industry in New Zealand. Ph.D. Thesis. Auckland University of Technology, 2013. doi:10.5130/ajceb.v15i1.4214.

[4] R. Griffiths, W. Lord, J. Coggins, Project Bank Accounts: The Second Wave of Security of Payment?. Journal of Financial Management of Property and Construction, 22(3) (2017), pp. 322-338. doi 10.1108/JFMPC-04-2017-0011.

[5] J. Fiocco, Final Report to the Minister for Commerce: Security of Payment Reform in the

WA Building and Construction Industry. The Department of Mines, Industry Regulation and Safety – Building and Energy Division, Western Australia, 2018.

[6] P. Yung, K. Rafferty, Statutory Adjudication in Western Australia: Adjudicators' Views. Engineering, Construction and Architectural Management, 22(1) (2015), pp. 54-72. doi 10.1108/ECAM-03-2014-0033.

[7] P. Evans, Statutory Review of the Construction Contracts Act 2004 (WA). University of Notre Dame Australian Law Review, 18 (1) (2016), pp. 124-161: http://researchonline.nd.edu.au/undalr/vol18/iss1/4.

[8] A. Dorri, S.S. Kanhere, R. Jurdak, P. Gauravaram, Blockchain for IoT security and privacy: The case study of a smart home. IEEE international conference on pervasive computing and communications workshops (PerCom workshops) (pp. 618-623). IEEE. doi: 10.1109/PERCOMW.2017.7917634, 2017.

[9] M.A. Khan, K. Salah, IoT security: Review, blockchain solutions, and open challenges. Future Generation Computer Systems, 82 (2018), pp. 395-411. doi.org/10.1016/j.future.2017.11.022

[10] K. Salah, M.H.U. Rehman, N. Nizamuddin, A. Al-Fuqaha, Blockchain for AI: review and open research challenges. IEEE Access, 7 (2019), pp. 10127-10149. doi: 10.1109/ACCESS.2018.2890507

[11] H.R. Hasan, K. Salah, Combating Deepfake Videos Using Blockchain and Smart Contracts. IEEE Access, 7 (2019), pp. 41596-41606. doi:10.1109/ACCESS.2019.2905689

[12] A. Chaer, K. Salah, C. Lima, P.P. Ray, T. Sheltami, Blockchain for 5G: Opportunities and Challenges. Conference: IEEE Globecom 2019, At Waikoloa, HI, USA. Retrieved from https://www.researchgate.net/publication/335518169_Blockchain_for_5G_Opportunities_and_Challenges, 2019. (Accessed 4 January 2020)

[13] Y. Dai, D. Xu, S. Maharjan, Z. Chen, Q. He, Y. Zhang, Blockchain and deep reinforcement learning empowered intelligent 5g beyond. IEEE Network, 33(3) (2019), pp. 10-17. doi: 10.1109/MNET.2019.1800376

[14] J. Murray, Review of Security of Payment Laws: Building Trust and Harmony. Canberra, ACT: Department of Jobs and Small Business, 2017. https://docs.jobs.gov.au/documents/review-security-payment-laws.

[15] R. Kenney, G. La Cava, D. Rodgers. Why Do Companies Fail? Perth, Western Australia: Reserve Bank of Australia, 2016. https://www.rba.gov.au/publications/rdp/2016/pdf/rdp2016-09.pdf.

[16] H. Euler, Euler Herms Quarterly Overdue Payments Report. London, UK: Euler Herms, 2017. https://www.eulerhermes.com/en_global/media-news/news/press-release-eh-uk-late-payments-hit-two-year-high-at-2015-year.html.

[17] Small Business and Family Enterprise Ombudsman, Review of payment terms, times and practices, 2019. https://www.asbfeo.gov.au/sites/default/files/documents/ASBFEO-

payment-times-report-2019.pdf. (Accessed 28 January 2020)

[18] C. Smith, Report of the Inquiry into the Building Industry of Western Australia. Perth, Western Australia: Government of Western Australia, 1973. https://archive.sro.wa.gov.au/index.php/inquiry-into-the-building-industry-of-western-australia-au-wa-a852.

[19] J. Hinze, A. Tracey, The contractor-subcontractor relationship: the subcontractor's view. Journal of construction engineering and management, 120(2) (1994), pp. 274-287. https://doi.org/10.1061/(ASCE)0733-9364(1994)120:2(274)

[20] The State of Western Australia. Construction Contracts Act 2004 (WA), Western Australia, 2004. https://www.legislation.wa.gov.au/legislation/former/swans.nsf/(DownloadFiles)/Construction+Contracts+Act+2004.pdf/$file/Construction+Contracts+Act+2004.pdf. (Accessed 26 January 2020)

[21] N.A.N.A. Ali, A Construction Industry Payment and Adjudication Act: Reducing Payment Default and Increasing Dispute Resolution Efficiency in Construction." Master Builders 3rd Quarter, pp. 1-13, 2006. Retrieved from http://www.cicqs.my/main/files/PaymentAct_Article_Part1%5B1%5D.pdf (Accessed 26 January 2020).

[22] B. Penzes, Blockchain Technology in the Construction Industry. London, UK: Institute of Civil Engineers, 2019. https://www.ice.org.uk/ICEDevelopmentWebPortal/media/Documents/News/Blog/Blockchain-technology-in-Construction-2018-12-17.pdf. (Accessed 26 January 2020).

[23] G. Peters, E. Panayi, Understanding Modern Banking Ledgers Through Blockchain Technologies: Future of Transaction Processing and Smart Contracts on the Internet of Money. London, UK: University College London, 2015. doi:10.2139/ssrn.2692487.

[24] O. Nawari, S. Ravindran. Blockchain and the Built Environment: Potentials and Limitations. Journal of Building Engineering, 15(1) (2019), pp. 1-16. doi:10.1016/j.jobe.2019.100832.

[25] S. McKinney, R. Landy, R. Wilka, Smart Contracts, Blockchain, and the Next Frontier of Transactional Law. Washington Journal of Law, Technology & Arts, 13(3) (2018), pp. 314-347. http://digital.law.washington.edu/dspace-law/bitstream/handle/1773.1/1818/13WJLTA313.pdf.

[26] N. Szabo, Formalizing and securing relationships on public networks. First Monday, 2(9) (1997). doi:10.5210/fm.v2i9.548.

[27] T. Arnold, N. Guar, S. Manicka, B. Perepa, Cloud Customer Architecture for Blockchain. Needham, MA: Cloud Standards Customer Council, 2017.

[28] J.P. Wang, X. Wu, X. Wang, and W. Shou, The Outlook of Blockchain Technology for Construction Engineering Management. Journal of Engineering Management, 4(1) (2017),

pp. 67-75. doi: 10.15302/J-FEM-2017006

[29] J. Li, D. Greenwood, M. Kassem, Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases." Automation in Construction, 102(2019), pp. 288-307. https://doi.org/10.1016/j.autcon.2019.02.005

[30] S. Voshmgir, Token Economy: How Blockchain and Smart Contracts Revolutionize the Economy, 2019. 1st ed. doi:10.1016/j.bushor.2019.08.003.

[31] J.A. Fitzgerald, A. Mussomeli, A. Daechor, M. Chandramouli, Using Smart Sensors to Drive Supply Chain Innovation. Deloitte Industry Report, 2018. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-cons-smart-sensors.pdf.

[32] J. Song, C. Haas, C. Caldas, E. Ergen, B. Akinci, Automating the Task of Tracking the Delivery and Receipt of Fabricated Pipe Spools in Industrial Projects. Automation in Construction, 15(2)(2005), pp. 166-177. doi:10.1016/j.autcon.2005.03.001.

[33] T. Cheng, J. Yang, J. Teizer, Automated Construction Resource Location Tracking to Support the Analysis of Lean Principles. Paper Presented at the 18th Annual Conference of the International Group for Lean Construction, Haifa, Israel, 2010.

[34] J. Wang, H-L. Chi, W. Shou, H-Y. Chong, X. Wang, A Coordinated Approach for Supply-Chain Tracking in the Liquefied Natural Gas Industry. Sustainability, 10 (12) (2018), pp. 4822. doi:10.3390/su10124822.

[35] D.G. Torrent, C.H. Caldas, Methodology for automating the identification and localization of construction components on industrial projects. Journal of Computing in Civil Engineering, 23(1) (2009), 3-13. https://doi.org/10.1061/(ASCE)0887-3801(2009)23:1(3)

[36] J.R. Adler, A. Berryhill, Z. Veneris, N. Poulos, N. Veira, A. Kastania, Astraea: A Decentralised Blockchain Oracle. Paper Presented at the IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), Halifax, Nova Scotia, Canada, 2018. doi:10.1109/cybermatics_2018.2018.00207.

[37] F. Zhang, E. Cecchetti, K. Croman, A. Jules, E. Shi, Town Crier: An Authenticated Data Feed for Smart Contracts. Presented at the 2016 ACM SIGSAC Conference on Computer and Communications Security, Vienna, Austria, 2016. doi:10.1145/2976749.2978326.

[38] G. Guven, E. Ergen, M.A. Erberik, O. Kurc, Providing Guidance for Evacuation During an Emergency Based on a Real-Time Damage and Vulnerability Assessment of Facilities. Paper presented at the International Conference on Computing in Civil Engineering, Clearwater Beach, Florida, 2012. doi/abs/10.1061/9780784412343.0074.

[39] H. Ufuk, K. Umut, Holistic System Architecture for Energy Efficient Building Operation. Journal of Sustainable Cities and Society, 6(1) (2013), pp. 77-84. doi:10.1016/j.scs.2012.07.003.

[40] H. Ufuk, K. Umut, Multi Dimensional Energy Monitoring, Analysis and Optimization System for Energy Efficient Building Operations. Journal of Sustainable Cities and Society, 10(1)(2014), pp. 161-173. doi:10.1016/j.scs.2013.08.004

[41] M. Alves, P. Carreira, A.A. Costa, BIMSL, A generic approach to the integration of building information models with real-time sensor data. Automation in Construction, 84 (2017), pp. 304-314. doi.org/10.1016/j.autcon.2017.09.005

[42] R. Zheng, J. Jiang, X. Hao, W. Ren, F. Xiong, Y. Ren, bcBIM: A Blockchain-Based Big Data Model for BIM Modification Audit and Provenance in Mobile Cloud. Mathematical Problems in Engineering, March (2019) 1-13. doi:10.1155/2019/5349538.

[43] R. Kumar, Research Methodology: A Step-by-Step Guide for Beginners. 4th ed. London: SAGE Publications, 2014. doi:10.7748/nr.19.3.45.s5.

[44] K.L. Barriball, A. While, Collecting data using a semi-structured interview: a discussion paper. Journal of Advanced Nursing-Institutional Subscription, 19(2)(1994), pp. 328-335. doi.10.1111/j.1365-2648.1994.tb01088.x.

[45] E. Yourdon, Dataflow Diagrams. 1st ed. Massachusetts, United States. YOURDON inc, 2006. doi:10.1016/b978-0-408-03741-9.50013-1.

[46] H-Y. Chong, B. Balamuralithara. Construction contract administration in Malaysia using DFD: A Conceptual Model. Industrial Management & Data Systems, 111 (9) (2011), pp. 1449-1464. doi:10.1108/02635571111182782.

[47] J. Pallant,. SPSS survival manual. McGraw-Hill Education (UK), 2013.

[48] H. Kaiser, A Second Generation Little Jiffy. Journal of Psychometrika, 35(1970), pp. 401-15. doi:10.1007/bf02291817.

[49] M.S. Bartlett, A Note on the Multiplying Factors for Various Chi Square Approximations. Journal of the Royal Statistical Society, 16 (series B)(1954), pp. 296-298. doi:10.1111/j.2517-6161.1954.tb00174.x.

[50] R.B. Catell, The Scree Test for Number of Factors. Journal of Multivariate Behavioural Research, 1(1966): pp. 245-76. doi:10.1207/s15327906mbr0102_10.

[51] J. Green, D. Martin, J. Bulich, Power Ledger. White Paper, 2018. https://www.powerledger.io/wp-content/uploads/2019/05/power-ledger-whitepaper.pdf.

[52] H.W. Wang, J.R. Lin, J.P. Zhang, Work package-based information modeling for resource-constrained scheduling of construction projects. Automation in Construction, 109 (2020), 102958. https://doi.org/10.1016/j.autcon.2019.102958

[53] R. Almadhoun, M. Kadadha, M. Alhemeiri, M. Alshehhi, K. Salah, A user authentication scheme of iot devices using blockchain-enabled fog nodes. In 2018 IEEE/ACS 15th International Conference on Computer Systems and Applications (AICCSA) (pp. 1-8). IEEE, 2018. doi: 10.1109/AICCSA.2018.8612856