

**DEVELOPMENT OF A DECENTRALIZED AND
AUTOMATED CONTRACT MANAGEMENT SYSTEM
FOR CONSTRUCTION PROJECTS**

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AUTOMATED CONTRACT MANAGEMENT SYSTEM
FOR CONSTRUCTION PROJECTS**

by

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(2019CEZ8240)

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*Submitted in fulfilment of the requirements of the degree of
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*I dedicate this work to the Almighty,
my grandfather - Late Prof. S. L. Gupta,
and my teacher - Late Prof. K.C. Iyer,
for their blessings, values and
knowledge.*

CERTIFICATE

This is to certify that the thesis entitled, “**Development of a Decentralized and Automated Contract Management System for Construction Projects**”, submitted by **Ms. Purva Gupta** (Entry No. 2019CEZ8240) to the Department of Civil Engineering, Indian Institute of Technology, Delhi, for the fulfilment of the requirements of the award of the degree of Doctor of Philosophy, is a bonafide record of the research work carried out by her.

She has worked under my supervision and guidance and has fulfilled the requirements for the submission of this thesis, which, to my knowledge, has reached the requisite standard. The contents of this thesis, in part or full, have not been submitted to any other University or Institute for the award of any degree or diploma.

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Ultimately, I want to underscore that a doctoral research journey is more than just an academic milestone. Such accomplishments are seldom the result of solitary efforts but are instead the product of many individuals propelling us forward to achieve our goal.

Purva Gupta
New Delhi, May 2024

ABSTRACT

With the economy and businesses worldwide increasingly driven by automation and digitization, there is an enormous amount of digital information and data flooding in projects. The increasing exchange of digital information and assets without much regard to contractual requirements has resulted in various data corruption, privacy, and security issues escalating to claims and disputes. The need for a well-structured legal and contractual framework is seen as a necessary pre-condition for successful collaboration in projects. Hence, there is a need to institute reforms in the existing contracting system to achieve a more efficient, collaborative, and transparent system. However, little research has been done on the digitalization of the contracting process, which continues to be traditional. An efficient legal and contractual system requires an environment that supports trust and sophistication in data from multiple stakeholders. If the contracts are executed in a transparent and decentralized environment, with due consensus of stakeholders, then trust is in-built into the system by design.

Blockchain technology is increasingly gaining traction across different aspects of the business world due to its intrinsic qualities of transparency and security. Consequently, this research is driven by the motivation to explore how blockchain technology can be integrated into the current contracting processes. The present study is one of the first to develop a digital and automated contract management system leveraging blockchain technology and smart contracts. The research pursues a twofold goal: 1) automation of the construction contract clauses using blockchain-based smart contracts and 2) decentralization and automation of the contract implementation system. The computable contract clauses would enhance certainty and reduce the scope for misinterpretation and ambiguity for different parties, thereby mitigating many

afterthought claims. Simultaneously, the blockchain-based decentralized and secured environment would improve collaboration between the stakeholders, incorporating transparency and accountability.

The research endeavors to develop a decentralized and automated contract management system encompassing the following - (1) a decentralized permissioned network of stakeholders with well-defined roles and approval workflow, (2) automated contract execution based on pre-defined conditions using smart contract clauses, and (3) preservation of transaction history integrity with time stamps through a secured blockchain-based data structure. Design science research methodology is adopted to achieve the goal. Based on systematic literature review, the problem statement of the research is defined. Subsequently, the rationale for integration of blockchain technology into the contracting system is established. Following this, a conceptual model for the proposed decentralized contract management system is developed comprising three key features: 1) Automated smart legal contracts, 2) Decentralized blockchain network, and 3) Digital blockchain platform. The entire system involves multiple layers of digital and communication technologies which are represented in the form of an architecture stack. Next, an integrated framework for blockchain-based contract execution is presented, outlining the process of information exchange and contract administration throughout all project phases, including tendering, design, execution, and maintenance.

The practicality, limitations, and advantages of the suggested contracting system are examined through its application in a real-life construction megaproject case. A conceptual blockchain network is established, comprising the key project stakeholders, using a permissioned blockchain architecture. The roles, responsibilities, and access controls of the stakeholders within the network are defined using the RACI

(Responsible Accountable Consulted and Informed) matrix. Computable and automated smart legal contract clauses are formulated for the industry and academia, focusing on the ‘extension of time, delay compensation, and variation’ that can be applied to all projects worldwide, regardless of the complexity or scale.

Further, a prototype of the proposed contracting system is developed, showing its applicability, feasibility, and ease of use. This prototype is then presented to a group of experts in contract management for megaprojects. Their feedback was sought through a follow-up questionnaire post-demonstration based on two criteria: user-based requirements and system attributes. The validation of the prototype by industry experts confirms the proposed system as a workable solution to enhance cooperation and improve traceability and accountability. The case study of a legal construction dispute is used to triangulate the findings and demonstrate the application of the system in early dispute identification and avoidance.

This study offers researchers, lawyers, and practitioners an insight into the interdisciplinary confluence of engineering, law, and technology. It offers a novel approach for future research across a diverse array of sectors and domains. Some of the perceived benefits of the research are:

- Reduced transaction time and costs by digitization;
- Enhanced security and authenticity;
- Trust distributed equally across the contracting parties;
- Computable and flexible contract conditions;
- Self-executing and transparent payments based on performance;
- Standardized risk allocation; and

- The ability to trace information and determine accountability in the event of claims and disputes.

Keywords: automation; blockchain; collaboration; computable contracts; contract management; digitalization; dispute cause; dispute avoidance; megaprojects; smart contract; stakeholder management.

सारांश

दुनिया भर में अर्थव्यवस्था और व्यवसाय तेजी से स्वचालन और डिजिटलीकरण द्वारा संचालित हो रहे हैं, इसलिए परियोजनाओं में भारी मात्रा में डिजिटल जानकारी और डेटा है। संविदात्मक आवश्यकताओं की परवाह किए बिना डिजिटल जानकारी और परिसंपत्तियों के बढ़ते आदान-प्रदान के परिणामस्वरूप विभिन्न डेटा-संबंधी, गोपनीयता और सुरक्षा संबंधी समस्याएं पैदा हो गई हैं। परियोजनाओं में सफल सहयोग के लिए एक अच्छी तरह से संरचित कानूनी और संविदात्मक ढांचा एक महत्वपूर्ण आवश्यकता है। इसलिए, अधिक कुशल, सहयोगात्मक और पारदर्शी प्रणाली प्राप्त करने के लिए मौजूदा अनुबंध प्रणाली में सुधार आवश्यक है। हालाँकि, मौजूदा अनुबंध प्रणाली पारंपरिक बनी हुई है, और अनुबंध प्रक्रिया के डिजिटलीकरण पर बहुत कम शोध हुआ है। एक कुशल कानूनी और संविदात्मक प्रणाली के लिए ऐसे वातावरण की आवश्यकता होती है जो कई हितधारकों के डेटा में विश्वास और परिष्कार का समर्थन करता हो। यदि अनुबंधों को हितधारकों की उचित सहमति के साथ पारदर्शी और विकेंद्रीकृत वातावरण में निष्पादित किया जाता है, तो डिजाइन द्वारा सिस्टम में विश्वास अंतर्निहित होता है।

ब्लॉकचेन तकनीक पारदर्शिता और सुरक्षा के अपने आंतरिक गुणों के कारण व्यापार जगत के विभिन्न पहलुओं में तेजी से लोकप्रियता हासिल कर रही है। नतीजतन, यह शोध यह पता लगाने के लिए प्रेरित है कि ब्लॉकचेन तकनीक को वर्तमान अनुबंध प्रक्रियाओं में कैसे एकीकृत किया जा सकता है। वर्तमान अध्ययन ब्लॉकचेन प्रौद्योगिकी और स्मार्ट अनुबंधों का लाभ उठाते हुए एक डिजिटल और स्वचालित अनुबंध प्रबंधन प्रणाली विकसित करने वाले पहले अध्ययनों में से एक है। इस शोध के दो लक्ष्य हैं: 1) ब्लॉकचेन-आधारित स्मार्ट अनुबंधों का उपयोग करके निर्माण अनुबंध खंडों का स्वचालन और 2) अनुबंध कार्यान्वयन प्रणाली का विकेंद्रीकरण और स्वचालन। स्वचालित अनुबंध खंड निश्चितता बढ़ाएंगे और विभिन्न पक्षों के लिए गलत व्याख्या और अस्पष्टता

की गुंजाइश कम करेंगे, जिससे विवाद कम होंगे। इसके साथ ही, ब्लॉकचेन-आधारित विकेन्द्रीकृत और सुरक्षित वातावरण पारदर्शिता और जवाबदेही को शामिल करते हुए हितधारकों के बीच सहयोग में सुधार करेगा।

इसलिए, इस शोध में, हम निम्नलिखित को शामिल करते हुए एक विकेन्द्रीकृत और स्वचालित अनुबंध प्रबंधन प्रणाली विकसित करने का प्रयास कर रहे हैं - (1) स्पष्ट रूप से परिभाषित भूमिकाओं और अनुमोदन प्रक्रिया के साथ हितधारकों का एक विकेन्द्रीकृत अनुमति प्राप्त नेटवर्क, (2) स्मार्ट अनुबंध खंडों का उपयोग करके पूर्व-परिभाषित अनुबंध शर्तों के आधार पर स्वचालित अनुबंध निष्पादन , और (3) एक सुरक्षित ब्लॉकचेन-आधारित डेटा संरचना के माध्यम से डेटा अखंडता का संरक्षण। लक्ष्य को प्राप्त करने के लिए इस शोध में डिज़ाइन विज्ञान अनुसंधान पद्धति को अपनाया गया है। शोध का समस्या कथन व्यवस्थित साहित्य समीक्षा के आधार पर परिभाषित किया गया है। फिर अनुबंध प्रणाली में ब्लॉकचेन प्रौद्योगिकी के एकीकरण का औचित्य स्थापित किया गया है। इसके बाद, प्रस्तावित विकेन्द्रीकृत अनुबंध प्रबंधन प्रणाली के लिए एक वैचारिक मॉडल विकसित किया गया है जिसमें तीन प्रमुख विशेषताएं शामिल हैं: 1) स्वचालित स्मार्ट कानूनी अनुबंध, 2) विकेन्द्रीकृत ब्लॉकचेन नेटवर्क, और 3) डिजिटल ब्लॉकचेन प्लेटफॉर्म। पूरे सिस्टम में डिजिटल और संचार प्रौद्योगिकियों की कई परतें शामिल हैं, जिन्हें आर्किटेक्चर स्टैक के रूप में दर्शाया गया है। इसके बाद, ब्लॉकचेन-आधारित अनुबंध निष्पादन के लिए एक एकीकृत ढांचा प्रस्तुत किया गया है, जिसमें निविदा, डिज़ाइन, निष्पादन और रखरखाव सहित सभी परियोजना चरणों में सूचना विनिमय और अनुबंध प्रशासन की प्रक्रिया को रेखांकित किया गया है।

प्रस्तावित अनुबंध प्रणाली के व्यावहारिक अनुप्रयोग, सीमाओं और लाभों को निर्धारित करने के लिए, इसे वास्तविक जीवन के निर्माण मेगाप्रोजेक्ट मामले में लागू किया है। एक सैद्धांतिक

ब्लॉकचेन नेटवर्क विकसित किया है, जिसमें एक अनुमति प्राप्त ब्लॉकचेन आर्किटेक्चर का उपयोग करके प्रमुख परियोजना हितधारकों को शामिल किया गया है। RACI (जिम्मेदार जवाबदेह परामर्श और सूचित) मैट्रिक्स का उपयोग नेटवर्क के भीतर हितधारकों की भूमिकाओं, जिम्मेदारियों और पहुंच नियंत्रण को परिभाषित करने के लिए किया है। स्वचालित स्मार्ट कानूनी अनुबंध खंड तैयार किए गए हैं, जो 'समय के विस्तार, देरी मुआवजे और मूल्य भिन्नता' पर ध्यान केंद्रित करते हैं, जिन्हें जटिलता या पैमाने की परवाह किए बिना दुनिया भर में सभी परियोजनाओं पर लागू किया जा सकता है।

प्रस्तावित अनुबंध प्रणाली का एक प्रोटोटाइप विकसित किया गया, जो इसकी प्रयोज्यता, व्यवहार्यता और उपयोग में आसानी को दर्शाता है। फिर इस प्रोटोटाइप को विशेषज्ञों के एक समूह के सामने प्रस्तुत किया और उनकी प्रतिक्रिया दो मानदंडों के आधार पर प्रदर्शन के बाद एक अनुवर्ती प्रश्नावली के माध्यम से मांगी गई: उपयोगकर्ता-आधारित आवश्यकताएं और सिस्टम विशेषताएं। उद्योग विशेषज्ञों द्वारा प्रोटोटाइप का सत्यापन सहयोग बढ़ाने और जवाबदेही में सुधार के लिए एक व्यावहारिक समाधान के रूप में प्रस्तावित प्रणाली की पुष्टि करता है। प्रारंभिक विवाद पहचान और परिहार में प्रणाली के अनुप्रयोग को केस अध्ययन का उपयोग करके प्रदर्शित किया गया है।

यह अध्ययन शोधकर्ताओं और उद्योग जगत को इंजीनियरिंग, कानून और प्रौद्योगिकी के अंतःविषय संगम में एक अंतर्दृष्टि प्रदान करता है। इसके अलावा यह विभिन्न प्रकार के क्षेत्रों में भविष्य के अनुसंधान के लिए एक नया दृष्टिकोण प्रदान करता है। अनुसंधान के कुछ अनुमानित लाभ हैं:

- डिजिटलीकरण से समय और लागत में कमी;
- सुरक्षा और प्रामाणिकता में वृद्धि;

- अनुबंध पक्षों में समान रूप से वितरित विश्वास;
- स्व-निष्पादन योग्य और स्वचालित अनुबंध;
- तेज़ और पारदर्शी भुगतान;
- मानकीकृत जोखिम आवंटन; और
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ABBREVIATIONS

ADB	Asian Development Bank
AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
API	Application programming Interface
BFT	Byzantine Fault Tolerant
BIM	Building Information Modeling
CFT	Channel Configuration
CFT	Crash Fault Tolerant
CLA	Client Application
DAB	Dispute Adjudication Board
DFC	Dedicated Freight Corridors
DFCCIL	Dedicated Freight Corridors Corporation of India Ltd.
DLT	Distributed Ledger Technology
DRB	Dispute Review/Resolution Board
DSL	Domain Specific Language
DSR	Design Science Research
EBIT	Earnings Before Interest and Taxes
EDFC	Eastern Dedicated Freight Corridor
EDMS	Electronic Document Management System
EoT	Extension of Time
FIDIC	Fédération Internationale des Ingénieurs Conseils
FIR	Fourth Industrial Revolution
GCC	General Conditions of Contract
GDP	Gross Domestic Product
HLF	Hyperledger Fabric
ICT	Information and Communication Technology
IoT	Internet of Things
IPC	Interim Payment Certificate
IR	Indian Railways
JICA	Japan International Cooperation Agency
LD	Liquidated Damages
MoR	Ministry of Railways

MS	Milestone
MSP	Membership Service Provider
NC	Network Configuration
P2P	Peer to Peer
PCC	Particular Conditions of Contract
PMC	Project Management Consultant
POW	Proof of Work
POS	Proof of Stakes
PPP	Public Private Partnership
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PV	Price Variation
RACI	Responsible Accountable Consulted and Informed
RFID	Radio-Frequency Identification Devices
RFP	Request for Proposal
RFQ	Request for Qualification
ROW	Right of Way
SC	Smart Contract
SDK	Software Development Kit
SPV	Special Purpose Vehicle
VS	Visual Studio
WB	World Bank
WDFC	Western Dedicated Freight Corridor

GLOSSARY

Application Programming Interface: It is a software intermediary with a set of definitions and protocols that enables different applications to communicate with each other.

Block: It is the building block of Object-Oriented Programming. It may be a process, a chunk of data, or a more abstract entity. Object is an instance of a class.

Blockchain: It is a type of distributed ledger technology that uses a sequential and linked structure of blocks to store data and secure it with a cryptographic hash.

Compiler: A computer software that translates the source code from a programming language into machine code that can be executed by the computer.

Container: A container is a standalone object that holds everything an application needs to execute, including libraries, resource files, and configuration files.

Data Model: A data model provides a framework for data, organizes data elements, and standardizes how the data elements relate to one another.

Distributed Ledger Technology: It is a technology that supports distributed and decentralized storage of transactions in real-time.

Docker: Docker is a platform designed to help developers build, share, and run container applications.

Domain-Specific Language: A programming language specialized to a particular application or domain.

Internet of Things: It is a network of physical devices (embedded with sensors) interconnected with each other and the computing systems. They communicate and exchange data with each other using wireless or wired systems.

Object-Oriented Programming (OOP): A computer programming model that organizes software design around data or objects rather than functions and logic.

Oracle: Blockchain oracles are entities that allow blockchain to connect with the off-chain data on external systems from the real world.

Parser: A parser is part of a compiler that breaks source code into small sections of tokens and analyzes it to ensure that the source code is syntactically correct, meaning it adheres to the rules and structure of the language in which it is written.

Plug-in: A software plug-in is a type of program module or file that adds functionality to the software product.

Smart Contract: A software code on the blockchain network that self-executes when pre-defined conditions are met.

Software Development Kit: A set of software development tools in one installable package specific to a particular platform.

Standard Programming Language: General purpose programming languages that can be used across domains. (e.g. C, C++, Java, Python).