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Framework Design of Smart Contracts-based Building Information Modeling Contracts Management in Material Supply Chain

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Abstract

Disputes in the construction industry occur from time to time. The development of the building information model enables the information in the process of project execution in the construction industry to be stored in the same model, which can find appropriate communication channels for disputes between different parties involved in engineering projects. As an emerging technology, Blockchain has received wide attention and is widely used in various fields because of its distributed storage, decentralization, and de-trust characteristics. Furthermore, smart contracts technology provides a new solution to the existing difficulties of disputes in the construction engineering industry from the perspective of replacing traditional contracts. Based on the research of Blockchain and smart contracts technology, this paper analyzes the feasibility of applying Blockchain and smart contracts to contracts management of the construction information model and discusses the implementation plan of combining Blockchain and contracts management of the construction information model with the actual scenario of material supply in the construction industry, choosing Ethereum blockchain platform as the underlying architecture and adopting " The development of smart contracts for construction material supply is carried out by adopting the "on-chain off-chain" data storage and business interaction method, and the specific design and implementation are carried out from the perspectives of system architecture, system deployment, contracts invocation mechanism, and contracts function.

Keywords: Smart Contracts, Building Information Modeling, Material Supply Chain, Blockchain

1. Introduction

The construction industry is usually the pillar industry of a country to support national economic growth. With the accelerating progress of social development, the competition among construction enterprises has become more and more fierce, which at the same time put forward higher requirements for growth. Under such a situation, construction enterprises, to improve their own enterprises' competitiveness, began to address the problems of construction enterprises to manage, from the initial rough to acceptable type. However, with the processing of project management, there will be much credibility of the BIM model to be verified, and the BIM model is easily tampered with by unrelated people because many people are using and building the model. In the construction industry, construction projects generally have problems such as project overrun, insufficient budget, high construction costs, etc. Moreover, since the cost of construction materials occupies a larger share of the total cost, construction enterprises often use jerry-building to obtain greater profits to gain more profits, so they need to form a unified management of material supply in the project construction process.

Blockchain technology has been a popular technology in information technology research in recent years. In the decade since its development, it has rapidly developed and become one of the representatives of the new generation of information technology [1], [2], [3]. In simple terms, blockchain is a distributed ledger. In the whole blockchain network, this "ledger" records the data of all "transactions" on the web, and all network nodes keep this "ledger" synchronously through distributed storage technology, consensus mechanism, peer-to-peer transmission technology, etc. All network nodes synchronously keep this "ledger" through distributed storage technology, consensus mechanism, peer-to-peer transmission technology, etc. The data content is secured by cryptography technology for transmission and access, thus making all nodes maintain the consistency of ledger data. Blockchain is an innovative application model with the characteristics of decentralization and data im- mutability. From the development trend of blockchain technology in the past ten years since its birth, blockchain can be divided into three development stages: blockchain 1.0, blockchain 2.0, and blockchain 3.0 [4]. The main application of stage 1.0 is a digital currency; the main application of stage 2.0 is smart contracts; the main feature of stage 3.0 is a programmable society, at which web 3.0 will land time blockchain applications in various industries and fields of society. For the many pain points of building information model applications and material management in the construction industry, the tamper-proof characteristic of blockchain is highly suitable for anti-tampering building information models and the smart contracts management of the material supply chain. In the material management of smart contracts technology, the material data is extracted and stored, and the process of managing the demand, transportation, acceptance, and payment of materials reduces the disputes arising from the contracts' payment issues during the project implementation.

2. Literature Review

To find out the relative work with the keywords of smart contracts, building information modeling, and material supply chain in the database of SCOPUS, then reached the viewpoints as follows:

2.1 Application of Smart Contracts in Many Areas

[1] Propose TENET, a pluggable and configurable confidential smart contracts framework. [2] create ScrawlD: an annotated data set of real-world smart contracts taken from the Ethereum network. Trust issues seriously affect users' willingness to participate and data credibility. The creditable and distributed incentive mechanism based on Hyperledger Fabric (HF-CDIM) is proposed [3]. [4] present techniques to investigate transactions in uncharted cryptocurrencies and services. [5] Describe a method for runtime monitoring of blockchain executions. [6] Evaluate six upgradeability patterns. The advantage of collaborative machine learning (CML) over most conventional ML lies in decentralized nodes or agents that result in better model performance and generalization [7]. [8] present POSE – a practical off-chain protocol for smart contracts that address existing solutions' shortcomings. [9] Propose a scalable architecture called DeBlock for data sharing in a trusted way among unreliable actors. This study aimed to build a dynamic supervision model suited to the circulation characteristics of the rice supply chain and implement construction, analysis, and verification [10].

2.2 The Difficulties of the Building Information Modeling Contracts Management

The literature review shows limited research investigating the utilization of Augmented Reality (AR) to improve learning and understanding of architectural representations, precisely section views. [11] present an AR system prototype (BIMxAR), its new and accurate building-scale registration method, and its novel visualization features that facilitate the comprehension of building construction systems, materials configuration, and 3D section views of complex structures. Integrating AR, Building Information Modeling (BIM), and physical facilities. Three main applications are evident from a critical analysis of existing ontologies: (1) key performance indicator calculation, (2) building performance improvement, and (3) fault detection and diagnosis. Critical gaps are a holistic ontology for SCCx and insight into how such approaches should be evaluated [12]. [13] propose using logic-based executable formalisms (CLP and Constraint ASP) to couple BIM models with advanced knowledge representation and reasoning capabilities. [14] present a workflow for seamless real-time navigation and 3D thermal mapping in combined indoor and outdoor environments in a global reference frame. [15] aim to develop a conceptual BC-enhanced IM for HTD (BC-HTD) framework that addresses the challenges of HTD and promotes health and well-being. [16] aims to examine the last results of experimental and interdisciplinary research started in the archaeological area of Pompeii by "Federico. II" University in 2010, on the enlarged fruition in Pompeii. The main framework of green construction management based on building information modeling (BIM) is a construct, and the related theories of BIM and green buildings are researched in more detail [17]. The basis of the framework is to quantify and reduce these emissions. This comparative study is presented be- tween two buildings that could have a sanitary or any other type of use [18]. An autonomous LoRa-based system for monitoring a construction site in Lungro, Calabria, Italy, is presented [19]. The aim of [20] is to develop an advanced Building Information Modeling (BIM) model for automating and optimizing the design of building layouts and structural elements to reach minimum construction cost while abiding by the functionality constraints of the architectural design.

2.3 Material Supply Chain within the Building Information Modeling Contracts Management

To improve the recycling efficiency of C&D waste and promote the process of C&D waste management [21] propose a dual-channel recycling problem of C&D debris from the perspective of supply-chain operation. Aiming to study the impact of the selection of recycling channels and the government's economic intervention on pricing decisions. [22] develop a food-related Nr flow model based on a material flow analysis for the Beijing-Tianjin-Hebei region (BTH) during the years 1978-2017 [23].

3. Research Methodology

3.1 Smart Contracts Development Platform

Because smart contracts technology is installed and runs on a blockchain platform, The manager must choose a suitable blockchain platform for material supply contracts management in Building Information Modeling.

According to the research on the application of blockchain and smart contracts, they were combined with the pain points of material supply contracts management in the construction industry, including the arrival of materials and payment by cycle. With careful consideration of the development of blockchain technology and the need for material supply management based on building information modeling, the manager should select the following requirements.

3.1.1 High Maturity of Development, Many Developers and Active Development Community

Although blockchain technology is highly researched, the development time is relatively short. Many small and medium-sized blockchain platforms have not been tested for a long time, and it is unavoidable to encounter unforeseen problems in their development and version updates. Such uncertainty and uncontrollability will bring incalculable losses if applied in the commercial field. On the one hand, choosing a blockchain platform with high maturity means that its underlying code is more prosperous and perfect and has specific risk resistance and crisis-handling contingency measures. On the other hand, a mature platform often has more developers and a relatively active developer community, so it is easier to get solutions when encountering technical problems. Therefore, high platform maturity and high developer activity are the main principles for the selection.

3.1.2 Project Code is Open Source and Supports Secondary Development

Open-source blockchain platforms are the current mainstream form. Most blockchain projects' underlying code and related components are freely available from open-source project management platforms such as GitHub. Open-source projects mean that all developers worldwide can contribute to their code, and open-source projects are often managed by large foundations, providing the same reliability as closed-source projects. In addition, the open-source code is open and transparent, so companies can have full access and personalized expansion according to their own business, with good control, avoiding the risks associated with plagiarism code. At the same time, the platform's support for secondary development determines.

3.1.3 Suitable for Enterprise Business Management

The smart contracts design for material supply belongs to the cross-enterprise application scenario in the supply chain, so the chosen blockchain platform must be suitable for enterprise-level business, preferably with good data processing capability and low latency. For practical applications, the platform should have richer functions and interfaces, good extensibility for custom development, and be easy to deploy across nodes and post-maintenance.

The Ethernet platform supports complex smart contracts development, with a wide range of applications, high maturity, and many active developers, and is suitable for most application environments. The material supply chain in the construction industry starts from the shipping factory (supplier), and to realize smart contracts, it is necessary to involve transportation enterprises, terminal receiving enterprises, construction site supervisors, payment personnel, payment institutions, etc. in the contracts structure. With the characteristics of many kinds of businesses and many participating organizations, therefore, the Ethernet platform is chosen as the development platform for material supply in the construction industry in the study.

3.2 Scenario Analysis of Material Supply China Application in Construction Information Model Based on Smart Contracts

As a carrier of information, the building information model carries all the process information and information of participants in the whole process of construction projects, etc. Therefore, integrating the material supply chain management based on smart contracts in the building information model can associate much material information in the same model, and can coordinate the purchase of each part of the material with one model.

Therefore, the material management of the building information model based on smart contracts is divided into four parts, which are, respectively, the stage of dividing the material supply contracts of the building information model, the stage of contracts generation, the stage of material transportation, and the stage of signing and settlement.

According to the management of different types of contracts in the building information model, corresponding management standards are established. For the material supply contracts, the main part involved is the material category that needs to be purchased, which can be directly obtained through the building information model data, so that the information on the material to be purchased can be determined easily and quickly. From the building information model, the supplier of the material category is found, and a paper contract is signed with it.

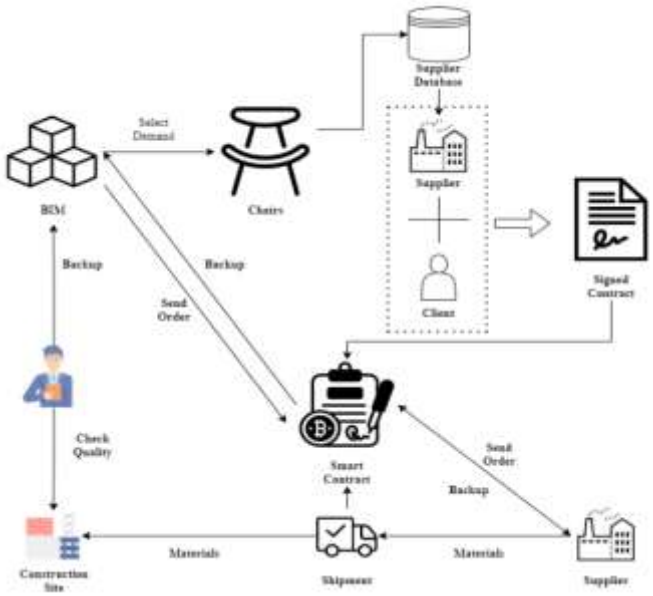

Figure 1. The Framework of the Smart Contracts Application

3.2.1 Contracts Generation Stage

Users can effectively execute the contract signed by both parties. The smart contract system is generated at this stage, which mainly includes the filling of contract information. The creation, deployment, or release of contract documents, and the participants are primarily material suppliers and material-using customers.

After both parties sign the contract, the supply contract information is filled in the corresponding interface, and the customer's node broadcasts in the form of a "transaction"; the contract information and contracting (creation) time of the whole procurement business are recorded on the blockchain.

3.2.2 Contracts Execution Phase

The contracts execution phase includes delivering materials from the supplier to the logistics and the site. The transporter will upload all the location information and information of the materials provided during the material transportation process to the blockchain platform through different parties. The records are handed over to various parties with access to the goods for execution. The blockchain system can synchronize these data, such as status and location and record them on the smart contracts to be used as the execution judgment condition.

3.2.3 Signing and Settlement Stage

When the materials are delivered to the site, the materials will be inspected by the site supervisors, and when the inspection meets the requirements, the supervisors will give confirmation on the building information model through their authority, and at this time, the project managers also know through the building information model that the corresponding part of the material procurement process has been completed, so they can give payment instructions through the smart contracts, and the affiliated payment collectors can receive payment through The corresponding collector can get the cost through the smart contracts.

3.3 Smart Contracts-based Material Supply China Strategy Design in Building Information Model

In the existing contracts management based on the building information model, the contract is often attached to the building information model as an annex, which is not a good way to implement the contracts, so when managing the material supply in the building information model, the following process can be used.

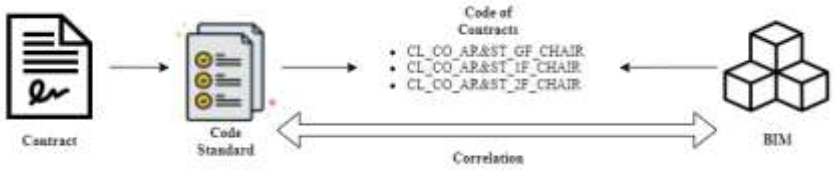

Figure 2. The Correlation of Contracts and BIM Model

In the smart contracts design, which is carried out based on the paper contracts signed by the owner and the supplier, the smart contracts follow the business link in a dynamic process, and at the same time should be able to interact with the participants functionally to achieve status updates. According to the analysis of the material supply chain scenario in the building information model, the implementation of the material supply smart contracts needs to meet the functional requirements of the main participants in all aspects. On this basis, other participants within the blockchain alliance, including third-party financial institutions and regulators, do not directly interact with the smart contracts and only need to realize the basic verification functional requirements.

Table 1. Basic Interactive Function

Participants	Interactive Function	Function
Supplier	Identity information input	Input
	Materials information input	Input
	Contracts information input	Input
	Query contracts information	Read
Shipment	Identity information input	Input
	Materials information input	Input
	Contracts information input	Input
	Query contracts information	Read
Client	Make Smart Contracts	Input
	Confirmation Smart Contracts	Input
	Query contracts information	Read

Smart contracts have a built-in scenario triggering mechanism, which judges different scenarios to execute corresponding operations based on the input data situation. Three types of basic logical judgment mechanisms need to be implemented, including an identity verification mechanism, material acceptance processing mechanism, and sign-off settlement mechanism.

3.3.1 Identity Verification Mechanism

The identity verification mechanism mainly uses the identity authentication of the owner, material supplier, and supervisor and requires. That the participants have authenticated accurate identity information on the relevant business network (blockchain system or information platform) to ensure the reliability of the identity of "Party A" and "Party B" in the contracts. The reliability of the identity of "Party A" and "Party B" in the agreement.

3.3.2 Material Acceptance Processing Mechanism

The material transportation process from the factory to the transportation company and then to the site acceptance needs to ensure that the overall process of material information is consistent with the data uploaded to the blockchain through the building information modeling. The final site acceptance of the materials information should also be compatible with the information in the building information model, according to the characteristics of the automatic execution of smart contracts, the trigger condition of automatic execution is set to the site supervisors to match the material information with the information in the building information model. The trigger condition for automatic execution is set to match the materials information with the information in the building information modeling.

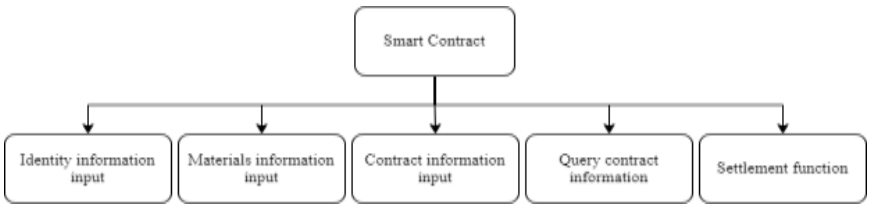

Figure 3. The Structure of the Smart Contracts Platform

3.3.3 Acceptance and Settlement Mechanism

The supplier often has many disputes with the owner because the goods have been delivered to the site, but the settlement needs to wait until after a period of the payment cycle, so the introduction of smart contracts is to confirm the goods information on site to maintain consistent automatic payment. Reduce the mutual disputes between the owner and the supplier.

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3.4.1 Smart Contracts-based Material Supply China Implementation in Building Information Modeling

The business architecture combined with the blockchain system can be divided into the application layer, contracts layer, and system layer. The application layer contains the business and participants is the top layer of the architecture; the contracts layer and system layer belong to the content of the blockchain system, the contracts layer represents the smart contracts and its operating environment, and the system layer is the underlying platform of the blockchain system.

A Network Layer is a system administrator where it is to set up a Blockchain cluster, operation, and maintenance. A Consensus mechanism and authority management Layer is for managers of alliances and organizations, is to implements certificate management and consensus mechanism configuration. On the other hand, a Smart Contracts business layer is for Smart Contracts business developers, and it is responsible for realizing chain code transactions and other relevant business codes. While the WEB Application Business Layer, for upper-layer business application developers and is mainly to realize the center and database, front-end module, through the front-end directly to the user.

4. Result

According to the above business scenario analysis, contracts model design, trigger mechanism design, etc., combined with the specific needs of materials supply chain management based on building information model contracts management, the main functions of materials smart contracts can be divided into five major categories, Identity information input, Mate- rials information input, Contracts information input, Query contracts information, Settlement function.

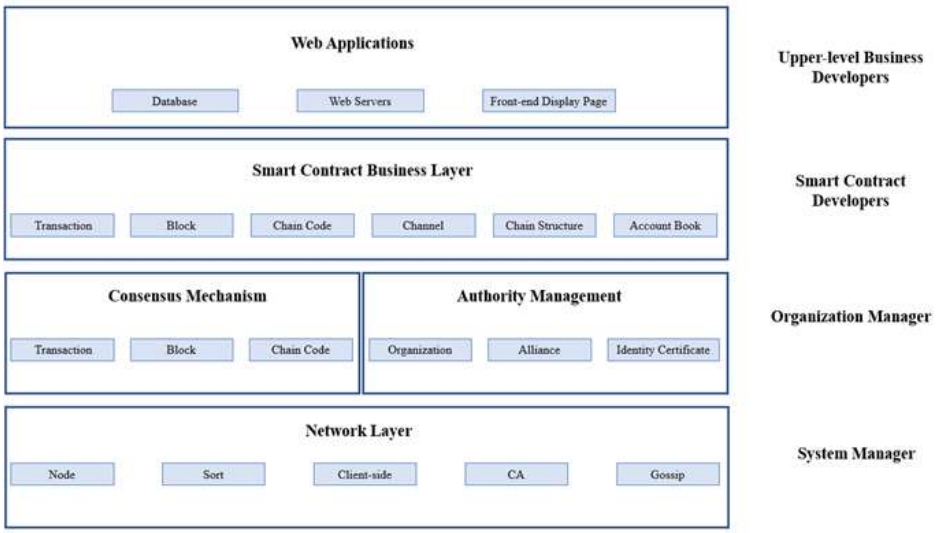

Figure 4. The Structure of the Smart Contracts

4.1 Development Environment Deployment

When conducting smart contracts testing, need to choose a more appropriate environment deployment tool. Remix is an open-source web and desktop integrated development environment for developing Ethernet-based applications. It is an online tool for writing, compiling, and deploying Solidity smart contracts directly from the browser. With a rich set of plugins and an easy-to-use graphical user interface (GUI) and does not require any type of setup. Therefore, for the deployment of smart contracts in this project, Remix was chosen to be based on the Ethernet development platform and Solidity version 0.4.26 was chosen to be compiled.

4.2 Smart Contract Writing

The construction information input in the above contracts, architecture is selected as the main functional test point. The contract is written based on Solidity0.4.26. The contract code is as follows.

```
pragma solidity ^0.4.26;

contract send_information {

    string public message;
    address public manager;

    constructor () public {
        manager = msg.sender;
    }
    function setMessage (string _message) public {
        string memory tmp;
        tmp = _message;
        message = tmp;
    }
    function getMessage() public view returns (string) {
        return message;
    }
}
```

Figure 5. The Program of the Smart Contract

Figure 6. The Information Input by Smart Contract

4.3 Construction Information Input Testing

This test is based on the project's superintendent monitoring the quality of the materials received at the site and he needs to send a message of acceptance to the person responsible for payment.

Figure 7. The Transaction Result of the Smart Contract

5. Conclusion

This paper describes the application of smart contracts in building information model contracts management. Taking the material contracts management as the entry point, determining the application process of smart contracts and the overall architecture setting of smart contracts, and finally determining the effective use of the contracts through smart contracts testing. Thus, it solves the practical problems of clutter in building information model contracts management and the inability to implement data to the specific execution of the contracts.

The development of blockchain technology has nearly a decade of history, but the blockchain platform and smart contracts based on commercial applications can be said to be still in their infancy, with privacy issues, legal issues, security issues, mechanism issues, performance issues, and many other aspects of the blockchain and smart contracts are very significant challenges. The current smart contracts are only smart, but there is still a big gap between the brilliant and intelligent.

Many people believe that smart contracts have both technical and legal properties, while others believe that smart contracts only use technical means to add a guaranteed function to traditional contracts to assist performance. Nevertheless, the progress of technology will gradually solve these uncertainties, and the application of smart contracts on the ground is an inevitable trend in the development of blockchain technology, and the future application of smart contracts will certainly bring a new impact on traditional laws and traditional industry models.

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