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Application of Blockchain Technology in Building Materials Supply Chain Management and Research on Carbon Emission Reduction Effect

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Abstract: *In the process of building materials supply chain management, there are problems such as information opacity, low logistics coordination efficiency, difficulty in material quality traceability, and weak trust mechanism among supply chain entities, which lead to rising costs, low efficiency, and waste of resources. In addition, the construction industry has a large amount of carbon emissions, and the impact of supply chain management on carbon emission reduction cannot be ignored. To this end, this paper introduces blockchain technology to improve supply chain transparency, optimize logistics management, enhance material quality traceability, and explore its role in carbon emission reduction. This paper constructs a blockchain-based building materials supply chain management system, using distributed ledgers to ensure data transparency, smart contracts to automate procurement, acceptance and payment, which is a material traceability system to ensure quality control, the Internet of Things combined with blockchain to optimize logistics management, and establish a carbon emission monitoring and optimization mechanism to achieve real-time data recording and low-carbon scheduling. The system built in this study shows significant advantages in multiple key indicators. The overall carbon emissions of the supply chain in the experimental group are 88 tons of CO_2, a 12% decrease compared to 100 tons of CO_2 in the control group. The average transportation time in the experimental group is 4.5 hours, while that in the control group is 8.2 hours, a 45.1% decrease. The application of blockchain technology has effectively improved the efficiency and transparency of building materials supply chain management, optimized logistics and material quality control, and played a positive role in carbon emission reduction.*

Keywords: *Blockchain Technology; Building Materials Supply Chain; Smart Contracts; Material Traceability; Carbon Emission Reduction*

1. Introduction

With the advancement of globalization, supply chain management is becoming increasingly important in all walks of life, especially in the construction industry, where the efficient operation of the supply chain has a vital impact on project cost control, quality assurance and environmental protection. However, traditional supply chain management models are often faced with problems such as cumbersome approval processes, opaque information, logistics and transportation delays, slow response to quality issues, and poor carbon emission control. This study aims to explore the application of blockchain technology in the supply chain management of construction projects, especially its potential in improving procurement efficiency, quality management, logistics optimization and reducing carbon emissions. By comparing with the conventional paradigm of managing a supply chain, this study aims to verify the advantages of blockchain technology in improving supply chain transparency, efficiency and sustainability, and provide theoretical support and practical basis for supply chain innovation in the future construction industry.

This paper first introduces the background and purpose of the study, and explains the possibilities and practical importance of the technology of blockchain in construction-related supply chain administration. Then, the paper describes the experimental design and methods in detail, including the construction of the experimental platform, data sources, and the selection of experimental subjects. Subsequently, the experimental results are analyzed, and the advantages of blockchain technology are demonstrated by comparing the differences between the experimental group and the control group in procurement efficiency, quality management, logistics efficiency, and carbon emissions. Finally, the paper summarizes the research results, discusses the limitations of the research, and prospects the development direction of blockchain technology is used in building supply chain management in the future.

2. Related Work

As the construction industry pays more and more attention to sustainability and supply chain management, scholars have been exploring how to optimize the supply chain operations of construction projects through innovative technologies. Okika et al. aimed to comprehensively identify supply chain risks and their causes in construction projects, analyze the factors affecting supply chain management, and explore effective risk control techniques. The results showed that delivery reliability, funding arrangements, inventory management, supply chain coordination, etc. were key factors affecting construction supply chain management. At the same time, the bad attitudes of contractors and subcontractors, procurement delays, etc. were the main sources of risk[1].Okika and Arun explored the impact of COVID-19 on the construction supply chain and analyzed the key factors affecting supply chain performance under uncertainty. The findings indicated that the supply chain agility, resilience, and information technology capacities improved efficiency of supply chains, and that medium-size builders were most negatively impacted by the pandemic[2]. Based on the Complex Adaptive Systems (CAS) theory, Ciccullo et al. explored the coordination and integration mechanism of the Circular Supply Chain (CSC) and how enterprises design CSC and create value. The study found that the design of CSC was driven by sustainability, and value may be recovered within or outside the same or different supply chains and industries[3]. Ali et al. explored the application of Green Supply Chain Management (GSCM) practices in the Iraqi construction industry and evaluated its impact on supply chain integration. The results showed that the acceptance of GSCM by Iraqi construction companies has gradually increased, which is conducive to environmental protection and commercial feasibility[4]. Oyefusi et al. proposed a fuzzy hierarchical analysis multi-criteria decision-making model to evaluate GSCM performance by integrating environmental, economic, organizational and social factors. The model can be used as a benchmark to help decision makers in the construction industry evaluate supply chain practices, find improvement directions, and promote sustainable development[5]. Oyefusi et al. analyzed the actual industry situation through 15 semi-structured interviews and proposed an RSC (reverse supply chain) application model suitable for the Brazilian Amazon based on the existing conceptual model. The results showed that the current legal framework was not sufficient to promote effective construction and demolition waste RSC, and it is recommended to promote its development through government regulation and public-private partnership models[6]. Singh et al. used the best-worst method to identify and prioritize the three major economic, environmental and social indicators for the selection of sustainable suppliers in the Indian construction industry. The results showed that environmental factors were the most crucial, then economic considerations[7]. Sadeghi et al. used the fuzzy ordinal priority method to prioritize these requirements. The results showed that the key requirements included the development of circular economy attributes on the platform, internal coordination within the organization, and the construction of technical and cooperative infrastructure[8]. Duong et al. investigated how risk affected the Vietnamese pharmaceutical industry's supply chain operation and built a sophisticated network to assist managers in anticipating and proactively managing unforeseen hazards. The study showed that multiple risk factors in the supply chain interact, restricted or promoted each other[9]. Iqbal et al. analyzed the key success factors for the adoption of Energy Efficient Supply Chain (EESC) in Pakistan's construction industry and constructed an analytical framework using the Delphi method, ISM (Interpretive Structural Modeling), and cross-impact matrix and application ranking methods. The findings demonstrated that the most important elements for the successful implementation of EESC were backing from upper management, international pressure, and environmentally friendly policy pressure[10]. Gualandris et al. found carbon dioxide emissions concentrations in the supply chain of Japanese homes made of wood and suggested a supply chain clustering technique based on house functional categories. The findings indicated that almost 40% of the carbon footprint of wooden buildings was caused by the top ten emission hotspots, with the steel and cement clusters contributing over 75% of the carbon dioxide emissions[11]. Existing research has mostly focused on the single application of blockchain technology in supply chain management, lacking in-depth analysis of its comprehensive application effect in construction projects, and most studies have not considered the differences in construction projects of different regions or scales.

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3. Method

3.1 Division of Building Materials Supply Chain Entities

The supply chain of building materials covers multiple links such as procurement, production, transportation, and distribution, involving raw material purchasers, manufacturers, logistics transporters, material suppliers, construction units, supervision agencies, and waste recyclers. The starting point of the supply chain is the procurement of raw materials. The purchased raw materials are processed and produced into building materials, then transported to suppliers through logistics, and finally delivered to the construction site and stored to meet construction needs, ensure the smooth progress of the project, and avoid construction delays caused by material shortages. At the same time, the supply chain of building materials also needs to consider waste recycling and treatment during the construction process to optimize resource utilization efficiency and reduce environmental impact.

Effective supply chain management of building materials can reduce costs, improve construction efficiency, and reduce material waste, maximizing the interests of all parties. In this process, the application of blockchain technology can enhance data security sharing capabilities, optimize supply chain management, improve information transparency, and promote the digital transformation of the construction industry.

3.2 Material Supplier Selection and Dynamic Management Based on the Supply Chain

In the production chain for building materials, the selection of material suppliers is directly related to the stability of the supply chain and the operational efficiency of the construction company. Since construction companies and material suppliers are often in a long-term cooperative state in the supply chain environment, the supplier selection needs to follow the following process:

(1) Market environment analysis: The competitive situation in the construction industry is learned and the availability and price fluctuations of material supply are evaluated.

(2) Supplier standard setting: The supplier access standards are clarified to ensure that they can respond quickly to demand, reduce material procurement costs, and improve overall project satisfaction.

(3) Supplier evaluation system: Based on the characteristics of different building materials, a multi-dimensional evaluation system is established to ensure that the materials provided by suppliers meet the requirements in terms of quality, price and supply stability.

(4) Expert evaluation: A professional team composed of procurement, technical and budget departments conducts a comprehensive evaluation of suppliers to ensure that the selected suppliers meet the standards for long-term cooperation.

In addition, the introduction of third-party professional logistics organizations on the basis of the existing supply chain model can realize the integration of logistics resources, lower transportation expenses and raise the supply chain's general effectiveness. Through blockchain technology, logistics information is integrated with the supply chain management system to achieve data sharing and optimize the coordination ability of the supply chain.

3.3 Application of Blockchain Technology in Building Materials Supply Chain Management

Decentralized administration, indestructibility, and traceability are some of the traits of the distributed ledger technology, which has several applications in the supply chain management of building materials. These features are primarily seen in the following areas:

(1) Supply chain transparency: Based on blockchain-based distributed ledger technology, data records of the entire construction materials supply chain can be recorded, improving the traceability of the supply chain.

(2) Smart Contract Management: Smart contracts are used to automatically execute supply contracts, ensuring that materials are delivered on time, reducing human intervention and improving execution efficiency.

(3) Secure data sharing: The encryption mechanism of blockchain ensures data security, prevents supply chain information leakage, and improves supply chain collaboration efficiency.

(4) Classification and management of building materials: Based on the supply model of building

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materials, building materials are divided into three categories: standard materials in stock, standard materials produced on order, and customized materials. Standard materials in stock can be stored in batches, such as standard building blocks; materials produced on order need to be produced according to project requirements, such as commercial concrete of different strength grades. Customized materials need to be planned in advance, such as special specifications of glass and exterior wall decoration materials.

(5) Green building management: Blockchain technology records the carbon footprint of building materials, tracks the entire process data of building materials from production to waste recycling, and promotes the implementation of carbon emission reduction policies in the construction industry.

3.4 The Role of Blockchain Technology in Promoting Carbon Emission Reduction

The application of blockchain technology can promote carbon emission reduction in the construction industry in the following aspects:

(1) Optimizing material use: Using supply chain data analysis to reduce material waste and improve resource utilization.

(2) Low-carbon logistics management: Optimizing logistics scheduling through the blockchain platform to reduce carbon emissions in the transportation process.

(3) Promote circular economy: Realizing the full life cycle management of building materials and improve the recycling rate of construction waste.

(4) Carbon emission monitoring and verification: Smart contracts automatically record carbon emission data to ensure that the company's carbon emission reduction goals are achieved.

(5) Supply chain intelligent collaboration: Through the distributed architecture of blockchain, various entities can share supply chain information in real time, improve decision-making efficiency, and reduce unnecessary energy consumption in the supply chain process.

4. Results and Discussion

4.1 Experimental Environment and Platform

This study builds a blockchain experimental environment based on Hyperledger Fabric or Ethereum, and combines smart contracts, Internet of Things (IoT) sensors and big data analysis technology to optimize the top leadership of constructing projects' supplier chains .The experimental data comes from real construction projects, including purchase orders, logistics and transportation records, material quality inspection data and carbon emission data to ensure the authenticity and feasibility of the research. The experimental subjects are construction projects that adopted different supply chain management models. The experimental group (blockchain supply chain) uses blockchain smart contracts, data on-chain and the Internet of Things combined with blockchain technology for management, while the control group (traditional supply chain) relies on traditional manual approval, paper contracts and manual data entry for supply chain management.

4.2 Key Experimental Variables

(1) Independent variable: whether blockchain technology is adopted.

(2) Dependent variable:

Supply chain transparency (data traceability and record completeness of each link in the supply chain);

Contract execution efficiency (purchase approval and settlement time);

Material quality traceability (quality problem identification and response time);

Logistics efficiency (transportation time, delivery accuracy, loss rate);

Carbon emissions (total carbon emissions during material production, transportation, and construction).

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4.3 Indicator Measurement and Analysis:

This study compares blockchain supply chain management with traditional supply chain management models through a series of key indicators, including procurement efficiency, quality problem identification, quality accident response, logistics efficiency, and carbon emissions. These indicators provide a basis for in-depth analysis of the application effect of blockchain supply chain management in the construction industry.

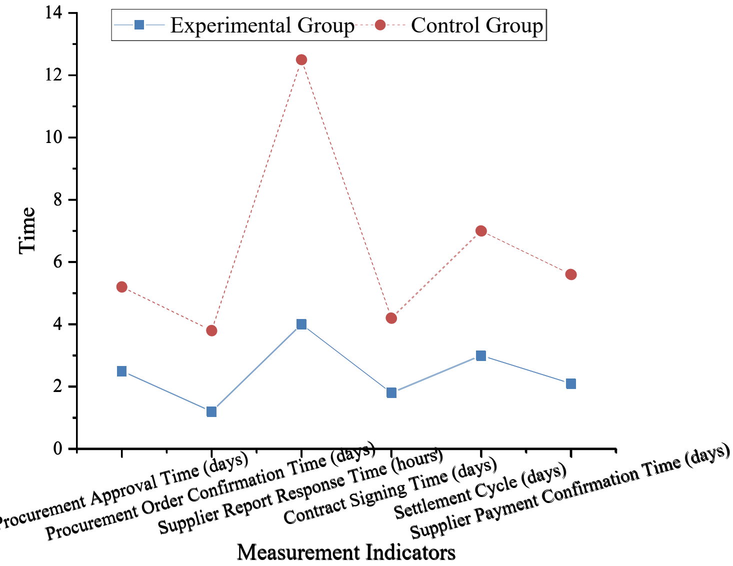

Figure 1 Procurement and contract execution efficiency

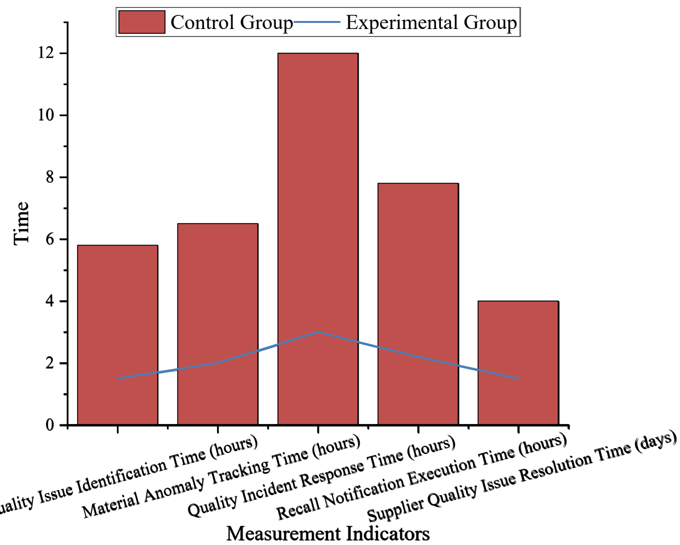

Figure 2 Material quality traceability is evaluated through problem identification and response time

In terms of procurement approval time, the experimental group (blockchain supply chain) is 2.5 days, significantly lower than the control group (traditional supply chain) of 5.2 days, showing the advantages of blockchain technology in simplifying the approval process and reducing manual intervention. In addition, the purchase order confirmation time is also shortened from 3.8 days in the traditional model to 1.2 days, indicating that the efficiency of blockchain technology in automated data recording and information transmission can help speed up the response of the supply chain. In terms of supplier report response time, the experimental group is 4 hours, while the control group is 12.5 hours. Blockchain technology significantly shortens the supplier's response time to demand and problem feedback through real-time data sharing and transparency, thereby improving the agility and responsiveness of the supply chain. In terms of contract execution efficiency, the contract signing time of the experimental group is 1.8 days, which is significantly better than the 4.2 days of the control group, indicating that the automated execution of smart contracts reduces the cumbersome process of manual signing in the traditional model (as shown in Figure 1). In addition, the settlement cycle is shortened from 7 days to 3 days, and the supplier payment confirmation time is reduced from 5.6 days to 2.1 days, which shows that blockchain technology has effectively improved the speed of capital circulation and optimized the overall operational efficiency of the supply chain through automated settlement processes and real-time payment verification.

The data in Experimental Figure 2 shows that blockchain technology significantly improves the efficiency of quality problem identification and quality incident response. Specifically, in terms of quality problem identification time, the experimental group (blockchain supply chain) is only 1.5 hours, compared with 5.8 hours in the control group (traditional supply chain), the improvement rate is as high as 74.14%. This shows that blockchain technology significantly shortens the identification time of quality problems through real-time data sharing and traceability functions, which helps to quickly locate and solve potential quality problems. In terms of material abnormality tracking time, the experimental group is 2 hours, significantly lower than the control group's 6.5 hours, with an improvement rate of 69.23%. The blockchain's immutability and transparent recording characteristics allow the flow information of each batch of materials to be traced at any time, greatly improving tracking efficiency. In terms of quality accident response time, the experimental group is 3 hours, while the control group is 12 hours, with an improvement rate of 75%.

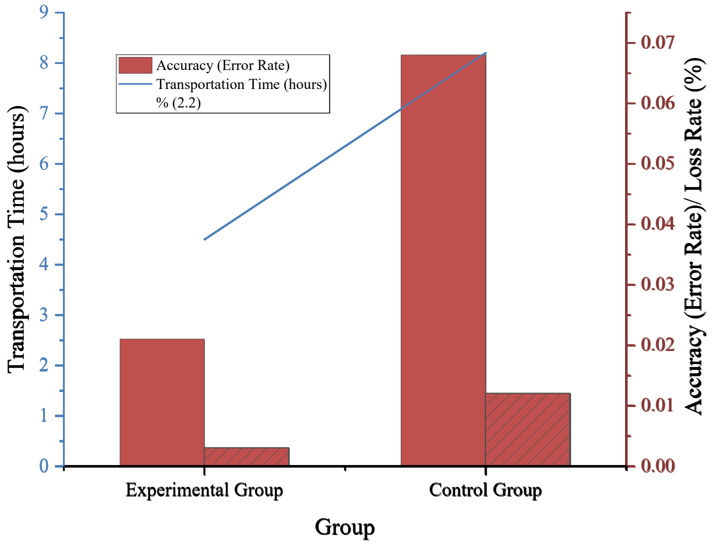

Figure 3 Logistics efficiency measured by transportation time, accuracy and loss rate

The average transportation time of the experimental group is 4.5 hours, while that of the control group is 8.2 hours, a decrease of 45.1%, indicating that blockchain technology has optimized the logistics process and improved transportation efficiency. In addition, the accuracy error rate of the experimental group is 2.10%, significantly lower than the 6.80% of the control group, which shows that blockchain technology can improve the accuracy of logistics information through real-time data tracking and smart contracts, thereby reducing human errors and delays. In terms of loss rate, the experimental group is only 0.30%, far lower than the 1.20% of the control group, a decrease of 75%, showing that blockchain technology improves the traceability of the supply chain and helps reduce cargo loss, as shown in Figure 3.

Table 1 Comparison of procurement and contract execution efficiency

Measurement Indicators	Experimental Group	Control Group
Supply Chain Total Carbon Emissions (tons CO_2)	88	100
Transport Carbon Emissions (kg CO_2/ton·km)	15.6	19
Data On-Chain Integrity (%)	98	75
Supply Chain Traceability Rate (%)	95	65

The blockchain-based supply chain management model has significant advantages in carbon emission control and data management. As can be seen from Table 1, the overall carbon emissions of the supply chain in the experimental group is 88 tons of CO_2, which is 12% lower than the 100 tons of CO_2 in the control group, indicating that blockchain technology can optimize the supply chain process, improve resource utilization efficiency, and thus reduce carbon emissions. In the transportation link, the carbon emissions of the experimental group are 15.6 kg CO_2/ton·km, which is 17.89% lower than the 19 kg CO_2/ton·km of the control group, reflecting the potential of blockchain supply chain management in optimizing logistics routes and improving transportation efficiency. In addition, the data integrity of the experimental group reaches 98%, which is much higher than the 75% of the control group, indicating that blockchain technology has higher reliability and transparency in supply chain data management. In terms of the traceability rate of each link in the supply chain, the experimental group reached 95%, while the control group is only 65%, an increase of 46.15%, further verifying the application value of blockchain in supply chain visualization management.

5. Conclusion

The purpose of this study is to investigate how blockchain-based technology might be used to manage building projects' supply chains. By comparing the blockchain supply chain management model with the traditional supply chain management model, the advantages of blockchain technology in improving procurement efficiency, quality management, logistics efficiency and carbon emission control are evaluated. Experimental data show that:

(1) The time consumption of blockchain supply chain in procurement approval, order confirmation, supplier response and other links is significantly lower than that of traditional models, and blockchain also shows higher efficiency and accuracy in quality problem identification, material tracking, quality accident response and other aspects.

(2) By combining the Internet of Things and smart contracts, blockchain realizes real-time monitoring and transparency of supply chain information, improves data integrity and traceability of each link.

(3) Overall carbon emissions and transportation carbon emissions have also been effectively reduced, which promotes greener and lower-carbon supply chain management.

However, this study has some limitations. First, the sample size of the experiment is small and mainly focuses on specific construction projects, which may not fully represent the situation in all industries. Second, there are still challenges in the popularization of blockchain technology in practical applications, such as high cost, technical implementation difficulties, and compatibility issues with traditional systems. Therefore, future research can be verified on a larger scale, further optimize the implementation details of blockchain technology, and explore how to overcome technical and management barriers to promote the widespread application of blockchain technology in supply chain management.

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