Efficacy of Smart Contracts in Enhancing System-Based Trust in Construction Industry: System Dynamics Approach

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I dedicate my dissertation to my mother, my father, and friends

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Abstract

This research investigates the causative relationship between trust influencing factors and Blockchain-based smart contract features by addressing the complexity of trust dynamics in construction industry. The objective was to identify key factors causing system-based trust issues and see the impact of Smart Contracts in improving system-based trust among stakeholders. Increasing adversarial relationships and degrading culture of trust among construction stakeholders resulting from the failure of traditional contracts led to the development of problem statement. From literature key factors effecting system-based trust and the key features of Blockchain-based smart contracts were identified. Through content analysis, surveys, and field expert interviews these variables and their relationships were shortlisted. Finally, relationships among 9 features of smart contracts and 16 trust factors were studied in a systems thinking diagram and a system dynamics model. Systems thinking diagram indicated that smart contract based contractual system improved system-based trust. The selected stocks in System Dynamics (SD) model: Opportunistic Behavior, Protection from insolvency and Transparency, all showed positive impact once a smart contract was introduced in the system. This research provides a tech-based solution for the factors that engender trust issues among stakeholders in construction industry by proposing blockchain-based smart contracts. Majority of the studies in construction field has focused on the "black box" trust from a plethora of angles however it has not been discussed from the perspective of complexity. Similarly, neither have smart contracts been discussed for its efficacy in enhancing the system-based trust.

Keywords: Smart contracts, Trust, Automation, Complexity, System dynamics model, Causal Loop Diagram

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Chapter 1: Introduction

1.1 Brief Description/Abstract

Construction industry is one of the oldest industries in human history which it thrives on basic social attribute: trust. The mutual dealings and procurement processes have evolved over time. From verbal agreements to formal written contracts, attempts have been made to reduce the liabilities of this trust-based system. Trust in construction industry can be divided into the three main categories: System-based, affect based, cognition-based (Wong *et al.*, 2008). Wong categorized system-based trust in such a way that it included formal contracts, a range of communications modes and organizational policies. He argued that this type of trust plays a significant role in inter-organizational relationships. While substantial work has been carried out in the latter two categories, system-based trust is studied in this research. With the increase in the size and scope of construction projects, the management of a project life cycle has evolved. Present construction projects are complex and highly fragmented (Khan *et al.*, 2016). Good relations between project stakeholder have a significant impact on Project life cycle. When it comes to contracts that involve high levels of complexity and uncertain conditions, it is not sufficient to reply on the formal contractual governance (Zhang *et al.*, 2020). In practice,the usual rules of contracts are made to give legitimacy to competing strategies and behaviors (Kadefors, 2004). Studies have shown that mutual trust is essential for efficient operations of the project, harmony among stakeholders and long-term strategic supply chains. Despite an ever-increasing complexity of traditional formal contracts, the relation between stakeholders in construction industry remains adversarial and plagued with disputes (Laan *et al.*, 2011). This situation calls for out of the box thinking and the use of latest technology to improve the culture of trust in construction industry. For this purpose, Smart contracts need to be studied.

A smart contract is a computer based programmed that emulate the orthodox contracts through a computer code which is run on a blockchain network (Szabo, 1994). Blockchain system is distributed and no dependent on a single central system. All transactions are recorded in the form of bits and bytes and stored in these blocks and linked together to from a long chain of these blocks. Each of these blocks are timestamped by securing the information about its time of creation and subsequently this information is validated by the every node in the network. (Garzik and Donnelly, 2018). Legal clauses and instructions can be coded in the program. The program is made to execute on its own in the event where the contractual conditions coded in the contract are fulfilled. This feature makes smart contracts self-reinforced. Smart contracts allow information related to transaction such as payment amount to be incorporated and instantly share data among the contract parties. In other words, the transferable amount is locked in smart contracts in a way that no single party can access that transferable amount. This payment amount is then released to the concerned parties in the event of the fulfilled coded conditions (Ahmadisheykhsarmast and Sonmez, 2018). The binary logic of smart contracts makes them decisive meaning that the inputs and the outputs remain the same without any threat of tempering.

Trust is an intangible element. In a complex system like construction industry, an intangible element like trust can be best studied using systems dynamics approach. In order to avoid getting lost in the fine details of the system, it is helpful to see the behaviour of the system as a whole.

This research will assess the impact of smart contracts on the system-based trust in construction industry among different stakeholders. Distinct features of smart contracts such as decentralisation of system, information availability, self-enforcement, and decisive binary logic can have significant impact on inter-stakeholder's trust. Although, the construction industry is considered as reluctant and slow to adapt to latest innovative technologies, the prospects like having a protection against late payments might be a sufficient push factor for incorporating Smart Contracts.

1.2 Level of Research Already Carried Out on the Proposed Topic

The foremost challenge in construction corporations is the dearth of trust (Wang *et al.*, 2017). Trust have been discussed in multiple field from multiple perspectives however it was since 1980s that it was studied from management perspective (Kadefors, 2004; Zaghloul and Hartman, 2003). Psychologically, Trust is a that vulnerable state in which a belief exist where one expects the other party in question to meet one's positive expectations instead of their worst expectations (Jin and Ling, 2005; Lau and Buckland, 2001). Jiang worked on project success and inter-stakeholders trust based on their influential relationship (Jiang *et al.*, 2016). M. Gade worked on the type of Dispute resolution mechanisms that should be used in projects based on the level of pre-existing trust levels (Gad *et al.*, 2016). Shi worked on the moderating role of contracts and trust in managing the opportunistic behaviours of contractors (Shi *et al.*, 2018). This opportunistic behaviour is one of the main causes of lack of trust. Trust between relations are a cause of concern for every stakeholder in the construction industry such as clients, contractors and sub-contractors (Lau and Rowlinson, 2010). These trust relations are formalised and enhanced with the help of contracts. For the last two decades, contractual governance and relationship among stakeholders has been receiving an increasing attention (Zhang *et al.*, 2020). Unfortunately, the present contractual relationship among parties in construction industry reflect a deficit of trust because of their increasing reliance on confrontational clauses (Zaghloul and Hartman, 2003). Extensive work has been carried out in the areas of traditional contacts to safeguard parties in events of liabilities. More and more exculpatory clauses have been added. It can be observed that trust and they mode and type of contract is importing in shaping the success of a certain project (Zaghloul and Hartman, 2003).

Trust is one of the most fundamental element of blockchain technology (Wang *et al.*, 2017). Blockchain is a latest technology that has only recently gathered attention in construction industry. The traditional contractual system with its protection mechanism has failed to increase trust among contracting parties and there has been a dearth of perceived protection. Construction sector is a predominately contracts oriented business which is in need of smart contract technology to overcome the contractual disputes and the payment issues in this sector (Cardeira, 2015). Hamledari has worked on the Prospects of Block chain based smart contracts and progress payment automation (Hamledari and Fischer, 2021). Further work has been carried out by Shojaei in a conference paper where the integration of Building Information modelling and Blockchain has been discussed (Shojaei *et al.*, 2020).

Gap Analysis

Smart contracts are a new and recent addition to the field of research in construction industry, it is only gaining moment now. Work has been carried out on the technical aspects of its implementation. However, the more nuanced and psychological aspects have not yet been addressed. This research aims to address the impact of smart contacts on system-based trust among contracting parties using systems dynamics.

1.3 Reasons / Justification for Selection of the Topic

Construction industry is inherently complex. There is interaction between order and disorder, predictability and unpredictability, regularity, and chaos. These features make construction projects more prone to risks that result in trust issues. While a great amount of work is being carried out in the areas of traditional contracts to reduce room for mistrust, yet the issues persist. With advancements in Technology, it is imperative to address these trust issues using latest innovative technology like Blockchain based Smart Contracts.

1.4 Objectives

a) To identify factors affecting system-based trust in construction industry and key features of smart contracts.

b) To develop a system thinking diagram to find the impact of smart contracts on system-based trust.

c) To develop a systems dynamics model that can address the complexity of the impact of smart contracts on inter-stakeholder's trust.

1.5 Relevance to National Needs

Although Pakistan is a third world country, its construction industry faces almost the same nature of basic problems that exist throughout the world. In Pakistan, the construction industry relies heavily on trust relations. Formal contracts are seldom studied and discussed before the contracting parties go into contracts. Furthermore, issues like late payments and incomplete payments are rampant to the extent that it is causing sub-contractors to go into insolvency. Smart contracts can be the solution to a

Pakistani contractor's chief sources of distrust. Improved trust relations will also improve the quality of construction work in Pakistan.

1.6 Advantages

a) It will help understand the "black box" that is the relationship between contracts and trust from a unique perspective of complexity.

b) It will help address trust as a function of contracts which is often a neglected element in construction industry.

c) It will help answer the call for innovative solutions to address the issue of lack of trust in the industry.

1.7 Areas of Application

The major areas of application are Construction Contacts, Project management.

Chapter 2: Literature Review

2.1 Construction Industry

Construction industry is considered the mother of all industries as it not only provides the largest number of employment opportunities but serves as an impetus for a country's economy to grow (Fernández-Solís, 2008). There is a French saying:

"When the construction industry prospers everything prospers."

The major concern of construction industry is the improvement of the social, economic, and environmental sustainability indicators. The engineering and construction industry faces menacing challenges such as Trust issues (Khalfan *et al.*, 2007), lack of technological assimilation (Hargaden *et al.*, 2019), low profit margin, continuous project overruns in budget and schedule, and is further bothered with claims and counter-claims (Yeo and Ning, 2002).

2.2 Characteristics of Construction industry

The construction sector is essentially labor intensive. There is absence of environmental regulations (Galal and Moneim, 2016). Delays in construction projects are common due to which timely completion of the project is affected (Haseeb et al., 2011). Issues include fragmentation, lack of coordination, communication and trust among client, contactors and consultants effecting the supply chains, use of traditional contracting methods, lack of environmental regulations and a labor-intensive construction industry all create a lot of problems (Farooqui and Ahmed, 2008).

Construction sector has a huge potential in terms of its possible contribution to the GDP of country however its true potential remains untapped and unexploited (Nawaz *et al.*, 2013). This is because of certain problems which includes lukewarm political support, ineffective communication, unskilled labor force, incompetent contactors, project complexity, inefficient contracts and lack of mainstreaming of technological advancements (Ullah *et al.*, 2018).

2.3 What is trust?

In theory, trust is said to be a construct of society and psychology which is used in relation to the nature of relationship among different actors of a social system (Gad, 2012). Trust is beyond mere interpersonal phenomenon as it can relate the mutual dealings within and among different social groups which can include immediate family, friends, peer and organizations (Chalker and Loosemore, 2016). Ghada M. Gad defines trust as:

"a psychological state involving vulnerability, where a belief exists that the individual/organization on whom we depend will meet our positive expectations rather than our fears"(Gad, 2012)

The Oxford Dictionary defines trust as "the belief that one can rely on the goodness, strength, and ability of somebody or something."

It is pertinent to discuss in the context of social exchange theory. According to this, Trust is only a single aspect of an individual or firm's "*long-term orientation*" ("LTO") (Pesamaa and Hair, 2008). It can be said that all relationships irrespective of the length will involve a certain level of commitment or loyalty. Similarly, almost all the relationships involve some level of trust as well. However, it is usually difficult to ascertain how and where exactly this factor lie. This very concept of Trust is coupled with uncertainty in literature on trust (Herko and Hanna, 2017). The classical theorists see actors as self-serving and therefore always on the quest to maximize their interest by exploiting uncertainties (Herko and Hanna, 2017). Monitoring and controlling these opportunistic tendencies is expensive and may also have negative impact on performance (Husted and Folger, 2004).

Similarly, the need to keep this uncertainty in check and vulnerabilities accounted for gives rise to a new relationship between trust and control (Herko and Hanna, 2017). This control is achieved through contracting. Since going into a contract is an exercise to allocate risk and that a certain cost ought to be paid for that risk one can say that trust is a lubricant to minimize friction while reducing the overall cost of construction (Zaghloul and Hartman, 2003).

To answer the question whether trust and contractual control are interdependent, Gulati and Nickerson in their 2008 article summarizes, "*Trust may substitute for formal governance if the cooperative behavior trust generates offers a less costly and more effective safeguard than complex contracts or vertical integration*" (Roehrich *et al.*, 2020). Likewise, Gulati (1995) argues "*trust can substitute for hierarchical contracts in many exchanges and serves as an alternative control mechanism*." It is evident that trust is separated from contracting however formal contractual governance helps define and understand trust (Herko and Hanna, 2017).

In addition, Trust has two basic components to observe here. First, it is an interpersonal phenomenon. It is the people that Trust and not the organizations or firms (Khalfan *et al.*, 2007). Even so when there is an air of reliability of expectations, and it inculcates trust then this trust is due to the people who has these expectations not the organizations. Second, the focus is future. This means that the future orientation is tied to the past encounters, experiences and images of one another (Herko and Hanna, 2017).

2.3.1. Trust in Construction Industry

There has been an extraordinary effort placed on technology alone to improve the project success in the recent times whereas the soft and intangible aspects of project management-like trust, has been ignored (Gad and Shane, 2014). Trust is regarded as one of the most crucial elements necessary for making integrated project team and the eventual success of a project (Atkinson *et al.*, 2006). The Rethinking Project Management Network suggested more focus on the less concrete aspect of the project such as trust and creation of an organizational culture (Atkinson *et al.*, 2006). For the same reason there has been sufficient activism to include Trust as a part of Project Management discipline. It is important to understand how Trust is created and how trust is maintained throughout the lifecycle of the project (Gad *et al.*, 2016).

2.3.2. Types of Trust

Trust is a complex concept which involves multiple levels based on different determinants (Rousseau *et al.*, 1998). It is also dynamic in nature due to the fact that it is either increasing or decreasing (Cheung *et al.*, 2003). In order to categorize and expand trust, a plethora of theories and concepts have been applied to it according to the needs (Zaghloul and Hartman, 2003). However, since construction industry has its own dynamics and characteristics the vary from project to project, trust in construction sector has its own understanding and conceptualization (Ford, 2004; Kramer and Tyler, 1996).

The foremost categorization of trust in construction sector was done by Zaghloul and Hartman by classifying it in three broad categories using colors (Zaghloul and Hartman, 2003). These are:

<u>Blue trust</u>: Also called competence trust has everything to do with the competence and individual abilities. It is based on the perception that the party in question has the capacity to perform as per the requirements. In simple terms it is the answer to, "can you do the job?" (Zaghloul and Hartman, 2003).

<u>Yellow Trust</u>: Yellow trust is also called Integrity trust. It is based on the integrity of the other party and symbolize the perception of their attitude to be ethical, their regard for values and their seriousness in holding important which is fair. This type of trust is the chief check on opportunistic behavior. It answers the question, "Will you consistently take care of my interests?" (Zaghloul and Hartman, 2003).

<u>Red Trust</u>: Also called intuitive trust as it is based on intuition. It is a mix of emotional response and information processing regarding another person's intentions. It is can also be described as "gut feeling" (Zaghloul and Hartman, 2003).

Subsequently, Cheung and Wong proposed another framework for trust in a series of publications. Their proposal included three categories (Cheung *et al.*, 2011), they are:

<u>System-Based Trust</u>: It has a focus on formalized and procedure related setup. It includes elements like contracts and agreements, organizational policy and communication system (Wong *et al.*, 2008). This category of trust engenders certainty which results in the development of trust between parties (Lewis and Weigert, 1985).

<u>Cognition-Based trust</u>: This category of trust comes into force when a party becomes aware of the trustworthiness of the other party on the bases of certain knowledge. For this exchange of knowledge, good level of communication is necessary (Cheung *et al.*, 2011).

<u>Affect-Based trust</u>: It is based purely on emotions. The emotional attachment or quotient that one party's individuals have for another party's individuals is a prime variable (Cheung *et al.*, 2011; Wong *et al.*, 2008).

2.3.3. System-based Trust

Based on the available literature review, W. Wong proposed the categorization of different modes of trust in construction sector, one of which is system-based trust (Wong *et al.*, 2008). The formal control mechanism and arrangements is subsumed under this type of trust. It includes formal contracts, different forms of communications and organizational policies. Wong argues that this type of trust plays a vital role in shaping inter-organizational relationships. Having no place for emotional quotient in this type of trust, it is purely a product of how organizations formally plan to increase coordination, trust and mutual understanding based on concrete steps like contracts (Qian and Papadonikolaki, 2020). This type of trust can be enhanced in a number of ways like clearly defining a communication policy for more efficient collaboration (Zaghloul and Hartman, 2003). System trust is a function of bureaucratic sanctions and a product of a set of safe-guards through an effective legal system (Lewis and Weigert, 1985). System-based trust is the trust in institutions for their potency in regulating the opportunistic behavior of contracting parties (Rousseau *et al.*, 1998). It can also be called rule-based trust where the mutual understanding of the ground rules and the reverence for the system regulates interorganizational relationships (Kramer and Tyler, 1996).

The chief element of system-based trust is formal contracts. Contracts clearly defines the rules at play and minimizes the chances of opportunistic behavior thus reducing the level of risk for all parties (Wong *et al.*, 2008). System-based trust is the most important factor to increase trust as per the views of contractors and, client and consultants (Wong and Cheung, 2004). Smart contracts help reduce the need for relational trust and enhances dependence on system-based trust to reduce and regulate the rampant opportunistic behavior in construction industry (Qian and Papadonikolaki, 2020).

2.3.4. Factors affecting System-based trust in Construction Industry

The following factors as shown below in Table 1 were identified from literature review that impact the system-based trust in construction industry.

Table 1: Factors affecting System-Based Trust in Construction Industry from literature

ID	Factors	Sources
F1	Partnering among Stakeholders	(Jin and Ling, 2005; Kadefors, 2004; Laan *et al.*, 2011, 2012; Ruijter *et al.*, 2020; Wong *et al.*, 2005; Wood *et al.*, 2002; You *et al.*, 2018; Zaghloul and Hartman, 2003)
F2	Information sharing	(Cheung *et al.*, 2011; Chow *et al.*, 2012; Dewulf and Kadefors, 2012; Khan *et al.*, 2016; Naveed *et al.*, 2021; Wong *et al.*, 2008; You *et al.*, 2018)
F3	Reciprocation of Trusting Act	(Chalker and Loosemore, 2016; Cheung *et al.*, 2011; Chow *et al.*, 2012; Gad and Shane, 2014; Khalfan *et al.*, 2007; Laan *et al.*, 2011; Lewis and Weigert, 1985)
F4	Stakeholder's Integrity	(Ahmadisheykhsarmast and Sonmez, 2020; Cheung *et al.*, 2011; Laan *et al.*, 2011; Luo *et al.*, 2019; Nasir and Hadikusumo, 2019; Wood *et al.*, 2002)
F5	Integrity of Communication	*Ruijter et al., 2020; W. K. Wong et al., 2008)*

F6	Process of Evaluation	(Jin & Ling, 2005; Laan et al., 2012)
F7	Explainable Contract Information	*(Cheung et al., 2011; W. K. Wong et al., 2008)*
F8	Clear definition of Contract Documents	*(Dewulf & Kadefors, 2012; Kadefors, 2004;)*
F9	Clarification of terms and conditions before Commencement of work	(Dewulf and Kadefors, 2012; Gad *et al.*, 2016; Nasir and Hadikusumo, 2019; Wong and Cheung, 2004)
F10	Co-operation during Contract formation phase	(Bowen *et al.*, 2007; Cheung *et al.*, 2011; Gad and Shane, 2014)
F11	Accuracy of Information	(Ahmadisheykhsarmast and Sonmez, 2020; Chow *et al.*, 2012; Naveed *et al.*, 2021; Shojaei *et al.*, 2020; Swan *et al.*, 2005)
F12	Predictability of Measurements and Rewards	(Cheung *et al.*, 2003; Khalfan *et al.*, 2007)(Ruijter *et al.*, 2020)
F13	Mutual Dependence	*(Cheung et al., 2003; Khalfan et al., 2007; Wood et al., 2002)*
F14	Frequency and openness of communication	(Brewer and Strahorn, 2012; Chalker and Loosemore, 2016; Dewulf and Kadefors, 2012; Khan *et al.*, 2016; Nasir and Hadikusumo, 2019; Naveed *et al.*, 2021; Swan *et al.*, 2005; Wood *et al.*, 2002)
F15	Alignment of Effort and reward	*(Bowen et al., 2007; P. S. Wong et al., 2005; P. S. P. Wong & Cheung, 2004, 2005)*
F16	Effective and sufficient information flow	(Chow *et al.*, 2012; Dewulf and Kadefors, 2012; Khan *et al.*, 2016; Nasir and Hadikusumo, 2019; Naveed *et al.*, 2021)

F17	Respect and appreciation for the system	*(Cheung et al., 2003; Gad et al., 2016)*
F18	Perceived Fairness of Decision Processes	*(Laan et al., 2012; Zhang et al., 2020)*
F19	Quality of Contract Administration	(Bowen *et al.*, 2007; Dewulf and Kadefors, 2012; Drexler and Larson, 2000; Hamledari and Fischer, 2021; Luo *et al.*, 2019; Nasir and Hadikusumo, 2019; You *et al.*, 2018; Zaghloul and Hartman, 2003)
F20	Openness in mutual Dealings	(Ahmadisheykhsarmast and Sonmez, 2018; Cheung *et al.*, 2011; Da *et al.*, 2020; Jin and Ling, 2005; Khan *et al.*, 2016; Laan *et al.*, 2012; Wood *et al.*, 2002)
F21	Protection of Intellectual Property	(Chalker and Loosemore, 2016; Hamledari and Fischer, 2021)
F22	Willingness to co-operate	(Bowen *et al.*, 2007; Chalker and Loosemore, 2016; Chow *et al.*, 2012; Jin and Ling, 2005; Kadefors, 2004; Laan *et al.*, 2011; Wood *et al.*, 2002; You *et al.*, 2018)
F23	Delay in Progress payments	(Ahmadisheykhsarmast and Sonmez, 2018, 2020; Gad and Shane, 2014; Luo *et al.*, 2019; Nasir and Hadikusumo, 2019; Zaghloul and Hartman, 2003)
F24	Demand for discounts after agreement	(Ahmadisheykhsarmast and Sonmez, 2018)
F25	Full Payment on due amount	(Ahmadisheykhsarmast and Sonmez, 2020; Bowen *et al.*, 2007)
F26	Having to chase payments	(Ahmadisheykhsarmast and Sonmez, 2020; Bowen *et al.*, 2007; Hamledari and Fischer, 2021; Laan *et al.*, 2011, 2012; Nasir and Hadikusumo, 2019; Zaghloul and Hartman, 2003)

F27	Opportunistic behaviour	(Bowen et al., 2007; Chow et al., 2012; Gad et al., 2016; Jin & Ling, 2005; Kadefors, 2004; Korczynski, 1994; Ruijter et al., 2020; Zhang et al., 2020)
F28	Quality of Documentation	(Bowen et al., 2007; Drexler & Larson, 2000;Kadefors, 2004)
F29	Collusive Tendering	(Jin and Ling, 2005)
F30	level of Enforcement	(Ahmadisheykhsarmast and Sonmez, 2018, 2020; Cheung *et al.*, 2011; Gad and Shane, 2014; Khalfan *et al.*, 2007; Luo *et al.*, 2019; Zhang *et al.*, 2020)
F31	Alteration of Invoices	(Bowen et al., 2007; Jin & Ling, 2005)
F32	Post Contract Bargaining	(Jin & Ling, 2005; Kadefors, 2004)
F33	Initial Intent of the Project Participants	(Chen *et al.*, 2018)
F34	Integrity	*(Brewer & Strahorn, 2012; Kadefors,2004; Wood et al., 2002)*
F35	Reputation and reliability	(Brewer and Strahorn, 2012; Chen *et al.*, 2018; Cheung *et al.*, 2011; Gad and Shane, 2014; Kadefors, 2004; Khalfan *et al.*, 2007; Nasir and Hadikusumo, 2019; Swan *et al.*, 2005; Wong *et al.*, 2005; Wong and Cheung, 2004, 2005; Wood *et al.*, 2002; Zaghloul and Hartman, 2003; Zhang *et al.*, 2020)
F36	Active Search for innovative solutions	*(Jin & Ling, 2005; Kadefors, 2004)*
F37	Timeliness of communication	(Wong and Cheung, 2005)
F38	Level of Commitment	*(Swan et al., 2005; P. S. P. Wong & Cheung, 2005; Zhang et al., 2020)*
F39	Mutual Understanding	*(Gad et al., 2016; Khalfan et al., 2007; Zaghloul & Hartman, 2003)*

F40	Level of Deterrence	*(Chow et al., 2012; Nasir & Hadikusumo, 2019)*
F41	Perceived restriction	*(Kadefors, 2004; Zhang et al., 2020)*(Hamledari and Fischer, 2021; Laan *et al.*, 2011)
F42	Perceived safeguards	*(P. S. P. Wong & Cheung, 2004; You et al., 2018; Zaghloul & Hartman, 2003; Zhang et al., 2020)*
F43	Contractual Complexity	(Da *et al.*, 2020; Gad and Shane, 2014; Jin and Ling, 2005; Kadefors, 2004; Luo *et al.*, 2019; Qian and Papadonikolaki, 2020)
F44	Sufficiency of Contract documents	(Dewulf and Kadefors, 2012; Drexler and Larson, 2000; Kadefors, 2004; Nasir and Hadikusumo, 2019; Zaghloul and Hartman, 2003)
F45	Collaborative relationship	(Dewulf and Kadefors, 2012; Kadefors, 2004)(Laan *et al.*, 2011)
F47	Compatibility	(Wong *et al.*, 2005)(Brewer and Strahorn, 2012; Wong and Cheung, 2005)
F48	Contractors' involvement	*(Drexler & Larson, 2000; Nasir & Hadikusumo, 2019)*
F49	Contractual Flexibility	(Dewulf and Kadefors, 2012; Nasir and Hadikusumo, 2019; You *et al.*, 2018)
F50	Change orders	(Nasir and Hadikusumo, 2019)
F51	Level of Risk	(Nasir and Hadikusumo, 2019; Ruijter *et al.*, 2020)(Brewer and Strahorn, 2012)
F52	Cost of Non-Compliance	(Nasir and Hadikusumo, 2019)(Dewulf and Kadefors, 2012)
F53	Client's stronger contractual Position	(Nasir and Hadikusumo, 2019; You *et al.*, 2018)(Gad *et al.*, 2016)

F54	Transparency	(Dewulf and Kadefors, 2012; Laan *et al.*, 2011)
F55	Prior Inter-organisational Relationship	(Chen *et al.*, 2018; Laan *et al.*, 2011, 2012)
F56	Previous experience between stakeholders	(Chen *et al.*, 2018; Laan *et al.*, 2012) (Ahmadisheykhsarmast and Sonmez, 2018)

2.4 Trust and construction contracts

Although a contract is a legal documents made for the purpose of avoiding unnecessary risk, some view it as a driver of mutual trust among parties (Rousseau *et al.*, 1998). Researchers have shown considerable interest in understanding the nature of relationship between Trust and contracts. Contracts are adopted primarily to counter the opportunistic behavior of contracting parties (Herko and Hanna, 2017). Inculcating trust has also been identified as a potent tool to minimize this opportunistic behavior (Cheung *et al.*, 2011).

Researchers have tried to see the benefits of reducing the complexity and size of contract. Lau tried to find room for flexible contract execution while reducing the overall details of the contracts (Kadefors, 2004; Lau and Buckland, 2001). As per the results of the study, the_participant agreed that to work with less detailed contracts required a higher level of trust. However, those responded revealed that they would not be comfortable to work under such contract because of the higher level vulnerability (Lau and Buckland, 2001). Similar, Kadefors (2004) conducted a study to explore the factors that can engender the development of trust and cooperation. The study concluded that the current contractual system is responsible for producing uncooperative mutual relationship (Kadefors, 2004). A study on Cheung et al. (2006)

worked on creating a relational index by further dividing trust and also compared different types of contracts. Trust was observed to be a strong element in construction disputes resolution (Cheung *et al.*, 2011).

The level of trust that exists in construction sector contracts is low among the parties (Zaghloul and Hartman, 2003). The unique nature of the projects and the lack of enough motivation to establish partnering relationships has a toll on the relationships between stakeholders. These relationships are mostly driven by opportunistic behavior and the increasing complexity of construction contracts has only added to the widening trust deficit (Gad *et al.*, 2016). There is peculiar relationship between trust and contracts complexity. Trust is said to be at its maximum when there is practically no condition or oversight to control opportunistic behavior. hence, the need for more trust in relations and the need for an efficient and robust contract calls for a balanced approach (Jin and Ling, 2005).

2.5 Introduction to Blockchain Technology and Smart Contracts

2.5.1. Blockchain Technology

A blockchain is a peer-to-peer digital ledger or protocol that stores information in the form of binary language. The information is intelligently verified and confirmed through nodes for its veracity before storage (Mohanta and Jena, 2018). After every transaction, the record is validated by nodes and then secured through a hash function. Every single block of this chain is linked to the other blocks through their hash values making a chain of blocks hence called blockchain. The hash values of the block are impossible to change or temper once it is added to block. The transaction can be viewed by everyone who has the ledger making fraud and theft next to impossible. The chain is replicated on a wide range of computers and any change in one block is communicated to all participants while the time and sequence of the chain is updated uniformly (Chaveesuk *et al.*, 2020). The Validation of records is done through proof of work and proof of stake making the whole operation extremely transparent.

There are no formal definition of Blockchain however it can be said that it is a programmable distributed trust infrastructure (Turk and Klinc, 2017). This technology was formerly created as an accounting method for virtual Bitcoin currency. It provides a distributed and decentralized ledger technology which has a wide ranging of potential applications in commercial sector (Chaveesuk *et al.*, 2020). Presently this technology is being used as a verification method of the existing digital currencies however there is an option of coding to make it more diverse in use and applications. One of the main aspects of this technology is its decentralization, meaning that the whole community can act as the verification authority instead of one single central authority. With its robust inbuilt security system, digital currencies like Bitcoin are getting more and more popular among people (Chaveesuk *et al.*, 2020).

There are two main characteristics of Blockchain that are lacking in any other traditional Databases. These are:

- Every piece of transactional information, along with any of verified modifications and metadata, is recorded and protected in a digital signature that is cryptographically strong enough.
- There is no need for a centralized authority, the whole operations are decentralized.

Blockchain is the buzzword of 21st century. Since its inception at hands of a group of people by the name Satoshi Nakamoto in 2008, it has divided industry practitioners regarding its future. Some of them suggest that it will disrupt global business and financial system like the Internet disrupted local markets. (Cong and He, 2019). Initially blockchain technology was tied to cryptocurrency but with the birth of Blockchain 2.0, this technology was separated from currency (Zheng *et al.*, 2017). This separation created more options for its use in a wide range of areas. One of those applications is smart contracts.

2.5.2. Smart Contracts

Smart contracts in its most rudimentary form were envisioned by Nick Szabo in 1994 (Zheng *et al.*, 2017). He defined it as a "computerized transaction protocol that executes the terms of a contract" (Badi *et al.*, 2020). He was a computer scientist, a scholar of the law and a crypto scientist. In his quest for creation of distributed ledger system that does not require a third-party oversight, he created programmable smart contracts. It was not until 2008 when blockchain technology came into existence when the focus was shifted to integrating smart contracts and blockchain technology (Mohanta and Jena, 2018). He believed that the terms and conditions of a contract can be written in machine language that would make breaching of contracts more expensive. The idea was further refined when that small code, encompassing the contract clauses, was put inside a blockchain (Kerikmäe and Rull, 2016).

Vending Machine Analogy:

Smart contracts can be best explained and summarized with an example of a vending machine (Wang *et al.*, 2019). How does a vending machine work? A person slides in a few coins. The Machine Verifies the coins and allows the person to receive the value against the coins. The person selects an item commensurate with the value of the coins and the machine executes the terms of the contract by dropping down the item.

What is happening here is analogous to a smart contract at its simplest form. In the said example, there was no need for an intermediary (person). The machines store some rules. The coins inserted are verified and then the contract is executed automatically. So basically, smart contracts are very secure vending machines (Wang *et al.*, 2017). Hence it can be said that a smart contract facilitate has three basic functions. Smart contracts:

- Store Rules
- Verify Rules
- Self-execute Rules.

These simple yet powerful functions have promising implications in several areas.

The chief benefit of smart contract that makes it more viable than the traditional contract is the efficiency of its contractual process, e.g. it is easier to maintain the contractual history of the parties in question (Kerikmäe and Rull, 2016). Furthermore, smart contracts are self-enforcing in nature, as all programable codes are (Badi *et al.*, 2020). The conditions of the contract are executed automatically when they are fulfilled. Unlike traditional contracts, programming introduces if-this-then-that rules (Savelyev, 2017). The conditions of the contract can execute accordingly (Mohanta and Jena, 2018). The mainstreaming of blockchain technology makes smart contracts more safe and more resistant to tempering which inculcates trust factor (Kerikmäe and Rull, 2016; Mason and Escott, 2018).

As discussed earlier, the lack of reliance on formal entities of 'Trust', like Banks and lawyers, is an incredibly appealing facet of smart contract in several commercial sectors. The most profound evidence of the disruption brought by smart contracts is in the financial and banking sector. As per European Commission Trend Report (2016), it is estimated to decrease bank infrastructure costs by EUR 18.4 Billion per year by 2022, (Badi *et al.*, 2020). Similarly, the time wasted with lawyers and the formal paper work can be saved with smart contracts, which promises more efficient contract management process (Mason and Escott, 2018).

To subsume the discussion on smart contracts, it can be said that smart contracts are the next generation of contracts that promises more security, efficient enforcement mechanism and reduced dependance on third parties. It would be appropriate to mention Nick Szabo's example of choice. In case of a missed payment, a car loan based on a smart contract would automatically revoke your digital car keys making the car unavailable for use. This "speed of thought" execution and enhanced security of blockchain technology open new opportunities and possible applications in a wide variety of fields. For the same reason, it can be said that this disruptive and innovative concept offers profound impact on construction industry as well.

2.5.3. Smart contracts in Construction Industry

Construction industry is marred with problems and issues which the traditional contractual models have failed to resolve. Inter-stakeholder relationships are highly adversarial in Construction industry (Laan *et al.*, 2011). There is an inherent lack of trust between the parties due to insipid contractual safeguards (Chalker and Loosemore, 2016). There is an information asymmetry in the projects where the client and the contractor hides information for their own benefits (Wang *et al.*, 2017). Furthermore, an inquiry was initiated by the government of New South Wales to investigation the unusual rate of insolvencies of mid-tier builders. The final report suggested that the chief cause of insolvencies was late payments or lack of payments (Krone-Davis P, 2012). Disputes and litigation in construction sector are very costly in terms of time and money (Wang *et al.*, 2017). Neither client not contractors want any disputes, yet they always end up in finding themselves trying to protect their interests. The relationship between contractors and subcontracts is yet another interesting relationship that is a constant headache for the clients (Manu *et al.*, 2015). All these problems need to be addressed with the help of new and innovative technologies as the existing methods have failed to provide solutions. For this reason, Blockchain enabled smart contracts need to be studied as it some has some solutions to offer. smart contracts are potentially disruptive for the traditional models of contracting in the construction industry (Mik, 2017; Savelyev, 2017). The Traditional construction contracts are wasteful, since construction contracts are always blamed to be long, complex (Koc and Gurgun, 2020). During a construction industry conference in Canberra back in 1991, Brain Ernest said that:

"One can always have sympathy with the proposition that he who does the work should get paid for it" (Krone-Davis P, 2012).

Indeed, whether one has this sympathy or not, one cannot deny the fact that it is the right of the doer to get paid fully and on time. Unfortunately, in construction industry it is not so. The issue of late payment and incomplete payment is one of the most fundamental problems in this sector (Ahmadisheykhsarmast and Sonmez, 2020). The contractors usually must chase his payments as well. It has a profound impact on the quality of the project and the overall contractor-client relations (Gad and Shane, 2014). It is a demotivating factor, and the contractor usually is not able to pay the sub-contractors as well. The effect snowballs resulting in time and cost over runs. Smart contracts have the potential to protect main contractors and sub-contractors from influences due to these payment issues (Luo *et al.*, 2019). Automated contract execution enhances the relationship among stakeholders and thus positively affecting the performance of the project.

Lack of Trust is another important facet of construction sector. This lack of trust has many reason including payment issues, lack of collaboration, information asymmetry and poor contract management processes to name a few (Bowen *et al.*, 2007; Khalfan *et al.*, 2007). The characteristic features of smart contracts have promising future in eradicating these causes of distrust in construction industry (Koc and Gurgun, 2020). Smart contracts are temper resistant and protects contractors by blocking the payment in the contract from the start of the project for the code to execute upon the fulfillment of conditions (Turk and Klinc, 2017). Similarly, a unique nature of construction projects is that they are always a onetime project where two projects are rarely the same. This reduces chances of long-term strategic partnership. The stakeholders can give up opportunism and appreciate the extra mile which the other party is covering by adopting smart contracts. This can be an impetus for strategic partnerships (Wang *et al.*, 2017).

Furthermore, smart contracts offer decentralized system where there is no need for intermediaries like Banks, courts and lawyers anymore (Hargaden *et al.*, 2019). The very act of choosing to go for smart contracts instead of traditional contracts will positively impact the relations among the concerned parties (Cardeira, 2015; Mason and Escott, 2018).

2.5.4. Features of smart contract relevant to construction industry

These are the features of smart contracts that were identified from the literature review are listed in Table 2 below.

Table 2: Features of smart contracts from literature

ID	Features	Sources
A1	Reduction in enforcement cost of Commercial Transactions	(Ahmadisheykhsarmast and Sonmez, 2018, 2020; Szabo, 1994)
A2	Reduction in Fraud of Commercial Transactions	(Ahmadisheykhsarmast and Sonmez, 2020; Alan *et al.*, 2017; Badi *et al.*, 2020; Cardeira, 2015; Qian and Papadonikolaki, 2020; Szabo, 1994)
A3	Transaction information available for all parties	(Li *et al.*, 2019; Luo *et al.*, 2019; Mason and Escott, 2018)
A4	Automated Contract Execution	(Ahmadisheykhsarmast and Sonmez, 2020; Alan *et al.*, 2017; Chaveesuk *et al.*, 2020; Koc and Gurgun, 2020; Mohanta *et al.*, 2018; Szabo, 1994; Wang *et al.*, 2017)
A5	Reduced information Asymmetry	(Ahmadisheykhsarmast and Sonmez, 2020; Alan *et al.*, 2017; Cong and He, 2019; Meier and Sannajust, 2020;

		Mohanta *et al.*, 2018; Qian and Papadonikolaki, 2020)
A6	Reduced Transaction Time	(Ahmadisheykhsarmast and Sonmez, 2018, 2020; Chaveesuk *et al.*, 2020; Wang *et al.*, 2019)
A7	Savings in case of Foreign Transactions	(Meier and Sannajust, 2020)
A8	Reduced Possible Contract Breaches	(Alan *et al.*, 2017; Badi *et al.*, 2020; Koc and Gurgun, 2020; Meier and Sannajust, 2020; Szabo, 1994)
A9	Transparency	(Ahmadisheykhsarmast and Sonmez, 2020; Chaveesuk *et al.*, 2020; Cong and He, 2019; Luo *et al.*, 2019; Meier and Sannajust, 2020; Szabo, 1994)
A10	No need for Intermediaries like Banks? Decentralizationn	(Ahmadisheykhsarmast and Sonmez, 2018; Chaveesuk *et al.*, 2020; Li *et al.*, 2019; Meier and Sannajust, 2020; Qian and Papadonikolaki, 2020; Szabo, 1994)
A11	Freedom from incomplete payments	(Ahmadisheykhsarmast and Sonmez, 2018; Bartoletti and Pompianu, 2017; Chaveesuk *et al.*, 2020; Mason and Escott, 2018; Wang *et al.*, 2019)

A12	Mitigation of Delayed Progress payments	(Ahmadisheykhsarmast and Sonmez, 2018, 2020; Badi *et al.*, 2020; Cardeira, 2015; Chaveesuk *et al.*, 2020)
A13	Automated payment procedure	(Ahmadisheykhsarmast and Sonmez, 2018, 2020; Badi *et al.*, 2020; Cardeira, 2015; Li *et al.*, 2019; Luo *et al.*, 2019; Mason and Escott, 2018)
A14	Protection from payment Refusal	(Ahmadisheykhsarmast and Sonmez, 2018; Chaveesuk *et al.*, 2020; Li *et al.*, 2019)
A15	Protection from insolvency	(Ahmadisheykhsarmast and Sonmez, 2020; Alan *et al.*, 2017; Badi *et al.*, 2020; Cardeira, 2015; Koc and Gurgun, 2020; Luo *et al.*, 2019; Qian and Papadonikolaki, 2020)
A16	Lack of mainstreaming of smart contracts	(Mason and Escott, 2018; Qian and Papadonikolaki, 2020; Szabo, 1994)
A17	Temper Resistance	(Chaveesuk *et al.*, 2020; Cong and He, 2019; Li *et al.*, 2019; Luo *et al.*, 2019; Mohanta *et al.*, 2018; Qian and Papadonikolaki, 2020; Turk and Klinc, 2017; Wang *et al.*, 2019)

A18	Enhanced Auditability	(Wang *et al.*, 2019) *(Salar Ahmadisheykhsarmast & Sonmez, 2020; Luo et al., 2019)*
A19	Enhanced integrity	*(Salar Ahmadisheykhsarmast & Sonmez, 2020; Mohanta et al., 2018; Wang et al., 2019)*
A20	Instability of Cryptocurrencies	*(Cardeira, 2015)*(Wang *et al.*, 2019)
A21	Cumbersome procedure for fixing contracts bugs	(Wang *et al.*, 2019)
A22	Lack of Standards and Regulations	*(Li et al., 2019; Schmitt et al., 2019; Wang et al., 2019)(Cardeira, 2015)*
A23	Privacy and Legal Issues	*(Cong & He, 2019; Li et al., 2019; Schmitt et al., 2019; Wang et al., 2019)*
A24	lack of confidentiality	(Li *et al.*, 2019)
A25	Complexity of Coding contracts clauses	(Li *et al.*, 2019) (Hargaden *et al.*, 2019; Turk and Klinc, 2017)
A26	limited skills to interpret legal prose of coding	(Li *et al.*, 2019)
A27	Automated claims processing	*(Alan et al., 2017; Cardeira, 2015) (Mason & Escott, 2018; Wang et al., 2019)*

A28	Reduced amount of paperwork	*(Cardeira, 2015; Garzik & Donnelly, 2018)* (Garzik and Donnelly, 2018; Szabo, 1994)
A29	Enhanced Autonomy for all stakeholders	(Garzik and Donnelly, 2018)
A30	Backup available in case of lost document	*(Cardeira, 2015; Garzik & Donnelly, 2018)*
A31	Solely electronic in nature	(Ahmadisheykhsarmast and Sonmez, 2018; Li *et al.*, 2019; Mason and Escott, 2018; Savelyev, 2017; Szabo, 1994)
A32	Increased certainty	*(Savelyev, 2017)*

2.6 Systems Dynamics Approach

Systems Dynamics (SD) concept was introduced by Jay Wright Forrester, a professor at Massachusetts Institute of Technology (MIT) in 1950s. The goal of SD technique was to help connect variables to the dynamic systems of Industrial processes. The purpose of a system dynamics technique is to understand the dynamics of different processes and to search for the questions like; how and why. These answers are then used to improve management policies required to run these processes (Saysel *et al.*, 2002). Systems dynamics is basically created to cater for complex and large scale systems (Forrester, 1997). This technique is a combination of traditional management system and the science of feedback control mechanism (Ziemele *et al.*, 2016). Systems dynamics modeling is an efficient approach to understand and evaluate large scale complex systems (Barisa *et al.*, 2015). This system is an iterative and feedback incorporating process of modeling. Since a complex system has countless variables, a causal loop diagram (CLD) is developed to determine relationships which includes two types of loops (as shown in Figure 2); a balancing and a reinforcing loop (Tegegne *et al.*, 2018). Each variable in a SD model has a cause and an effect which shows the movement of the variable. There are polarities (as shown in **Figure *1***) among the variables that indicated the impact of change, negative or positive without showing the behavior as shown in the (Barisa *et al.*, 2015).

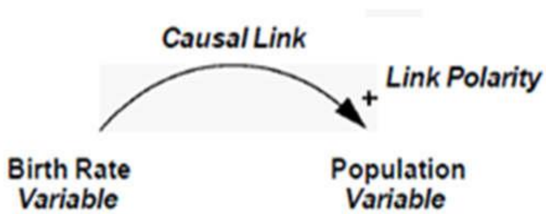

Figure 1: Causal Link and Polarity

The polarity of the arrow is determined by tracing the effect as it moves around the loop. There are two types of loops, one is positive loop and the negative loop. The positive loop is represented by “R” which means the effect of the variable is increasing and the same result is produced in that particular direction. The negative loop is represented by “B” which meaning the effect produced is balancing in nature and the effect is cancelling in nature (Coyle, 2009).

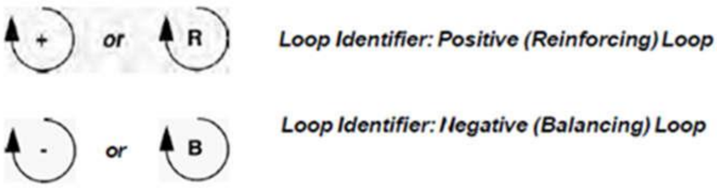

Figure 2: Positive and Negative loops

System dynamics models consists of three variables, namely: stock, flow, and auxiliary. Flows are of two types, namely: Physical/material and information. Both these two types interact in the system and respond to other variables. The stock and flow diagram consists of both stock and flows in the form of variables where feedback loops are essential for simulating the model. Stock and flow diagram provide a visual understanding of the basic principles at play in a complex system. One of the most important features of a system dynamics model is its ability to track the behavior of a system over a certain period of time and by combining different techniques and theories, it helps understand the overall behavior of a system (Forrester, 1997). Construction sector is of great essence for the socio-economic progress of a country. Since, the nature of construction projects have becomes more and more complex and multi-facet, complex systems dynamics approach is becoming more and more popular to understand the intricacies of the construction projects (Ogunlana *et al.*, 2003).

Chapter 3: Methodology

This chapter will now systematically put forward the steps involved in the methodology of this research study. It started with the grind to ferret out a research gap area, which is followed by formulating research objectives. Subsequently, the research progress through a thorough study literature while incorporating systems dynamics as a main methodology to address the research problem.

Research Methodology

In this research, system dynamics approach is used which takes input in the form of factors that were derived through an extensive literature review and a field survey. The factors were shortlisted based on their significance according to field score and literature. Field data was obtained through a Likert scale questionnaire survey. This research consists of four main phases that are illustrated in the Figure 3 below.

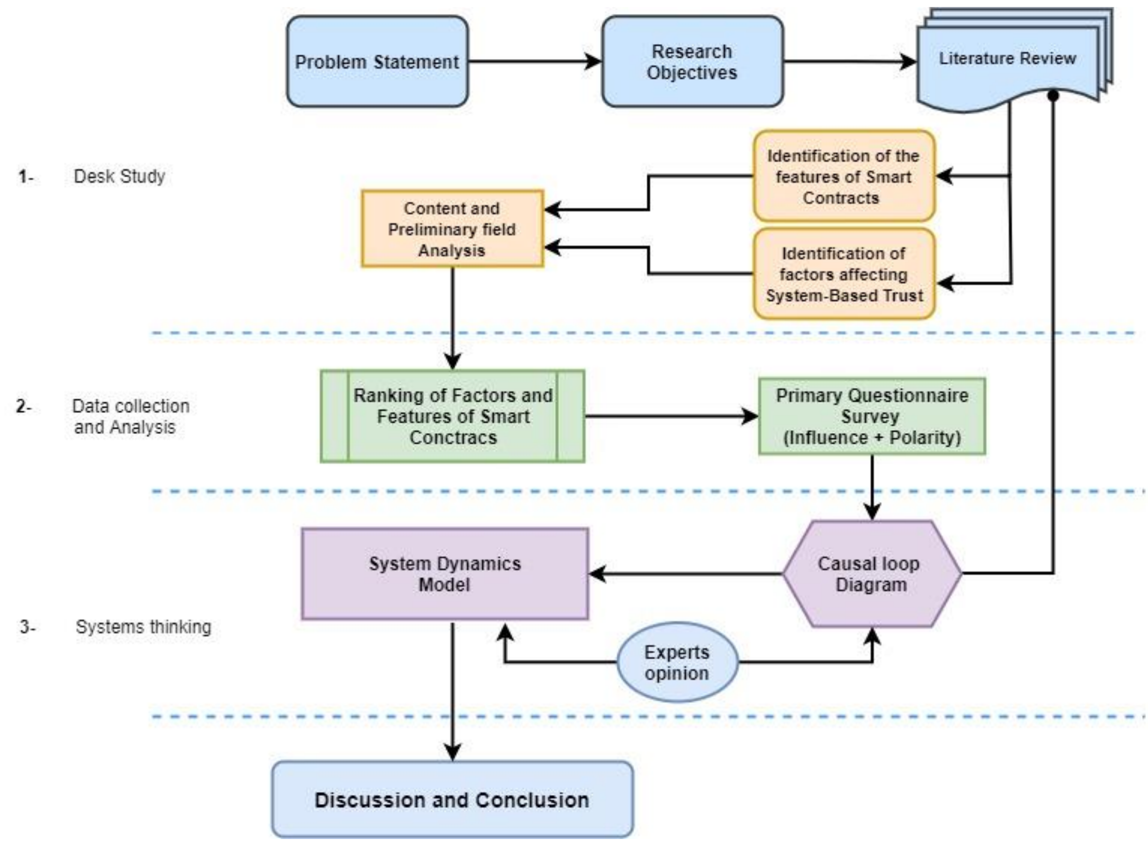

Figure 3: Systematic Representation of the Research Methodology

3.1 Phase 1: Desk Study

In the first phase of this research, a research gap analysis was conducted, and a research problem was ferreted out. Subsequently, this research problem was polished and refined into research objectives. Finding a research gap is a hectic process that require a thorough search both in the field and through an extensive study of literature. From the field it was identified that there is deficit of trust among contracting parties which is among other factors a function of the formal contracts and their inability to foster a culture of Trust. This led to an extensive review of the literature to find previous work on Trust and contracts. Upon reading countless research papers, research gap was narrowed down to the use of smart contracts in construction industry to foster Trust among Contracting parties. After this narrowing down, the research gap and research objectives were finalized in this phase.

3.2 Phase 2: Data Collection and Analysis

In this phase, the two-pronged literature review was conducted to target two different lines of studies. The first part included studying all the articles that addressed Trust dynamics in terms of construction industry and the second part included a thorough study of the literature available on blockchain technology and smart contacts. During both these studies, a separate sheet of excel was prepared to list down the identified factors. The first sheet included factors that affected system-based trust in construction industry while the other such sheet included features of smart contracts that were relevant for construction industry. A total of 32 features of Smart contracts were identified from literature review. Similarly, 56 factors that affect Trust among construction stakeholders were identified. Both these features and factors were ranked based on normalized scores in a technique called content analysis. It included literature review and a preliminary survey. To improve the quality of the work, the literature review was substantiated with a field questionnaire survey. The survey was based on a five-point Likert scale and experts from a diverse range of backgrounds were asked to give a number from 1 to 5 to the identified factors based on their significance. (1=Very Low, 2=Low, 3=Medium, 4=High, 5=Very High). A preliminary Survey was created via Google forms. These forms were circulated online in the developed world through LinkedIn. Due the inability of a free LinkedIn account to access the right group of people, a premium subscription was obtained for this purpose. A total of 32 responses were obtained, two of which were discarded and 30 were accepted. The details are shown in **Table 6**.

This research is intended to target the developed world primarily. Hence 20 responses were intended to be from the developed world and the rest of 10 responses from the developing world. The country of Work of the respondents is shown in **Table 6.**

obtained responses were then analysis with a technique called content analysis. The literature scores were normalized based on their total literature score. Similarly, the field data was also normalized based on their overall score. In the next step, a one-way ANOVA Analysis was performed and p value of 1 was obtained. After ANOVA

Table 3: Shortlisted Features of smart contracts

ID	**Factors**	**Normalized Score**	**Cumulative Score**	**Rank**
A15	Protection from Insolvency	0.070412882	0.070412882	1
A17	Temper Resistance	0.070412882	0.140825765	2
A14	Protection from payment Refusal	0.066896708	0.207722473	3
A5	Reduced information Asymmetry	0.063380534	0.271103006	4
A9	Transparency	0.063380534	0.334483540	5
A2	Reduction in Fraud of Commercial Transactions	0.059864359	0.394347899	6
A4	Automated Contract Execution	0.059864359	0.454212258	7
A1	Reduction in enforcement cost of Commercial Transactions	0.031013850	0.485226108	8
A3	Availability of Transaction information for all parties	0.031013850	0.516239958	9

analysis a 50/50 weightage distribution (50% Literature and 50% field) was adopted for Features of smart contracts and a 60/40 weightage in favor of Field score was adopted for Factors affecting Trust in construction industry. The normalized score of literature review and Field score were given 50% weightage for both set of sheets. 9 features of smart contracts out of 32, and 14 factors affecting Trust out of 56 were selected using pareto analysis. It implies simple principle where 80% of the effect can be generated using only 20% of the available content. Hence all those factors/features were selected that came above the 50% cumulative impact. Table 3 shows the details of the features of smart contracts including their normalized score and their ranking.

Similarly, Table 4 show the details of the selected factors that affect the Trust dynamics in Construction industry.

Table 4: Shortlisted Factors Affecting System-Based Trust**.**

ID	Factors affecting SBT	Normalized Score	Cumulative Score	Rank
F1	Partnering	0.03639513	0.0363951	1
F22	Willingness to co-operate	0.03639513	0.0727903	2
F11	Accuracy of Information	0.03227425	0.1050645	3
F14	Frequency and openness of communication	0.03227425	0.1373387	4
F30	level of Enforcement	0.03227425	0.1696130	5
F35	Reputation and reliability	0.03227425	0.2018872	6
F43	Contractual Complexity	0.03227425	0.2341615	7
F3	Reciprocation of Trusting acts	0.03090062	0.2650621	8
F4	Stakeholder's Integrity	0.03090062	0.2959627	9
F19	Quality of Contract Administration	0.03090062	0.3268634	10

F20	Openness in mutual Dealings	0.03090062	0.3577640	11
F23	Delay in Progress payments	0.03090062	0.3886646	12
F26	Having to chase payments	0.03090062	0.4195652	13
F16	Effective and sufficient information flow	0.02952699	0.4490922	14
F27	Opportunistic behaviour	0.02952699	0.4786192	15
F2	Information sharing	0.02677974	0.5053989	16

Primary data of this research was collected, and analysis was performed using different tools and techniques. A detailed questionnaire for primary survey was developed using Google ™ docs. The survey consisted of two sections. First was related to personal and professional information of the target respondents while the second section required input regarding the strength of causal relationship and polarity between features of smart contracts and the factors affecting system-based trust. The respondents were intended to choose two options from five options per row. First option to rank the causal strength as Low (1), Medium (3) or High (5), and the second option to assign polarity as direct or indirect Relationship.

A shortlisted 9 features of smart contracts and 16 factors affecting system-based trust were incorporated in the final detailed questionnaire survey. The survey was so designed to obtain the causal strength and the polarity of this relationship between the features of smart contracts with the factors affecting system-based trust. A total of 67 responses were obtained of which 4 were considered invalid resulting in 63 valid responses that were used for further Analysis. It is generally acknowledged that a minimum sample size of 30 or above is required to satisfy the central limit theorem (Chan et al., 2018). Once the data was collected, it was then arranged, and responses were evaluated for reliability and consistency using Cronbach Alpha on SPSS software. The Cronbach's coefficient alpha method was used for measuring the reliability and consistency of collected data. The minimum acceptable value for Cronbach's alpha is 0.7 (Wang et al., 2019). The collected data had a Cronbach's alpha value of 0.976 which represented the data to be reliable and consistent. The main sources used to obtain these responses included LinkedIn®, Facebook®, Gmail®. The respondents were forehead vetted for their relevance to construction industry, especially contracts as well their knowledge of blockchain technology.

3.2.1. Shortlisting of relationships

The responses of the detailed survey were checked for reliability and internal consistency using basic statistical tests using SPSS ®. The data was checked for internal consistency and Reliability and Normality. To analysis the Likert scale data, an analysis technique was required. For this reason, Relative importance index (RII) method was used to rank the relationships using the significance indices as per the responses. Data collection through final questionnaire revealed 29 relationships between the features of smart contracts and factors affecting system-based trust. The following formula was used to reduce the sample size (Kometa et al., 1994; Azman et al., 2019), and obtain the most important causative relationships between features of smart contracts and system-based trust influencing factors.

Relative Importance Index (RII) = $(\sum W)/(A*N)$

where,

W = weights assigned in Likert Scale
A = maximum weight assigned in the scale,
N = total number of respondents, and
The RII has a minimum and maximum value of 0 and 1 respectively

It is pertinent to note that to represent the structure of the system it is necessary to consider the most immediate causes instead of all influences (Sterman, 2002). Therefore, the obtained responses were categorized according to their (RII), like that adopted by Roodhdi et al., (2018). The categories ranged from 0-2 as “very Low”, 0.2 to 0.4 as “Medium-Low”, 0.4 to 0.6 as “Medium, 0.6 to 0.8 as “Medium-High” and 0.8 to 1 as “Very High”. In this research, only those relationships were considered for future study that had an RII value ≥ 0.8. Only these relationships were weighed as the most important or most immediate for further analysis using systems thinking.

Table 5: Shortlisted Relationship

ID	**Features of Smart Contracts**	**ID**	**Factors affecting System-Based Trust**	**Polarity**	**Relative Importance Index RII**
A15	**Protection from Insolvency**	F1	Partnering	+	0.867724868
		F7	Contractual Complexity	+	0.888888889
		F12	Delay in Progress payments	-	0.878306878
		F13	Having to chase payments	-	0.857142857
		F15	Opportunistic behaviour	-	0.899470899
A17	**Temper Resistance**	F6	Reputation and Reliability of Contractual System	+	0.888888889
		F10	Quality of Contract Administration	+	0.920634921
		F15	Opportunistic behaviour	-	0.867724868
A14	**Protection from Payment Refusal**	F5	level of Enforcement	+	0.915343915
		F12	Delay in Progress payments	-	0.888888889
		F13	Having to chase payments	-	0.888888889
		F15	Opportunistic behaviour	-	0.878306878
		F11	Openness in mutual Dealings	+	0.883597884

A5	**Reduced Information Asymmetry**	F14	Effective and sufficient information flow	+	0.888888889
		F15	Opportunistic behaviour	-	0.894179894
A9	**Transparency**	F3	Accuracy of Information	+	0.920634921
		F10	Quality of Contract Administration	+	0.878306878
		F15	Opportunistic behaviour	-	0.904761905
A2	**Reduction of Fraud in Commercial Transactions**	F5	level of Enforcement	+	0.894179894
		F10	Quality of Contract Administration	+	0.91005291
		F15	Opportunistic behaviour	-	0.888888889
A4	**Automated Contract Execution**	F7	Contractual Complexity	-	0.904761905
		F12	Delay in Progress payments	-	0.899470899
		F13	Having to chase payments	-	0.857142857
A1	**Reduction in enforcement cost of Transactions**	F6	Reputation and Reliability of Contractual System	+	0.867724868
		F15	Opportunistic behaviour	-	0.904761905
A3	**Availability of Transaction Information for all parties**	F9	Stakeholder's Integrity	+	0.899470899
		F11	Openness in mutual Dealings	+	0.888888889
		F15	Opportunistic behaviour	-	0.904761905

3.2.2. Demographics of the Survey

The primary Questionnaire survey was intended to target Construction industry professionals such as Project managers, construction managers, contracts specialists, Design specialists and others from different regions of the world. 41% of the respondents had a master's degree, followed by 39% Doctorate and 18% respondents

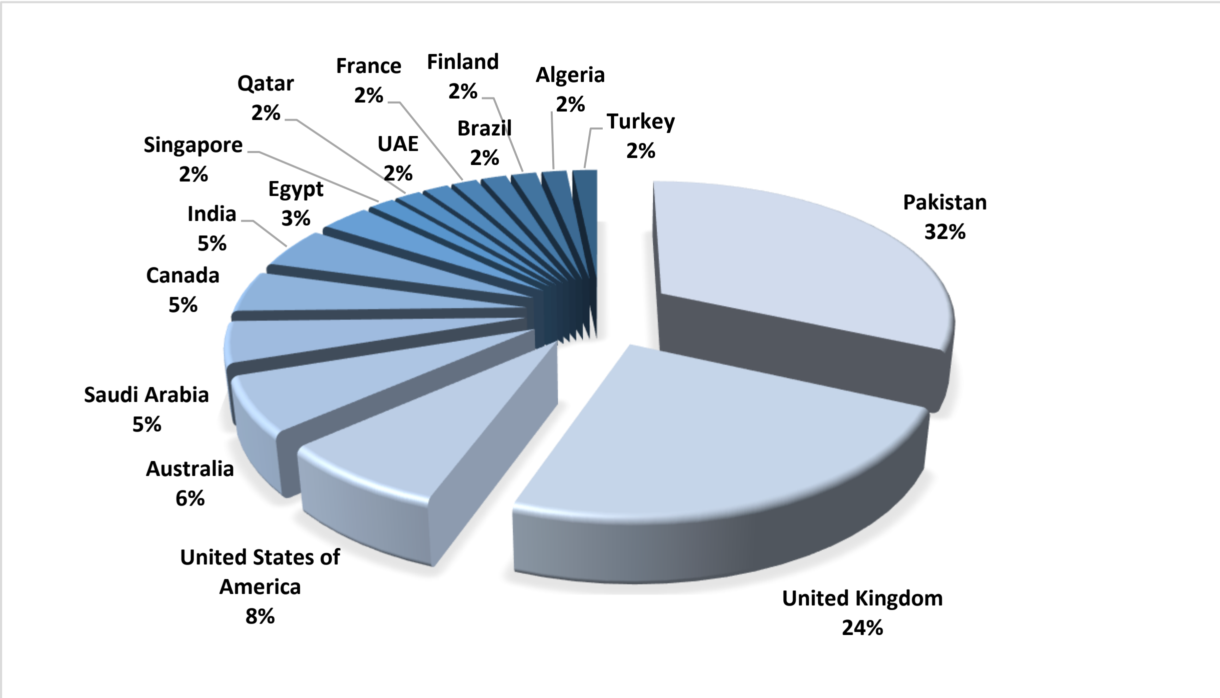

Figure 4: Regional distribution of responses

had bachelor's degree. In terms of years of experience, 37 % respondents had 11-15 years of experience, 34% had 16-20 years of experience while 16% respondents had 6-10 years of experience.

Most of the respondents belonged to Contractors, followed by 25% belonging to educational institutions and 21% belonging to consultants and 17% of them belonged to clients. This shows a healthy mix of organizational representation. Of 63 responses the major chunk of respondents was from Pakistan and United Kingdom with 32% and 24% representation. Followed by 8% responses from United States of America and 6%

responses from Australia. As the responses indicates, developed countries were targeted from the primary questionnaire survey. The detail can be seen in

Figure 4.

Table 6: Frequency distribution of primary survey responses

Profile	Frequency	Responses
Total Responses 63		
Field of Work		
Architectural	5	8%
Building design	12	19%
Infrastructure management	19	30%
Construction management	37	59%
Quantity surveying	12	19%
Engineering	12	19%
Site execution	12	19%
Project management	39	62%
Financial consultancy	1	2%
Years of Experience		
0 to 1	2	3%
1 to 5	5	8%
6 to 10	9	14%
11 to 15	25	40%
16 to 20	17	27%
>20	5	8%
Educational Background		

Bachelors	10	16%
Masters	28	44%
Doctorate	24	38%
Post-Doctorate	1	2%
Understanding of system-Based Trust		
No understanding at all	0	0%
Slight	14	22%
Moderate	37	59%
Exceptional	12	19%
Understanding of Smart Contracts		
No understanding at all	0	0%
Slight	10	16%
Moderate	47	75%
Exceptional	6	10%

3.3 Phase 3: System Dynamics Model

The final stage of research work was the establishment of system dynamics approach. The final shortlisted 29 relations (as shown in Table 5) were then used for developing the causal loop diagram indicating the significant loops. The causal loop diagram was developed using VENSIM® software. The process of developing CLD was a trial and error, repetitive and frequentative practice where all variables were connected to each other in relation and arranged using professional acumen. All nine Features of smart contracts, shortlisted in the 29 relations, were used as top variables. All features of smart contracts related to other variables (factors affecting system-based trust) along the trend of their impact. Either a negative or positive polarity is carried by each arrowhead. The negative arrow indicates an inverse relationship while the positive arrowhead indicates a direct relationship. The relationship arrows resulted in closed loops which were identified for their collective effect know as feedback mechanism are classified as either reinforcing or balancing loops. If the combined effect of a loop is multiplied in one direction, then the loop is labelled as a reinforcing loop while the loop with a combined balancing affect is labeled as a balancing loop. The development of system thinking diagram paved way for a system dynamics model. The CLD was first transformed into stock and flow diagram (SFD) and then finally into a SD model using VENSIM ® software. The SD model consists of three stocks that are chosen based on their degree of interconnectedness in the system. These stocks take inputs as inflows and produce outflows based on the equations known as flow rate. The data obtained from the survey and the relationship in CLD were used to develop the equations of these three stocks. After SD model was developed the boundary parameters were defined. 5 years duration was considered for the simulation period to check the behaviour of the system under smart contracts. The simulation results in behaviour over time graphs

(BOTGs). Then after satisfactory results were obtained, the model was check for its validity based on standard SD model validity test. These test check attribute of the model like parameter, boundary adequacy, structure verification and soundness of logic (Qudrat-Ullah and Seong, 2010). Furthermore, after these validation test, the SD model was also presented before industry professionals to obtain their expert opinion and to corroborate the findings of the model. The model was validated by experts belonging to different construction organizations. Finally, conclusions were drawn in the view of the system dynamics analysis and the research objectives.

Chapter 4: Results and Analysis

This chapter presents and explains the results and analysis of models developed using SD approach in this research. The CLD developed with all its reinforcing and balancing loops is explained here as well as the SD model with all its components and simulation graphs.

4.1 Causal Loop Diagram (CLD)

The CLD is based on findings from survey conducted for this research. It incorporates a total of nine (9) reinforcing and balancing loops, as shown as shown in

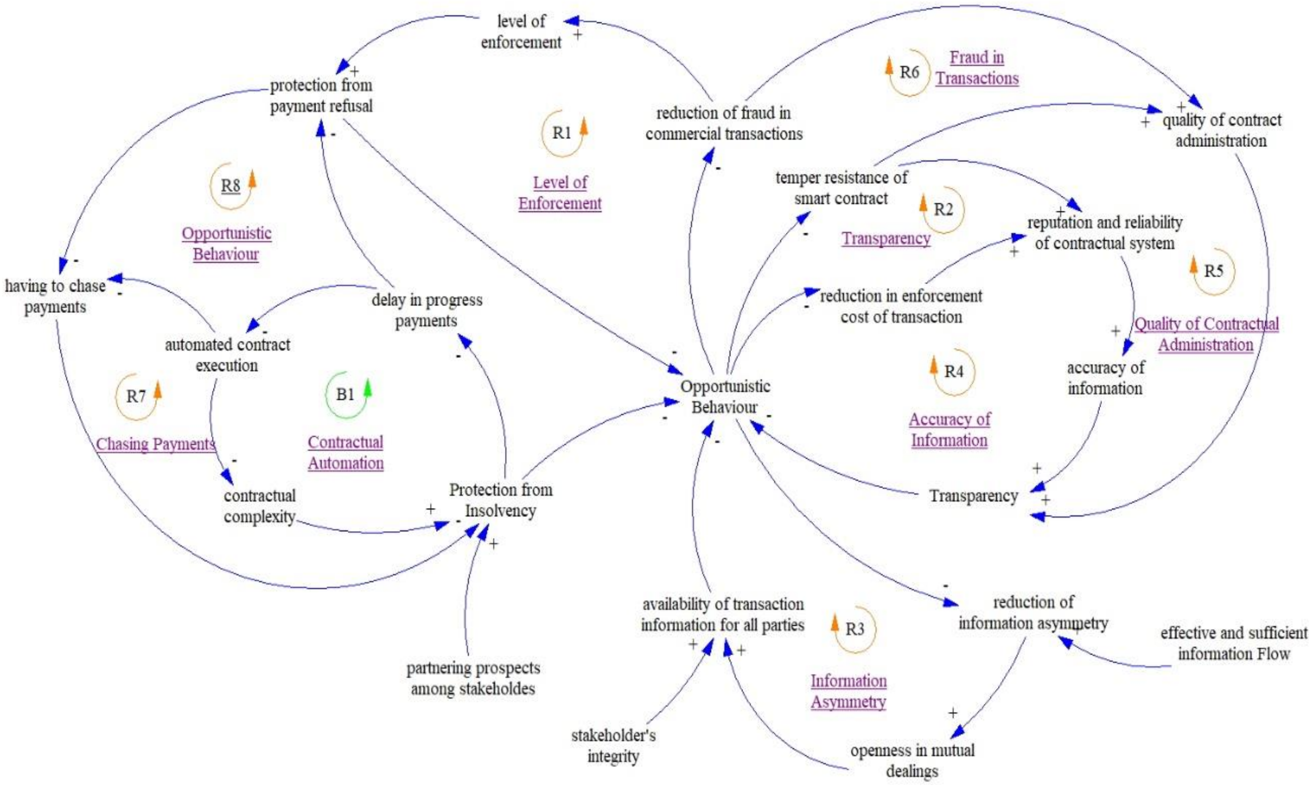

Figure 5: The CLD of Trust dynamics in the presence of a Smart contract

the ***Figure 5***. The reinforcing loops are labelled as 'R' whereas the balancing loops with balancing affects are designated with 'B'. The CLD consists of two types of variables: Features of smart contracts and factors affecting system-based trust in Construction Industry. All the loops are identified and explained below.

4.1.1. Balancing loop B1-Contractual Automation

Figure 8 implies that increase in "automation of a contract's execution" decreases the "contractual complexity". Due to this decrease in "complexity" via "automation" leads to an increase in "protection from insolvency" of constructors. As late payments, delayed payments and incomplete payments are some of the main reasons why contractors go into insolvencies, the automation of payments through a smart contract will significantly reduce insolvencies. The increased protection means that there are less chances of "delays in progress payment" in the system.

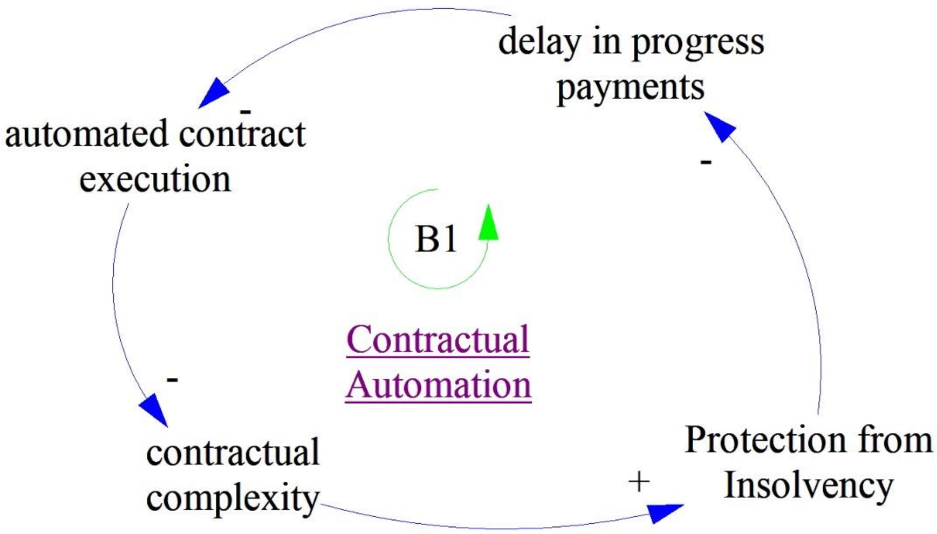

Figure 6 *Loop B1: Contractual Automation*

4.1.2. Reinforcing loop R1-Level of Enforcement

The "level of enforcement" of a contract increases, the more it provides contractors and sub-contractors "protection from payment refusal." When these contractors feel protected against payment refusals, they feel less inclined to indulge in "opportunistic behavior." Since opportunistic behavior is a motivation for fraud, if sufficient systemic barriers against the display of this behavior, then it reduces the chances of "fraud in commercial transactions." As this fraud is reduced, then it means that the "level of enforcement" of the contractual mechanism is increased. See **Figure 9**.

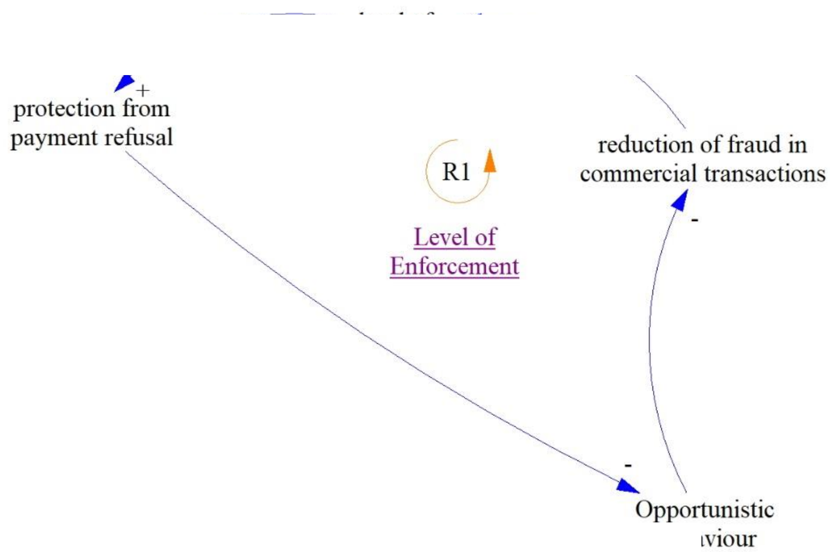

Figure 7: Loop R1- Level of Enforcement

4.1.3. Reinforcing loop R2-Transparency

This loop implies that "temper resistance" of SCs increases the "reputation and reliability of contractual system" which means there is more "accuracy of information" in the system. When stakeholders observe increase in "accuracy of information" then it improves a perception of "Transparency" in their mutual dealings and subsequently, it motivates them not to display “Opportunistic Behaviour.” Similarly, the increased “temper resistance” of smart contracts is also a motivation to increasingly stay away from displaying “Opportunistic Behaviour.” See **Figure 10**.

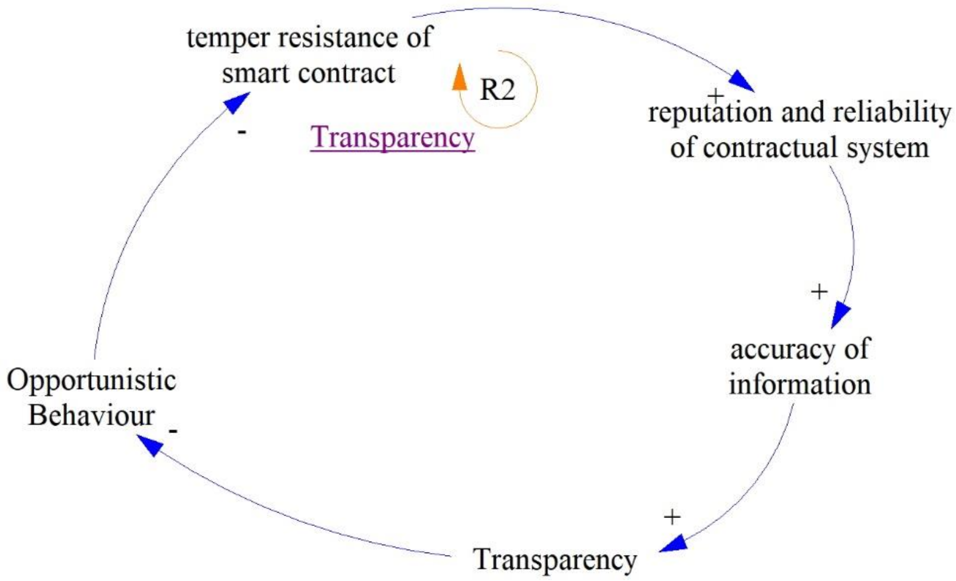

Figure 8: Loop R2 - Transparency

4.1.4. Reinforcing loop R3-Information Asymmetry

This loop in **Figure *11*** implies that as the “information asymmetry” among stakeholders reduces, the more it results in an increase in “openness in mutual dealings” which in turn increase the prospects of “availability of transaction information for all parties.” This results in the discouragement of shady business and favoritism which subsequently decreases the “Opportunistic Behaviour” of stakeholders thus again ensuring “reduction in information asymmetry.”

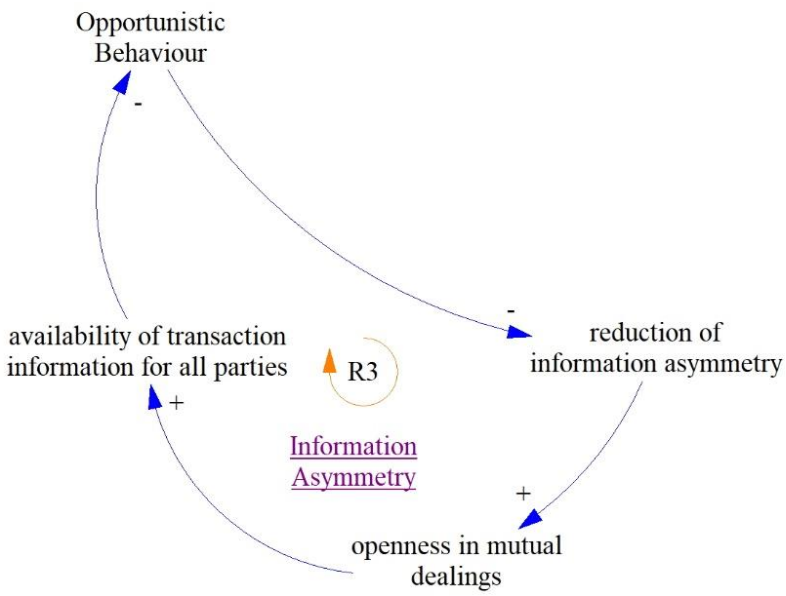

Figure 9: Loop R3 - Information Asymmetry

4.1.5. Reinforcing loop R4- Accuracy of Information

It implies that the "reduction in enforcement cost of transactions" increases the "reputation and reliability of the contractual system." Similarly, when the "reputation and reliability of contractual system" increases, so does the "accuracy of information"

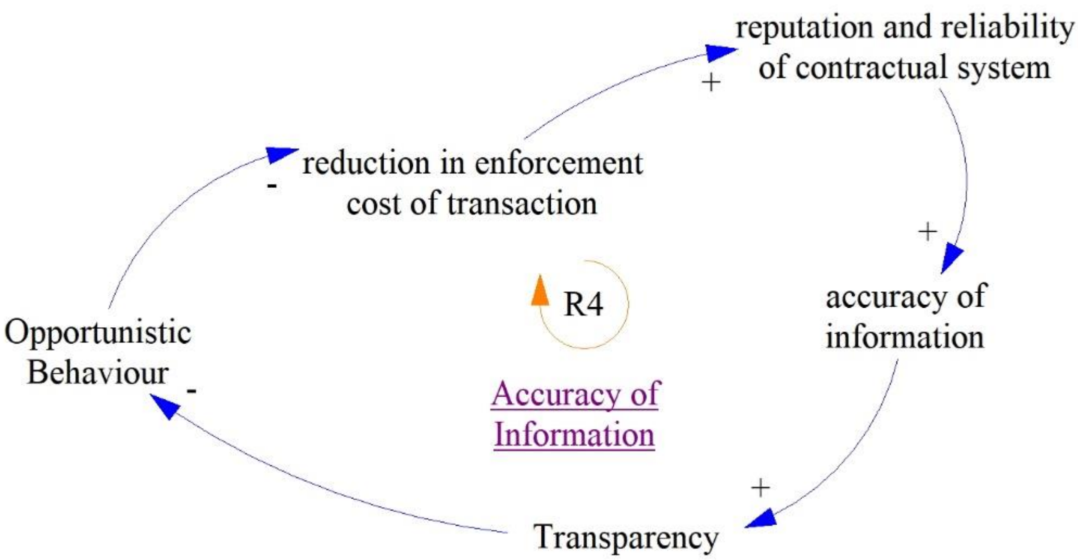

Figure 10: Loop R4 - Accuracy of Information

that is shared increases. A contract that ensures that contracting parties bear low financial burden and ensures the viability information equally for all parties is more likely to inculcate a sense of "Transparency" in the system. Hence, the "Transparency" offered by a smart contract will also improve with time. This "Transparency" then becomes a major force that increasingly discourage the parties from indulging in "Opportunistic Behaviour." See **Figure 12**.

4.1.6. Reinforcing loop R5- Quality of Contractual Administration

Loop in **Figure 13** illustrates that an increase in the "temper resistance of SCs" increases the "quality of contract administration" which in turn increases the "transparency" of the system. The more the contractual mechanism work in a transparent manner, it increases the trust of the stakeholders resulting in the reduction of behavior showing opportunism. This further motivates the contracting parties to improve the "temper resistance" as a feature of smart contracts.

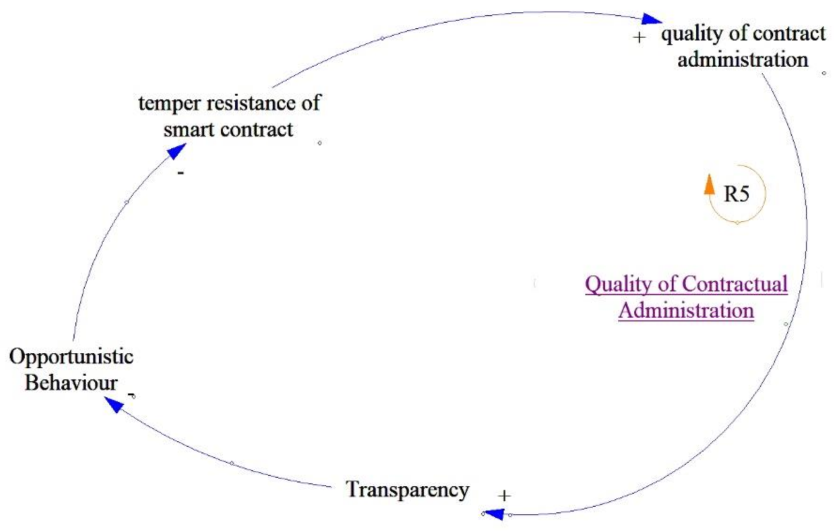

Figure 11: Loop R5 Quality of Contractual Administration

4.1.7. Reinforcing loop R6-Fraud in Transactions

Figure 14 shows a loop that implies that an increase in the "reduction of fraud in commercial transaction" increases the "quality of contracts administration." As the "quality of the contracts administration" increases in a project then it brings with it a sense of "Transparency" in the project. As discussed in previous loops, the relationship between "transparency" and "Opportunistic Behaviour" is negative or inversely proportional. This means that an increase in "Transparency" of the system and the contractual method, then it discourages or decreases the overall opportunistic tendencies of the stakeholders involved in the project.

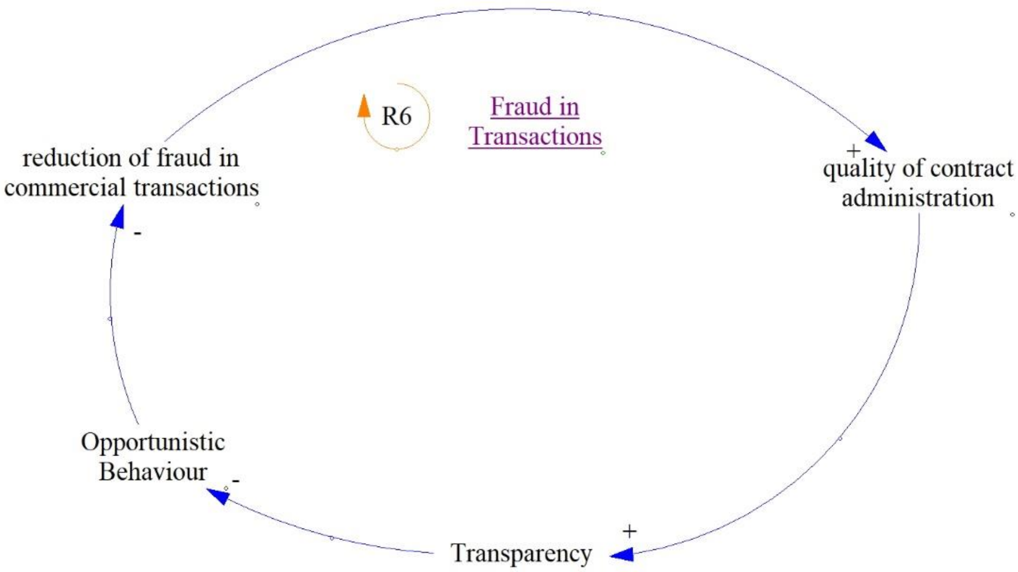

Figure 12: Loop R6 - Fraud in Transactions

4.1.8. Reinforcing loop R7-Chasing payments

Loop in **Figure 15** implies that a decrease in "having to chase payments" increasingly protects constructors and supplier from insolvencies. It is a common sight on construction projects that contractors are often seen chasing their own payments. This significantly affects their organizational structure as most small construction firms operate from one progress payment to another. “Protection from Insolvencies” is more when there is little “delay in the progress payments.” This is achieved through the “automation of smart contracts” where payments are automated and other stakeholders cannot delay or hold payments of constructors thus reducing their need to “chase payments.”

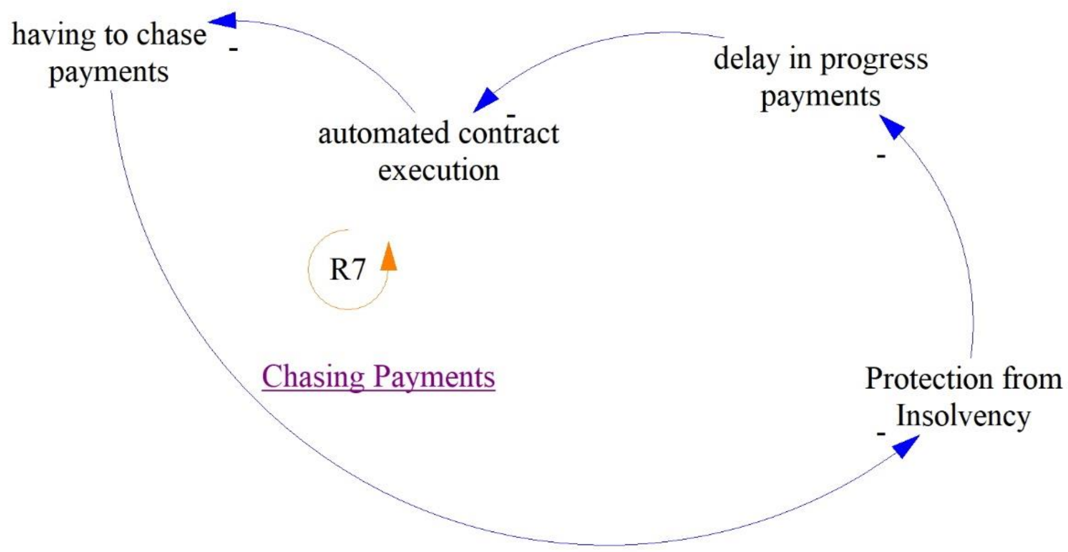

Figure 13: Loop R7 - Chasing payments

4.1.9. Reinforcing loop R8-Opportunistic Behaviour

Figure 16 implies that “reduction of fraud in commercial transactions” is increased due to increase in “level of enforcement.” Due to the increase in “level of enforcement” due to nature of smart contacts, the stakeholders are increasingly “protected from payment refusals.” The more the “protection from payment refusals”, the little time and energy will be spent on “chasing payments.” As increased “protection from payment refusal” ensures more “Protection from Insolvencies”, the impetus for stakeholders to indulge in “Opportunistic Behaviour” also decreases. This results in overall reduction of “fraud in commercial transactions.”

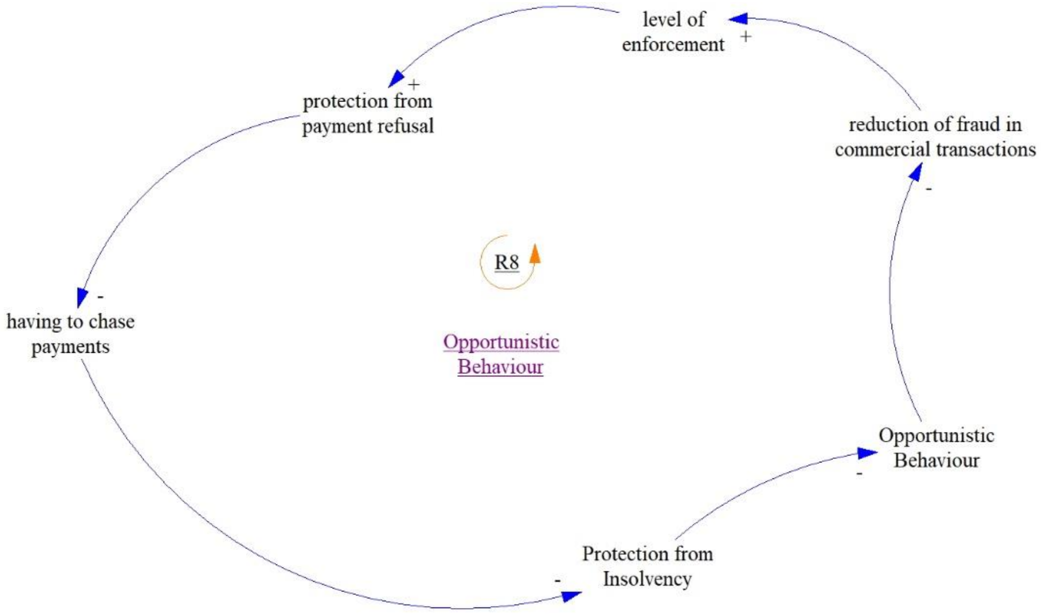

Figure 14: Loop R8 - Opportunistic behaviour

4.2 System Dynamics Model

After the development of causal loop diagram, the system dynamics model was developed using VENSIM® software. The system dynamics model consists of three main components (stocks): (a) Opportunistic Behavior, (b) Protection from Insolvency, and (c) Transparency, governed by inflows and outflows. The equations used in the system dynamics model were developed using the data collected through different surveys. The system dynamics model is shown in ***Figure 17***.

Inflow of Opportunistic Behavior = -(0.081*A15) - (0.083*A14) - (0.086*A9) - (0.089*A3) + (1*F27)

Outflow of Opportunistic Behavior = 1*F27

Inflow to Protection from Insolvency = (0.08*F43) - (0.078*F26) + (0.078*F1) + (1* A15)

Outflow to Protection from Insolvency = 1* A15

Inflow to Transparency = (0.088*F11) + (0.084*F19) + (1*A9)

Outflow to Transparency = 1*A9

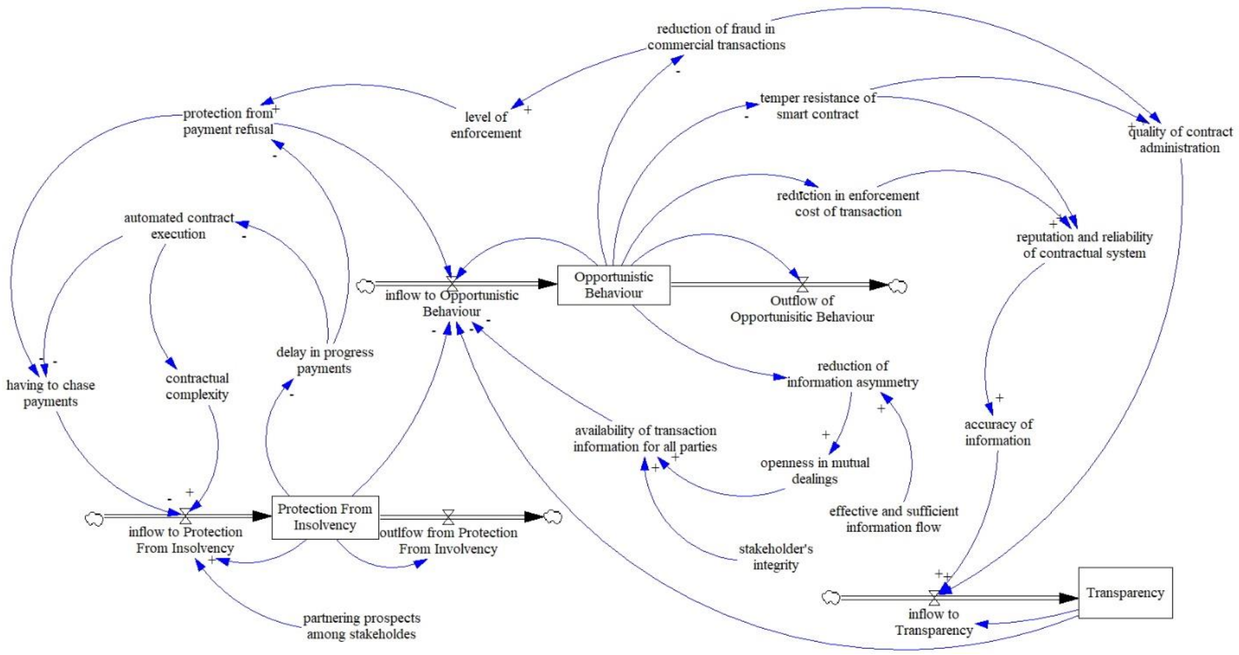

Figure 15: Systems Dynamics Model.

4.2.1. Simulation results and discussion

The simulation of the system's behavior was conducted over a period of five years, which is taken as the general project duration of a large-scale construction project. The movement along the curve of the simulation graphs are also explained. The simulation presents behavior over time graph (BOTGs). ***Figure 18*** shows the BOTGs of all the three stocks combined.

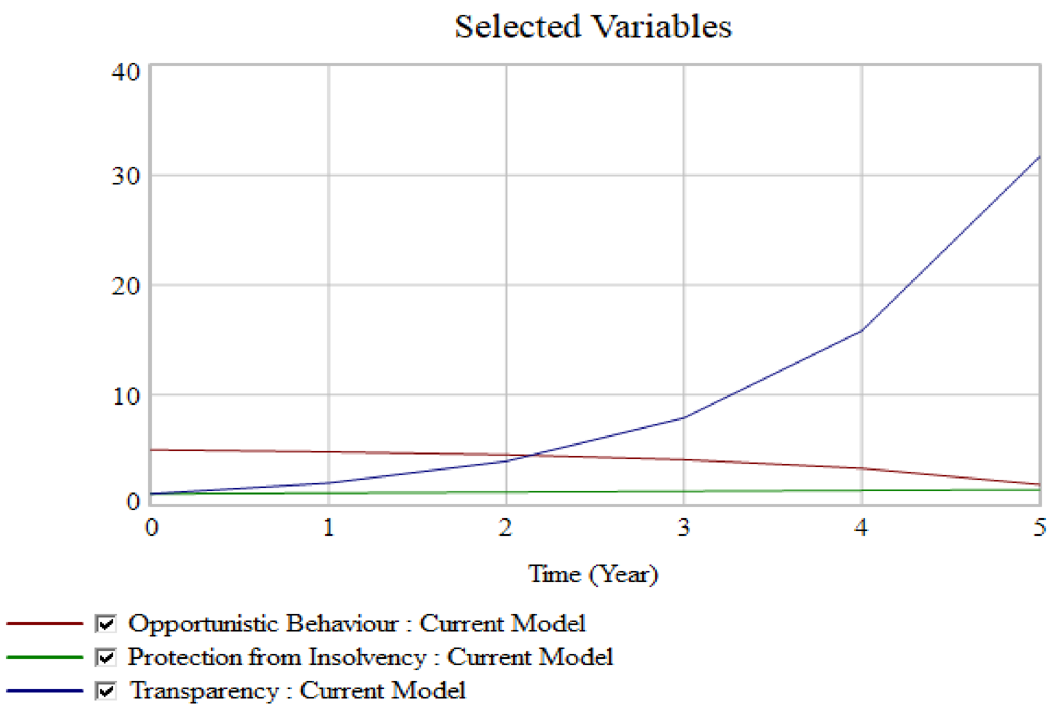

Figure 16: Simulation showing Behaviour over time of the three stocks.

The graph of 'Opportunistic Behavior' shows a draining process which implies that the factors in the loop are playing a negative role. Opportunistic Behavior is Maximum at first but with the passage of time it is decreasing; slowly in initial stages of the project and then rapidly gathers pace with the passage of time, decreasing

Figure 17: BOTG of the stock Opportunistic Behaviour

significantly till the end. The inflow of Opportunistic Behavior consisting of Protection from Insolvency, Protection from Payment Refusal, Transparency, and Availability of Transaction Information for all parties are collectively creating an effect that ends up reducing the Opportunistic Behavior in the system. Hence, these factors are the key to reducing the opportunistic behavior of the system. The simulation result for complexity is shown in **Figure 19**.

The graph of 'Protection from Insolvency' shows a multiplier effect which implies that the entities in the loop are playing a compounding role. Protection from Insolvency is minimum at first but with the passage of time it is increasing; there is a steady increase in initial days, and it continues with the passage of time, increasing till the end. The inflow of Protection from Insolvency consisting of Contractual Complexity, Having to Chase Payments, and Partnering Prospects among Stakeholders are increasing prospects of the Protection from Insolvency of the stakeholders in the system. To further increase the protecting from insolvency of the stakeholders, its

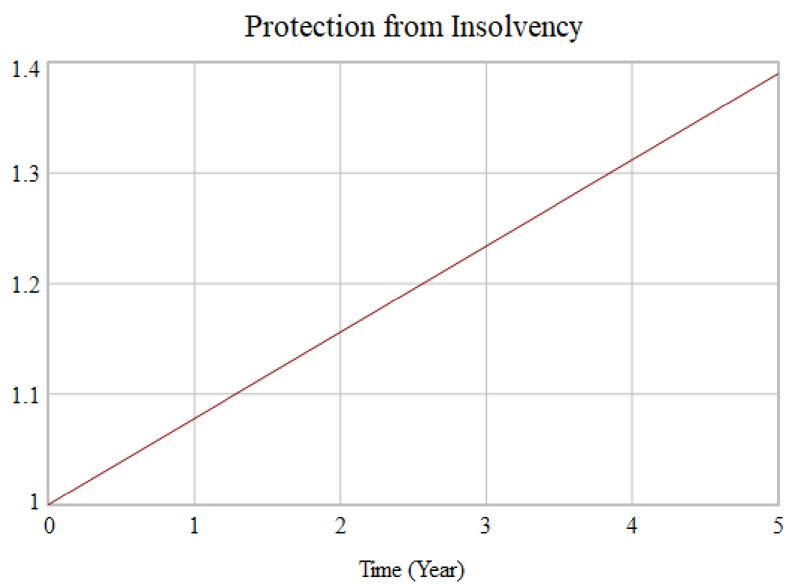

Figure 18: BOTG of the stock Protection from Insolvency

inflow variable needs to be catered for. The simulation result for Protection from Insolvency is shown in **Figure 20**.

The graph of 'Transparency' also shows a multiplier process which implies that the factors in the loop are playing a compounding role. Transparency is minimum at first but with the passage of time it is increasing; slowly in initial days and then rapidly with the passage of time, increasing with a second degree function till the end. The inflow of Transparency consisting of Accuracy of Information and Quality of Contract Administration are increasing Transparency of the system. In order to further increase the Transparency, the impact of these variables will have to be catered for. The simulation result for Transparency is shown in **Figure 21**.

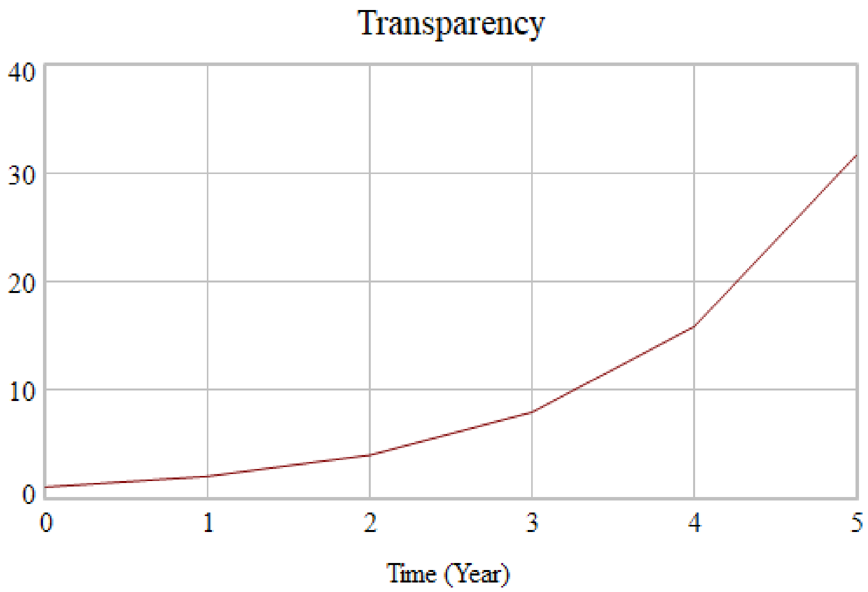

Figure 19: BOTG of the stock Transparency

4.2.2. Model Validation

Every system dynamics model is bound to address a certain specific problem and confidence on its application does not depend on its applicability to other problems (Sterman, 2002). The validation of any system dynamics model is purely the function of its purpose for which it was developed (Sterman, 2002). The purpose of this model was to replicate the complexity of relationship of blockchain-based SC with the trust dynamics among stakeholders during the life cycle of a project. Therefore, it is pertinent to valid the model for its boundary, structure, and its behavior in extreme conditions (Qudrat-ullah and Seong, 2010). For this purpose, the following four tests are used to validate the mode.

4.2.2.1. Boundary Adequacy Test

This test intends to answer three basic questions about a model; if all the necessary concepts or knowledge are endogenous to the structure, if the change in behavior of the model is significant under changing boundary conditions, if the results and recommendations change in case the boundary is stretched (Sterman, 2002). In this model, all concepts and entities are endogenous except partnering prospects among stakeholders, effective and sufficient information flow, and stakeholder integrity. Similarly, change in boundary conditions does not result in significant change in model behavior and same goes for the policy recommendation.

4.2.2.2. Structure Verification Test

The purpose of this test is to validate if the structure of the SD model is logical and consistent in its form and content. It is an important test that helps validate the system dynamics model. The current model is consistent in a sense that all variables have been identified through a through literature review and subsequently verified by field experts. SD model has been built upon causal loop diagram which was developed using the opinion of a diverse group of field and academic experts. The logic of CLD was again verified by experts for consistency and logic of causality among variables.

Therefore, it can be said that the SD model is logical, consistent, and closely mimics the complexity of the construction industry (Khan et al., 2016).

4.2.2.3. Parameter Verification Test

The parameters in the model need to be consistent in relevancy with descriptive and numerical knowledge of the system. This model satisfies this condition as the mathematical equations used int this model are causal strength and the polarity of interrelations. Both parameters were obtained through input from construction industry professionals.

4.2.2.4. Extreme Conditions Test

This tests the logic and structure of the system dynamics model in the event where extreme, yet possible values are assigned to the variables. The current model was assigned extreme condition values of up to 100% the initial values and it was observed

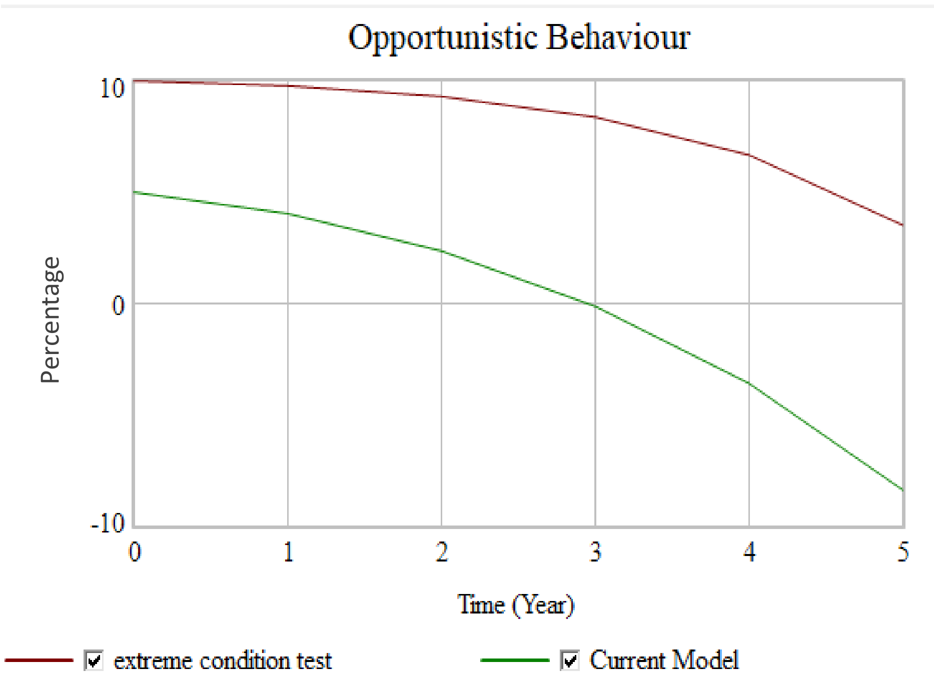

Figure 20: Extreme condition test for the stock Opportunistic Behaviour

that all the three stocks exhibited consistent behavior over the during of simulation (Tahir et al., 2021). The results are shown in below (see **Figure 22**, **Figure 23** and **Figure 24**)

Figure 22: Extreme condition test for the stock Protection from Insolvency

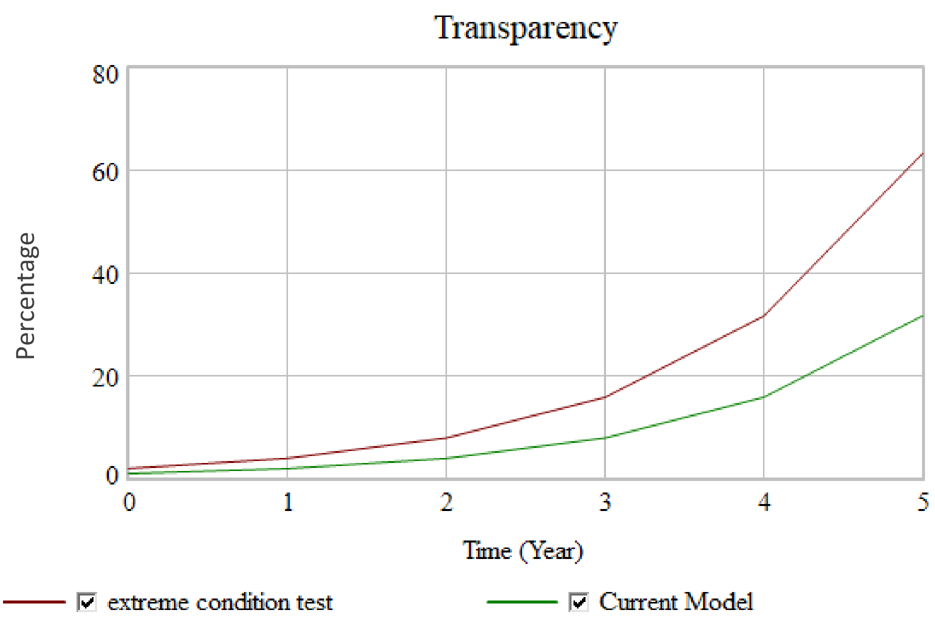

Figure 21: Extreme condition test for the stock Transparency

Chapter 5: Conclusion and Recommendations

The system dynamics model reflects a complex system that comprises of complex interconnecting components which helps apprehend Trust dynamics in the light of smart contracts as a substitute to the traditional contracts in construction industry. System dynamics approach is adopted to see the efficacy of smart contracts in enhancing system-based trust. To understand a complex problem, it is necessary to focus and understand the relationships and interconnectivity and not only the constituent parts in the whole system. The most important factors that affect system-based trust are Partnering among Stakeholders, Willingness to co-operate, Accuracy of Information, Frequency and openness of communication, level of Enforcement, Reputation and reliability, Contractual Complexity, Reciprocation of Trusting acts, Stakeholder's Integrity, Quality of Contract Administration, Openness in mutual Dealings, Delay in Progress payments, Having to chase payments, Effective and sufficient information flow, Opportunistic behavior and Information sharing. Whereas the most important features of smart contracts are Protection from Insolvency, Temper Resistance, Protection from Payment Refusal, Reduced Information Asymmetry, Transparency, Reduction of Fraud in Commercial Transactions, Automated Contract Execution, Reduction in enforcement cost of Transactions and Availability of Transaction Information for all parties. The involvement of multiple stakeholders with competing and often conflicting interests creates a relationship complexity that is either ineffectively addressed in the traditional contracts or engenders adversarial relationships. Recent studies have suggested the use of new innovative technologies to address this growing adversarial relationship among stakeholders to foster robust system-based trust. This research intended to address this concern by adopting blockchain based smart contracts as an alternative to the traditional contracts to see the impact on the inter-stakeholders' relationships and their subsequent trust in the system powered by smart contracts. Since trust is an intangible entity that cannot be quantified alone, system thinking approach was adopted using tools like causal loop diagram (CLD) and system dynamics (SD) model the relationship between system-based trust and smart contracts is studied.

To increase the trust of stakeholders in the system that they interact in, it was pertinent to ferret out the factors affecting this system-based trust. Similarly, to understand smart contracts better, main features of smart contracts were identified and then with the help of causal relationships, the impact of these features on system-based trust was studied. This research study contributes to the body of knowledge by assisting industry professionals to understand the dynamics of Trust in the dealings of the parties involved in construction projects and provides solution to address the problem of dearth of trust using new innovative technologies like smart contracts. This research study has practical implications where the adoption of smart contracts instead of or in addition to traditional contracts can help improve the overall trust of stakeholders in the contractual system.

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