Blockchain-based Framework for Securing Construction Worker Certification and Task Authorization

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Abstract –

The construction industry is widely recognized for its high risk of workplace accidents, making effective safety management a critical priority. Traditional safety systems often rely on manual processes and fragmented documentation, leading to inefficiencies and human error in managing worker certifications and task authorizations; Therefore, this study presents a blockchain-based decentralized application (DApp) for managing worker certifications and task authorizations using smart contracts on the Ethereum blockchain. The proposed system automates certification verification, ensuring that only certified workers are authorized for specific tasks, thereby reducing accidents caused by unqualified personnel. The DApp features a dual-application interface: one for worker registration and task authorization, and another for on-site certification verification. Testing and validation in a simulated environment demonstrated enhanced data integrity, real-time certification checks, and secure storage of certification records, preventing unauthorized modifications. This research highlights the potential of blockchain technology to revolutionize construction safety practices by offering an efficient, transparent, and tamper-proof certification management system. The findings contribute to the growing body of knowledge on blockchain applications in construction and lay the foundation for future advancements in safety compliance technologies.

Keywords – Blockchain; Construction Safety; Smart Contracts; Certification Management; Decentralized Applications (DApp)

1 Introduction

The construction industry is globally recognized as one of the most hazardous sectors, consistently leading in workplace fatalities, severe injuries, and occupational health risks [1–4]. Although many countries have implemented strict safety regulations and mandatory certification requirements, the industry continues to struggle with persistent safety challenges [5,6]. Ensuring that only properly trained and certified personnel are authorized to perform specific tasks is essential for mitigating safety risks on construction sites [5,7]. However, traditional systems, such as paper-based records or isolated databases, are prone to errors and inefficiencies, creating safety gaps [8]. Paper-based systems are prone to documentation loss, storage challenges, and tampering, while conventional digital databases face limitations in data security, cross-organizational verification, and real-time accessibility [9]. These shortcomings allow uncertified or improperly certified workers to undertake high-risk tasks, often resulting in preventable accidents and fatalities [7]. The growing complexity of construction projects, characterized by multiple contractors, diverse workforces, and varying regional safety standards, further complicates the task of effectively managing and verifying worker credentials [10].

Blockchain technology offers a promising approach to address these challenges by providing immutability, decentralization, and automation, which are critical for ensuring secure and tamper-proof certification management [11]. Unlike AI, which can be used for certification validation but still relies on centralized databases, blockchain eliminates single points of failure and reduces trust dependency by ensuring that all transactions are recorded transparently and cannot be altered retroactively [11]. The decentralized nature of blockchain ensures that worker credentials remain verifiable across multiple organizations without the risk of fraudulent modifications [11]. Additionally, smart contracts provide self-executing compliance mechanisms, automatically verifying worker certifications before authorizing hazardous tasks, thereby reducing the risk of manual oversight or manipulation [12]. By eliminating manual checks and enabling real-time compliance, blockchain-based systems can streamline safety management and reduce the risk of accidents. By introducing a blockchain-based decentralized application for real-time certification verification, this study addresses critical gaps in traditional safety systems, such as inefficiency, human error, and limited scalability, presenting a novel approach to safety compliance in construction.

This study explores the development of a blockchain-based decentralized application (DApp) for managing worker certifications and authorizing tasks in the construction industry. The proposed system uses smart contracts on a private Ethereum blockchain to securely store worker data, authorize tasks based on certification validity, and enable on-site certification checks. Additionally, a dual-application interface is designed to facilitate worker registration, task authorization, and on-site certification verification. Through this approach, the study aims to demonstrate how blockchain can enhance safety compliance, improve efficiency in authorization processes, and reduce human error in high-risk environments.

By combining blockchain technology with automated compliance checks, this research contributes to the advancement of safety management practices in construction. It presents a model that construction companies and safety managers can adopt to strengthen their oversight of worker qualifications, minimize unauthorized task assignments, and promote a safer, more efficient construction environment.

2 Literature Review

The construction industry is known for its high-risk nature, with worker safety remaining a significant concern globally. Many studies have explored various aspects of safety management, highlighting the critical role of proper training, certification, and task authorization in minimizing accidents [5,13–15]. This section provides an overview of key research in the areas of worker safety, certification management, and the role of blockchain technology in enhancing safety practices in the construction sector.

2.1 Worker Safety in Construction

Construction workers are exposed to a range of hazards, from physical injuries due to heavy machinery and equipment to long-term health risks like exposure to harmful chemicals and dust. According to a study by Newaz et al. (2021), effective safety management on construction sites requires comprehensive strategies that address both the physical and organizational aspects of safety [16]. These strategies include safety training, hazard identification, risk assessment, and the use of safety equipment. However, the effectiveness of these strategies often depends on the qualifications and competencies of the workers [16].

Proper training and certification have been identified as fundamental in mitigating risks [14]. Research by Başağa et al. (2018) emphasize that certified workers are significantly less likely to be involved in accidents, as they possess the requisite knowledge to identify hazards and follow safety protocols [14]. However, traditional certification systems often fail to address challenges like discrepancies in worker qualifications and the verification of training completion. These limitations create a pressing need for secure, real-time, and scalable certification management solutions.

2.2 Blockchain Technology in Construction

Blockchain technology has emerged as a promising solution for addressing challenges in various industries, including construction [11,12,17]. Blockchain is essentially a distributed ledger that records transactions in a secure, transparent, and tamper-proof manner. The decentralized nature of blockchain ensures that no single party has control over the data, thus reducing the risk of fraud or manipulation.

A review by Li and Kassem (2021) outlines several potential applications of blockchain in the construction sector, including supply chain management, project financing, and safety compliance [11]. While blockchain's utility in supply chain transparency and contract enforcement is well-documented, its application to worker certification management and task authorization remains underexplored. In the context of safety management, blockchain can significantly improve the accuracy and reliability of information [18–20]. A study by Yang et al (2022) demonstrated how blockchain can be used to manage scaffolding work information [21].

Smart contracts are one of the most promising applications of blockchain technology in construction [12,22]. These are programmable contracts that automatically execute predefined actions when certain conditions are met. In the context of worker certification and task authorization, smart contracts can automatically verify a worker's certification status and authorize or deny access to specific tasks based on pre-defined criteria.

Research by Ciotta et al. (2021) demonstrates that smart contracts can be used to automate various processes in the construction industry, such as managing payments, enforcing legal agreements, and verifying qualifications [12]. In the context of safety management, smart contracts can be used to ensure that workers are only assigned tasks they are qualified to perform, based on their training and certification records. The use of smart contracts can greatly reduce the administrative burden of manual checks, ensuring that safety standards are consistently met across construction projects. Building on this foundation, our research focuses on using smart contracts for real-time certification verification, a novel application that directly addresses safety compliance gaps in construction.

2.3 Research Gap and Contribution

This study contributes to the literature by addressing several key gaps in the current research on construction safety and certification management. Firstly, it explores the use of blockchain technology for real-time worker certification and task authorization, which is largely underexplored in the existing literature. Secondly, it tackles the challenges of scalability and data security by implementing a blockchain-based solution in a simulated environment, providing insights into its feasibility for large-scale construction projects.

The novelty of this research lies in its approach to applying blockchain with smart contracts for real-time safety compliance, providing a new method for ensuring that only certified workers are authorized to perform hazardous tasks. By automating the verification of worker qualifications and integrating this process with on-site certification checks, the proposed system offers a practical tool for improving safety management in the construction sector. This solution not only reduces administrative overhead but also enhances transparency and accountability, potentially reducing accidents and improving overall project safety.

3 Methodology

3.1 Research Design

This study employed a blockchain-based system design to enhance worker safety in the construction industry by ensuring only certified and trained workers were authorized for specific tasks. The system was developed as a decentralized application (DApp) using smart contracts on the Ethereum blockchain [19,23]. The research design involved the following steps as shown in Figure 1:

- System Development: Developed a smart contract to record worker certifications, training completion, and task authorizations.
- User Interface: Created two separate frontend applications, one for worker registration and task authorization, and another for certification checking at construction sites.
- Testing and Validation: Performed functional testing to ensure the system accurately registered workers, authorized tasks, and verified certifications.

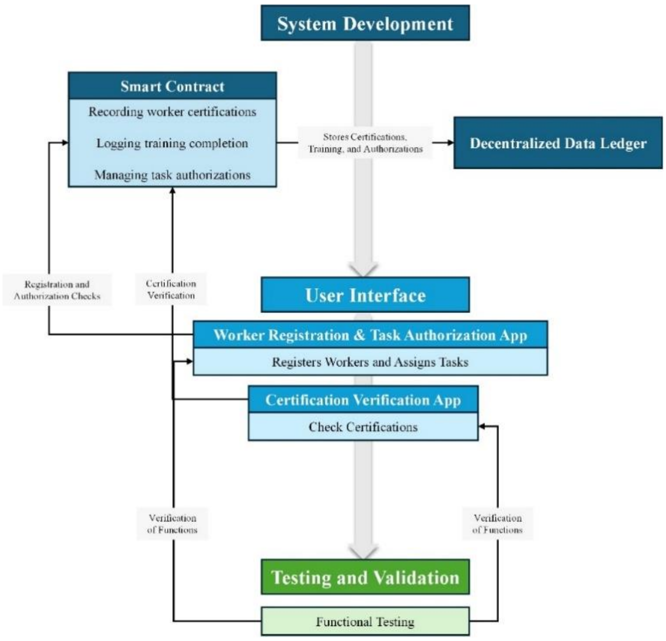

Figure 1. Research framework

3.2 System Architecture

The architecture consisted of four main components:

1. Blockchain Network: A private Ethereum network was set up using Ganache, simulating a blockchain environment for development and testing.
2. Smart Contract: A smart contract was written in Solidity and deployed on the Ethereum blockchain, maintaining data on worker IDs, certifications, training status, and authorized tasks.
3. Frontend Applications: Two React.js applications were developed to interact with the smart contract. The first application managed worker registration and task authorization, while the second was used at construction sites to verify certifications.
4. MetaMask Integration: MetaMask was used as the web3 provider to securely connect the frontend applications with the Ethereum network. It allowed users to interact with the smart contract by signing and authorizing transactions directly through the MetaMask wallet. This provided a secure and user-friendly interface for managing blockchain-based interactions.

3.3 Smart Contract Development

The smart contract was developed using the Solidity 0.8.0 programming language on the remix integrated development environment (IDE) [24] as shown in Table 1, and key functionalities were included as follows:

- Worker Registration: The contract enabled administrators to register workers, recording details such as worker ID, name, certification type, and certification status.

- Task Authorization: The contract allowed administrators to authorize specific tasks for workers based on their certification and training status.
- Certification Verification: A function was provided for querying a worker's certification status and authorized tasks to confirm their eligibility for on-site activities.

The contract code was tested using Remix IDE to ensure it met functional requirements and handled error scenarios, such as unauthorized access.

Table 1 Code for the Smart Contract for Worker Certification and Task Authorization

```
// SPDX-License-Identifier: MIT pragma solidity ^0.8.0;
contract WorkerCertification {
    // Worker data structure
    struct Worker {
        string workerId;
        string name;
        string certificationType;
        bool certificationValid;
        bool trainingCompleted;
    }
    // Mappings for workers and their authorized tasks
    mapping(string => Worker) public workers;
    mapping(string => string[]) public authorizedTasks;
    // Event for certification checks
    event CertificationChecked(string workerId, string taskId, bool isCertified);
    // ================================
    // Worker Registration
    // ================================
    function registerWorker(
        string memory _workerId,
        string memory _name,
        string memory _certificationType,
        bool _certificationValid,
        bool _trainingCompleted
    ) public {
        workers[_workerId] = Worker(
            _workerId,
            _name,
            _certificationType,
            _certificationValid,
            _trainingCompleted
        );
    }
    // ================================
    // Task Authorization
    // ================================
    function authorizeTask(string memory _workerId, string memory _taskId) public {
        authorizedTasks[_workerId].push(_taskId);
    }
    // ================================
    // Certification Verification
    // ================================
    function checkCertification(string memory _workerId, string memory _taskId) public {
        bool isCertified = workers[_workerId].certificationValid && workers[_workerId].trainingCompleted;
        emit CertificationChecked(_workerId, _taskId, isCertified);
        require(isCertified, "Worker is not certified for this task");
    }
    function getWorker(string memory _workerId)
        public
        view
        returns (
            string memory name,
            string memory certificationType,
            bool certificationValid,
            bool trainingCompleted
        )
    {
        Worker memory worker = workers[_workerId];
        return (
            worker.name,
            worker.certificationType,
            worker.certificationValid,
            worker.trainingCompleted
        );
    }
}
```

3.4 Frontend Development

Two separate frontend applications were built using React.js to interact with the smart contract [25]:

1. Worker Registration and Authorization Application: This application allowed administrators to register workers, authorize tasks, and manage certifications. It connected to the smart contract using Web3.js, enabling interaction with the blockchain.
2. Certification Verification Application: This application allowed on-site managers to verify a worker's certification status and task authorization by entering the worker ID and task ID. If the worker was certified and authorized, they were allowed to proceed with the task.

4 Results and Discussion

4.1 System Functionality

The blockchain-based certification management system was successfully implemented and tested in a simulated environment. The system achieved key functionalities, including worker registration, task authorization, and real-time certification verification at construction sites. Testing revealed that both frontend applications, the worker registration and authorization application and the certification verification application as shown in Figures 2 and 3, performed as intended, providing accurate, secure, and reliable data retrieval. The decentralized approach demonstrated a clear benefit by preventing data tampering and ensuring that only verified certifications were used to authorize tasks.

Figure 2. User interface for worker registration and task authorization

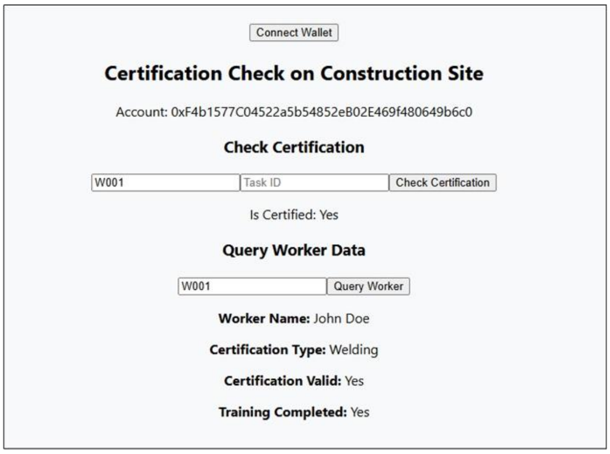

Figure 3. User interface for certification check

4.2 System Performance

The system's performance was evaluated by examining transaction execution in the Ganache environment, as shown in Figure 4. Ganache, a personal Ethereum blockchain, provided insight into the resource utilization and transaction handling efficiency of the Worker Certification DApp.

In Figure 4, each transaction involved deploying and interacting with the smart contract for worker registration and certification checking. The transaction logs indicate multiple interactions, including contract deployment, worker registration, and certification verification. MetaMask facilitated these interactions by enabling users to review and confirm each transaction before execution, providing a layer of security and transparency. Key aspects of the transactions are summarized below:

- Address and Balance: The Ethereum accounts displayed in Ganache each had initial balances, with balances updated after each transaction. For instance, the primary account used for transactions shows a slight reduction in balance due to gas consumption during contract calls.
- Gas Usage: The system consumed varying amounts of gas for different contract functions. Notably, the register Worker and check Certification functions incurred gas usage of approximately 68,487 units for certification-related transactions, suggesting the efficiency of these operations. This gas cost is reasonable for a private blockchain environment, highlighting the contract's resource efficiency.

The system was tested using a single worker registration, one task authorization, and one certification verification transaction. The purpose of this test was to validate the core functionality of the smart contract rather than stress-test scalability. The simulation was conducted in a controlled private Ethereum network using Ganache, where block mining was instantaneous, and gas fees were fixed. This setup ensured that transactions were processed efficiently, allowing us to verify the correctness of the smart contract logic.

The DApp successfully performed task authorization and certification verification within Ganache's simulated environment. Transactions were processed almost instantaneously due to Ganache's high-speed block mining, while MetaMask allowed secure and seamless interaction with the blockchain. In a real-world scenario, additional testing with multiple workers and varying workloads will be required to evaluate system performance under more complex conditions. Future work will focus on scalability analysis, transaction efficiency, and potential optimizations for deployment in an industry setting.

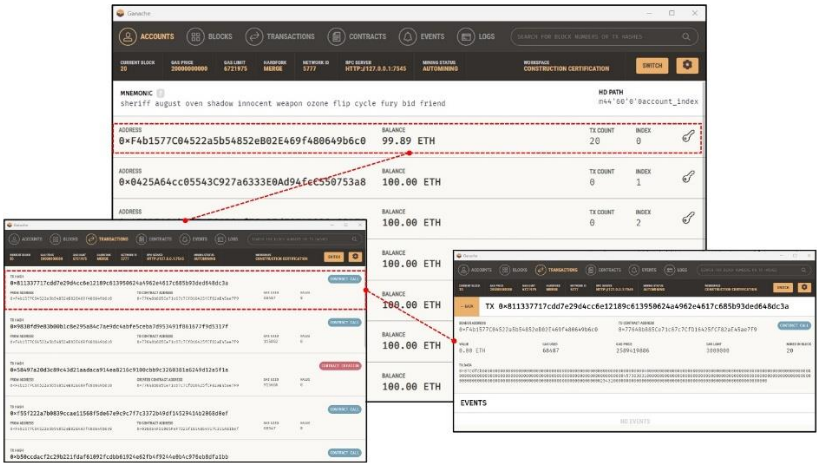

Figure 4. Transaction record in Ganache blockchain

4.3 Safety and Data Integrity

A major advantage of the blockchain-based approach is the secure storage of certification and authorization data, preventing unauthorized modifications. The smart contract's immutable nature ensured that worker data could not be altered once registered, enhancing data integrity. This feature is particularly valuable for construction safety, where accurate certification records are critical for regulatory compliance and risk management.

The results showed that the decentralized structure also effectively restricted access to only certified workers for specific tasks, reducing the likelihood of human error or intentional breaches in safety protocol. By enabling verification on a blockchain, the system provided transparency and accountability, which are essential in high-risk industries such as construction.

To address human error in certificate management, the worker registration and certification data entry process is managed by designated administrators. Before a new worker arrives on-site, their certification details are manually recorded into the system, verified against official records, and then uploaded to the blockchain. While manual data entry may introduce potential human errors, blockchain ensures that once recorded, data cannot be altered or manipulated.

4.4 Implications for Construction Safety

The proposed blockchain-based system introduces transformative changes to safety compliance in construction. By ensuring that only certified and trained personnel are authorized for hazardous tasks, the system directly addresses one of the primary causes of construction accidents: unqualified workers. The transparency of blockchain transactions further supports accountability, as immutable records provide a verifiable audit trail of certifications and authorizations.

In addition to improving safety, the system offers economic benefits by reducing administrative overhead associated with manual certification checks and preventing costly accidents caused by uncertified workers. To quantify these benefits, key performance metrics can be considered. These include the reduction in time spent on manual certification verification, which in traditional systems can be time-intensive, particularly for large projects involving multiple subcontractors. Furthermore, a reduction in administrative labor costs can be measured by comparing the staff hours required for certification management before and after blockchain implementation. Additionally, based on existing safety literature, a decrease in accident rates attributed to unauthorized or uncertified workers could provide an estimate of potential cost savings related to reduced compensation claims, legal liabilities, and project delays. While the implementation of blockchain-based certification management incurs initial development and integration costs, the long-term economic advantages can outweigh these expenses. The trade-off between cost and benefits can be analyzed through a cost-benefit framework, where initial investments in blockchain infrastructure, training, and deployment are weighed against projected savings in administrative labor, accident-related costs, and regulatory compliance efforts. This discussion underscores the system's feasibility and provides a foundation for future empirical validation in real-world construction environments. These findings suggest that blockchain technology has the potential to become an industry standard for safety compliance in construction.

5 Conclusion

This research demonstrates the potential of blockchain technology to revolutionize safety management in the construction industry by enhancing the verification of worker qualifications and task authorizations. By developing a blockchain-based decentralized application (DApp) that utilizes smart contracts on the Ethereum blockchain, this study successfully addresses key challenges in traditional safety management systems, such as inefficiency, human error, and unauthorized task assignments. The system provides a secure, transparent, and tamper-proof method for managing worker certifications and training completion, ensuring that only qualified workers are authorized for specific tasks.

The results from system testing show that the blockchain-based approach not only improved data integrity by preventing unauthorized modifications but also facilitated real-time certification checks at construction sites, offering immediate verification of worker eligibility for hazardous tasks. The two frontend applications developed, one for worker registration and task authorization and another for certification verification, performed effectively, demonstrating the practical feasibility of blockchain in the construction sector.

This study makes the following contributions. Firstly, in terms of technical contribution, this study provides a secure, transparent, and automated method for managing worker certifications using smart contracts, enhancing data integrity and reducing human errors. Secondly, regarding research contribution, the study demonstrates the feasibility of blockchain for safety compliance, laying the foundation for integrating blockchain with other construction systems and highlighting potential applications in high-risk industries.

Despite the promising results, this study has some limitations that should be addressed in future research. Firstly, the usability of the system was not evaluated, as this study focused primarily on developing the framework and testing its technical functionalities. Secondly, the system was tested in a simulated environment using a private Ethereum blockchain, which may not fully replicate the complexities and scalability challenges of real-world construction sites. Lastly, the user interface developed for this study was designed for administrative and supervisor-level interactions, but worker-facing applications were not explored in detail.

Future research should also consider key implementation requirements for real-world adoption, including scalability, interoperability with existing construction management systems, security, and regulatory compliance. Ensuring the system can handle a large volume of transactions efficiently is crucial for scalability, while integration with current digital safety platforms will enhance its usability. Additionally, robust security measures must be in place to prevent unauthorized access or tampering. Finally, legal and regulatory considerations should be addressed to align the system with construction industry safety standards and compliance frameworks.

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