ISAFEINCENTIVE: TRANSFORMING CONSTRUCTION SAFETY CULTURE THROUGH BLOCKCHAIN INCENTIVES

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ABSTRACT: *A significant challenge has long persisted in the construction industry: the lack of a robust incentive system to encourage and motivate workers to prioritize safety. While safety culture has been recognized as crucial, traditional approaches to incentivizing safe behaviours often encounter roadblocks, such as heavy documentation processes, recognition delays, and resource allocation difficulties. This paper addresses this problem by introducing an innovative approach to incentivize and cultivate a safety culture in the construction industry. iSafeincentive integrates blockchain technology and computer vision to develop a novel solution revolutionizing safety monitoring and incentive distribution. Computer vision technology is employed for real-time analysis of safety conditions based on on-site images, ensuring the immediate identification of safe practices. Simultaneously, blockchain technology safeguards the incentive distribution process's integrity and transparency, addressing traditional methods' shortcomings. The findings suggest that iSafeincentive offers an efficient and secure method for rewarding safe activities among workers. Furthermore, the integrated platform offers a promising pathway to enhance job site safety practices, ultimately reducing accidents and incidents within the construction sector.*

KEYWORDS*: Safety Culture, Incentive Programs, Blockchain Technology, Computer Vision, Construction Industry, Workplace Safety*

1. INTRODUCTION

The construction industry presents a dynamic workplace where the constant spectre of accidents and injuries casts a shadow over operations (Lim et al., 2021; Won and Soo, 2021). A robust safety culture within this sector is imperative, where safety transcends mere compliance and becomes an integral core value deeply entrenched in the organizational ethos. Such a culture is characterized by a collective commitment to hazard identification, risk mitigation, and the seamless integration of safety into all facets of work ((Zou, 2011); (Barg *et al.*, 2014); (Aksorn and Hadikusumo, 2008)). However, several critical challenges impede the development of this vital safety culture. First and foremost, construction sites often lack effective data management systems and reliable inspection and monitoring mechanisms. This deficit hinders the timely identification and rectification of potential hazards(Alexander Laufer and G. Jenkins, 1982). Secondly, there exists a dearth of incentive programs designed to motivate construction workers to prioritize safety ((Biggs, Sheahan and Dingsdag, 2005)). These programs have the potential to significantly reduce accidents and incidents on construction sites, fostering a resilient safety culture.

It is essential to emphasize the role of management in motivating construction workers to prioritize safety. Management must actively incentivize safe practices, linking desired outcomes to performance ((Alexander Laufer and G. Jenkins, 1982)). Furthermore, cultivating the right safety knowledge interpersonal skills, and fostering appropriate attitudes and beliefs are pivotal in nurturing a positive safety culture within the workforce ((Biggs, Sheahan and Dingsdag, 2005)). (Mohammadi, Tavakolan and Khosravi, 2018) provides insights into the multifaceted factors influencing safety performance in construction projects. (Helander, 1991) underscores the importance of monetary incentives as a catalyst for investing in construction safety. These findings collectively emphasize the significance of providing incentives, improving management practices, and shaping workers' beliefs and attitudes toward safety.

Incentives within the construction industry have shown a demonstrably positive impact on safety practices among workers ((Zulkefli, Ulang and Baharum, 2014)). They serve as structured mechanisms for recognizing and reinforcing safe practices, thereby contributing to amplifying and consolidating safety standards within the construction workforce. (Tang *et al.*, 2008) emphasizes the need for incentives in the Chinese construction industry, advocating for alignment with project features to enhance project delivery efficiency. (Huang and Sun, 2009) delves into various incentive smart contracts and their design principles, while Tinus (2014) highlights concerns regarding their impact on work productivity. (Nurul Fieqah and Ahmad Kazimi, no date) shed light on the challenges of implementing Occupational Safety and Health Act (OSHA) requirements, which can exacerbate administrative burdens and delay incentive distribution. It is crucial to address these issues and develop more efficient and streamlined incentive methodologies in construction. These methodologies should alleviate documentation burdens and enhance project performance, ensuring a harmonious balance between safety and economic sustainability.

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In summary, while incentive programs in construction can significantly enhance safety performance, their long-term effectiveness requires continuous evaluation and strategic resource allocation. Addressing challenges associated with traditional incentive methods is essential to boost safety and productivity in the industry. Streamlining the monitoring process is critical, as current safety inspections suffer from issues like infrequent and inadequate assessments, exacerbated by limited resources and human errors. Moreover, a shortage of safety professionals leads to less thorough evaluations. A significant limitation is the absence of a comprehensive incentive system aligning with inspections and rewarding safe behavior.

To effectively address these challenges, this study aims to develop and implement an innovative incentive system that harnesses blockchain technology and computer vision. This system is designed to enable real-time monitoring and recognition of safe behaviors exhibited by construction workers to comprehensively enhance safety practices across various construction sites.

2. LITERATURE REVIEW

In recent years, blockchain technology has gained substantial traction within the construction industry, presenting novel solutions to address enduring challenges. These studies investigate blockchain technology's adoption and potential applications, specifically focusing on its capacity to enhance efficiency, transparency, and safety in construction operations. For example, several studies have adopted blockchain for enhancing information management in Modular Integrated Construction. (Pan Zhang, 2023) employs game theory to delve into this subject, highlighting the pivotal role of diffusion rates influenced by benefits, costs, and government subsidies. The study advocates for implementing pilot projects and governmental incentives to facilitate adoption. In another study, (Minju Kim, 2023) introduces a blockchain-based system to optimize off-site construction supply chains. Using Bayesian updating and incentives, the study aligns contractor and supplier decisions, ultimately improving transparency and reliability.

Another investigation by (Pan Zhang H. W., 2023) employs game theory to analyze the adoption decisions surrounding blockchain technology in Modular Integrated Construction. This study echoes the importance of pilot projects and government incentives as drivers of adoption. (Hossein Naderi, 2023) introduces a decentralized application utilizing blockchain and computer vision to incentivize construction safety through token rewards. The application autonomously evaluates safety performance and issues unique Non-Fungible Tokens (NFTs) as rewards while maintaining user confidentiality. It presents promising prospects for various domains; however, scalability issues and challenges related to individual incentivization must be addressed through further development to expand its practical applications. In addition, (Namya Sharma, 2022) provides an exhaustive review of 33 global strategies for managing Construction and Demolition waste, focusing on integrating Circular Economy principles and lifecycle thinking, particularly in the Indian construction sector.

In another application, (Wenli Yang, 2022) proposes a master-slave chain model and a hybrid consensus algorithm to enhance the efficiency and security of multidomain conversational interactions on a blockchain. It effectively manages various scenarios concurrently while maintaining fault tolerance. However, it faces challenges related to high capacity demands due to diverse data types, necessitating further exploration of big data verification and consistent storage management. Finally, (Liupengfei Wu, 2022) introduces a blockchain-based supervision (BBS) model to improve supervision and security in cross-border logistics within modular construction. The model employs incentives to encourage data sharing, resulting in enhanced product accountability and data traceability compared to centralized platforms. Nevertheless, it encounters limitations, such as the potential for opportunistic behavior in data entry and a static incentive mechanism.

In conclusion, while these studies contribute significantly to our understanding of blockchain adoption and its applications in construction and related domains, they collectively share limitations such as theoretical orientation, lack of empirical evidence, oversimplified stakeholder models, and the need for further practical validation. Addressing these limitations is crucial for advancing the field and ensuring the real-world viability of these concepts.

3. RESEARCH METHOD

3.1 Process

To address the objective of this study, the approach is to integrate computer vision technology, which allows for the automated analysis of safety conditions from site images. Computer vision eliminates the need for extensive

manual inspections and enables more accurate and efficient safety assessments. With reduced human intervention, safety assessments become consistent and unbiased, greatly enhancing the reliability of inspection results.

The integration of blockchain technology, in conjunction with computer vision (Figure 1), presents a groundbreaking shift in the construction industry's management of safety inspection data. Blockchain's immutability is pivotal in upholding the integrity and permanence of safety inspection records. Once safety data is securely recorded on the blockchain, it becomes impervious to alteration or tampering, instilling a high level of confidence in the precision and authenticity of the information. This characteristic is paramount in safety inspections, as it safeguards historical safety assessment records, reinforcing their credibility for compliance verification, auditing, and accountability purposes. Furthermore, the symbiotic fusion of blockchain and computer vision technologies fosters enhanced collaboration among various stakeholders involved in construction projects. Digital platforms, underpinned by these innovative technologies, enable real-time data sharing and communication. This digital transformation empowers project managers, safety officers, construction workers, and regulatory authorities to access and comprehensively review crucial safety inspection data promptly.

Consequently, stakeholders can respond swiftly to emerging safety concerns, coordinate preemptive measures, and effectively address potential hazards, ultimately cultivating a safer work environment. This technological convergence signifies a pivotal departure from traditional paper-based data collection methods, significantly enhancing the efficiency of safety inspection processes. Eliminating manual data entry and paperwork markedly reduces the likelihood of errors and omissions, elevating the precision of safety assessments. Furthermore, digital platforms support automated data analysis, providing real-time insights and reports. This data-driven approach empowers safety officers and managers to make well-informed decisions expeditiously, proactively mitigating risks and amplifying overall safety performance.

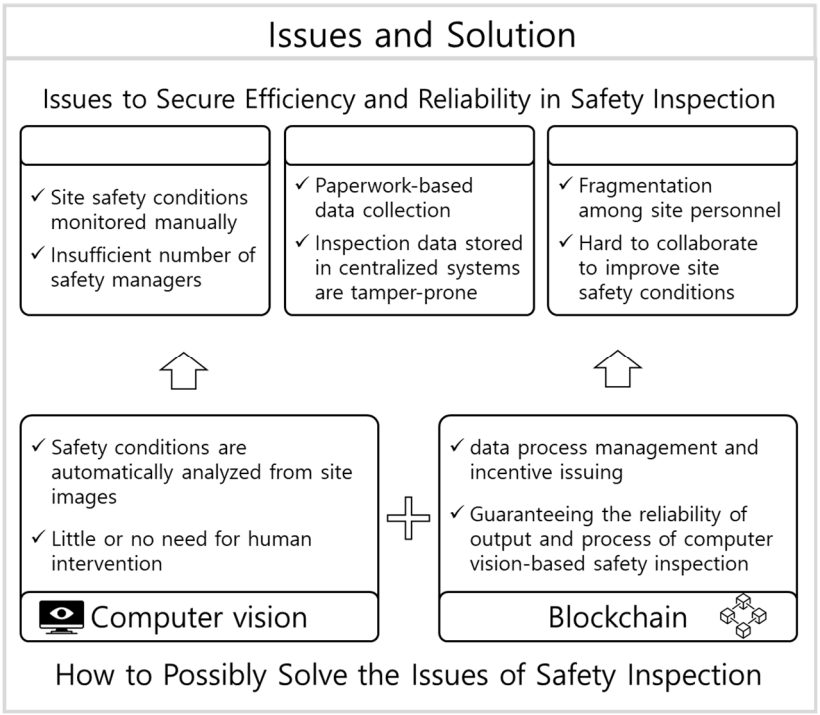

Fig. 1: The existing condition of safety inspections and suggested technological solutions to mitigate their challenges.

In the contemporary construction industry, a conspicuous challenge resides in inadequate motivation and incentives to stimulate safety performance and regulatory compliance among its workforce. This deficiency results in a series of interconnected issues that reverberate throughout the construction ecosystem. Site managers, at times overwhelmed by their responsibilities and bereft of tangible incentives for meticulous oversight, may inadvertently neglect safety protocols or make critical errors. Furthermore, the scarcity of qualified site managers compounds these challenges, leading to lapses in enforcing safety measures. Concurrently, the reliability of management records concerning safety compliance becomes questionable, diminishing the effectiveness of oversight

mechanisms. This confluence of factors not only jeopardizes the well-being of construction personnel but also raises concerns about the quality and safety of the final built environment.

In response to these pressing concerns, as depicted in Figure 2, a multifaceted approach is emerging within the construction industry, driven by the amalgamation of technological innovation and incentive systems. This approach extends from project bidding, wherein contractors can accrue additional points or insurance rate discounts for committing to stringent safety and quality standards, to insurance and guarantee providers offering reduced premiums as rewards for safety adherence. Notably, the proposal of a token-based incentive system underpins this transformation, leveraging blockchain and verification technologies to bolster the adequacy and reliability of information generated within the construction milieu. This incentive-driven paradigm fosters voluntary safety activities among all stakeholders, from equipment and material suppliers to structural consultants and safety inspection agencies. By incorporating bottom-up perspectives, this holistic shift aspires to invigorate safety culture within construction, ensuring that every participant is vested in the collective goal of elevating safety standards and mitigating risks across the industry.

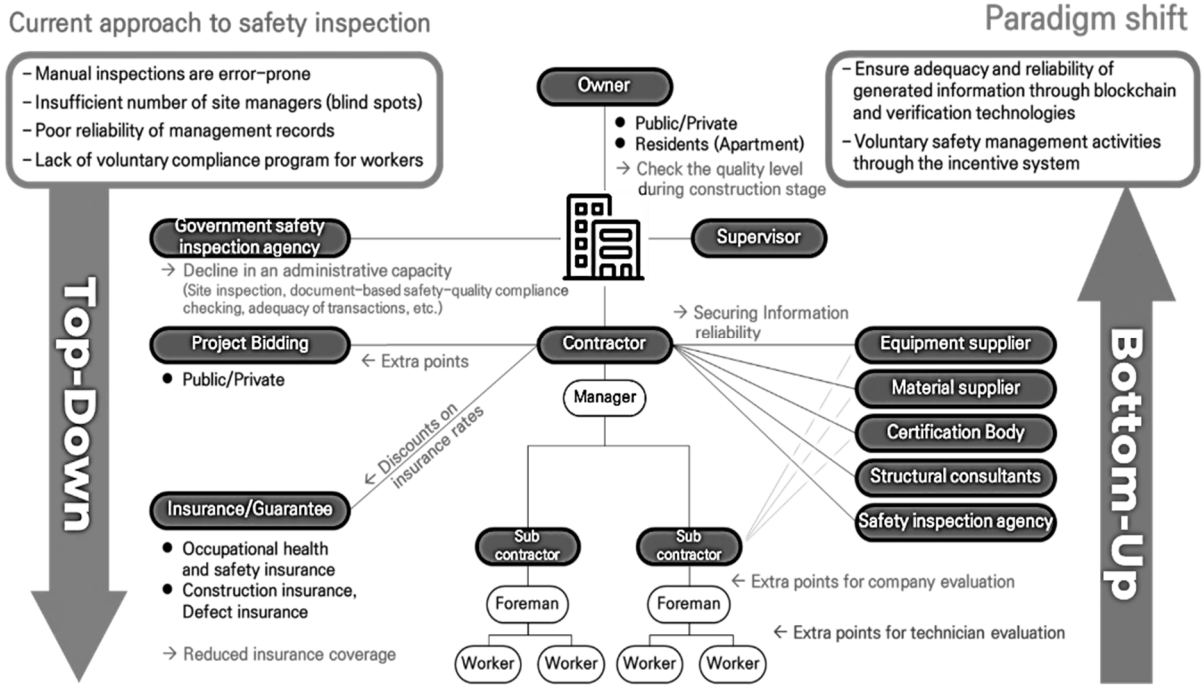

Fig. 2: Token-based incentive system

Furthermore, utilizing blockchain-based evaluations introduces a novel incentive structure that encourages the voluntary participation of managers and workers in safety activities. Rewards are distributed following the evaluation results, directly linking safety performance and tangible incentives. This incentivization model can significantly enhance safety awareness and engagement among construction personnel. In addition to rewards, the system can incorporate mechanisms such as additional bidding points, safety ratings, and reductions in insurance fees, all contingent upon the evaluation scores of the workforce held by companies. This multifaceted approach promotes safety at individual and organizational levels. It aligns safety objectives with broader project and financial considerations, making it a comprehensive and effective strategy for improving safety conditions in the construction industry.

3.2 Applications

3.2.1 Data management

The process of safety condition analysis from on-site images is a multifaceted procedure that seamlessly integrates automated image analysis through computer vision and robust data management, all while leveraging the security of blockchain technology. This comprehensive process involves regular and irregular inspections facilitated by deep learning-based models and cloud-based computing resources. In the first step, regular safety inspections are conducted as scheduled assessments of construction sites. Various devices, such as smartphones or cameras, capture images during these inspections. Subsequently, the captured images are uploaded to a cloud-based system for further analysis, combining the power of computer vision for real-time safety assessment. As shown in Figure

3, once images are uploaded, the inspection process is initiated through user queries and system management. Users interact with the system to initiate inspections based on predetermined intervals or specific triggers, ensuring that safety conditions are consistently monitored using computer vision technology. The system, in turn, effectively manages the entire inspection process, overseeing data collection, analysis, and database management, all while benefiting from the transparency and security of blockchain integration. This systematic approach ensures that inspections are conducted regularly and streamlines the overall process, reducing delays and improving safety outcomes. A key aspect of this procedure lies in data management, further enhanced by blockchain technology. Within the cloud-based system, various types of data are meticulously handled. This includes system management data to maintain the integrity and functionality of the inspection system, project data to manage project-specific details, and user data to regulate access rights and profiles. Inspection data remains at the core of this process, involving records of all inspections and associated metadata such as timestamps, geospatial information, media types, and automatic extraction of relevant metadata from the images. Blockchain technology ensures the immutability and transparency of these critical data records, providing a secure and tamper-proof foundation for the entire safety analysis and incentive distribution process.

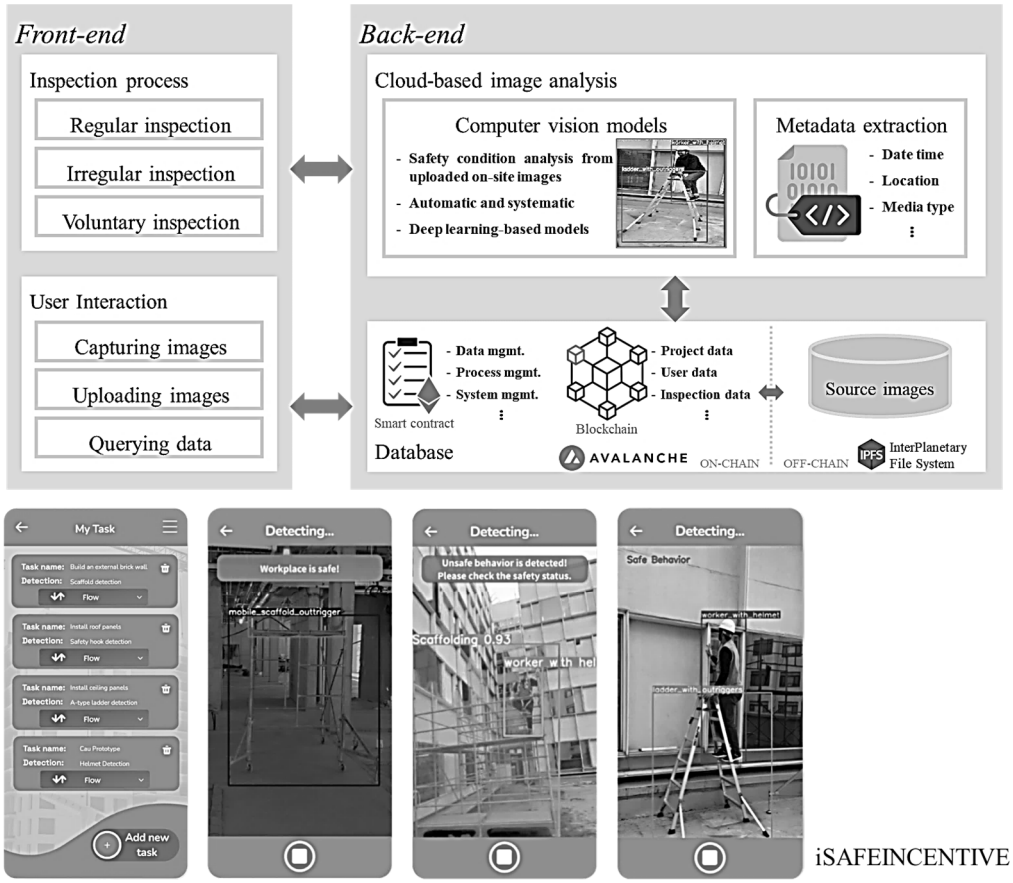

Fig. 3: Blockchain & Computer Vision Integration

3.2.2 Incentive mechanism

The token distribution process within the iSafeincentive platform, facilitated by blockchain technology, is characterized by a systematic sequence of actions. Commencing with continuous monitoring by the platform's AI detectors, the focus is assessing job site activities, including adherence to Personal Protective Equipment (PPE) regulations and safe conduct. Subsequently, vetted data undergoes scrutiny and validation to ensure accuracy and reliability. At the core of this process are smart contracts, meticulously crafted with predefined criteria and rules. These smart contracts serve as the automation engine, enabling the precise allocation of tokens in response to identified safe activities. Tokens are directed to the workers' digital wallets, tightly linked to their unique blockchain identities. Simultaneously, each transaction is recorded within the blockchain ledger, a fundamental feature that underpins transparency and traceability.

Worker notification follows promptly, serving dual purposes: acknowledging the safe behaviors observed and motivating continued adherence to safety protocols. Furthermore, this approach establishes an efficient and transparent record-keeping system. Figure 4 represents the utilization of blockchain technology to streamline the token distribution process. This systematic and secure procedure inspires trust among all stakeholders, enabling workers to employ their tokens in various capacities while cultivating a resilient safety culture within the construction industry.

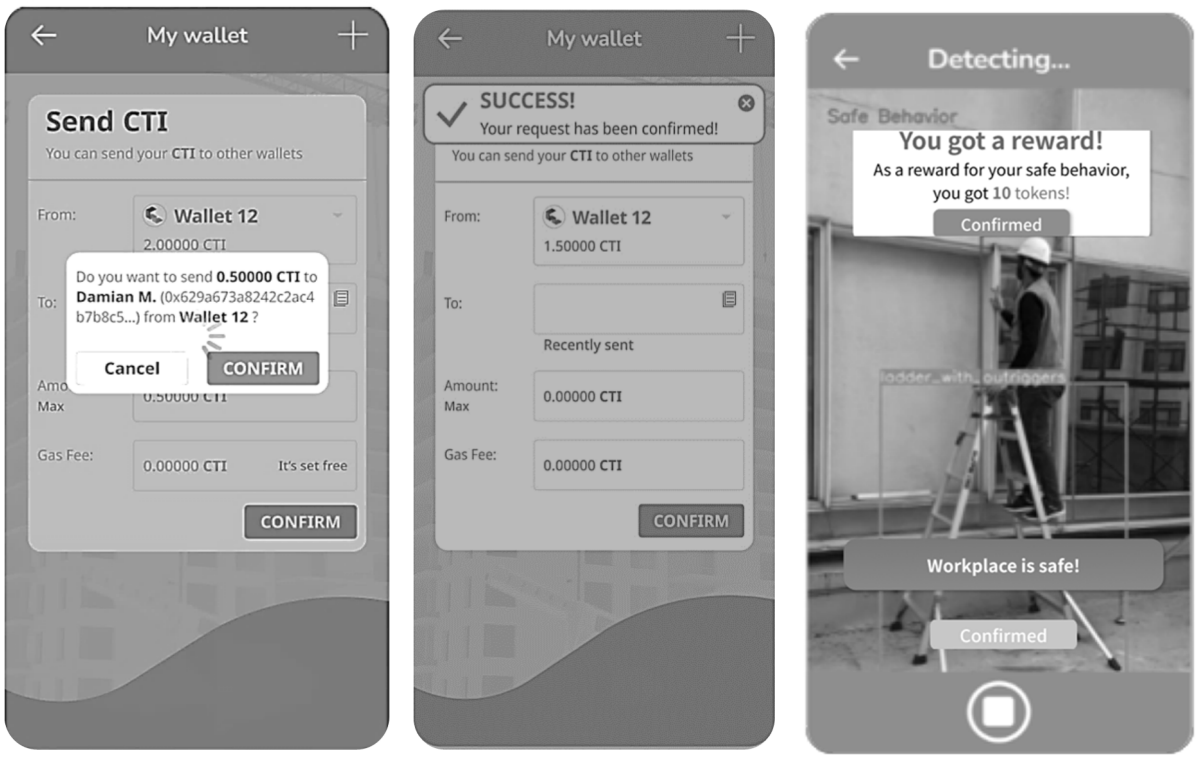

Fig. 4: The procedure for transmitting tokens once the safety measures have been verified through blockchain technology.

4. CONCLUSION

In conclusion, safety culture is vital in the construction industry, significantly influencing safety performance and outcomes. Empirical evidence supports the importance of a safety culture in reducing accidents and incidents within construction organizations. Motivating construction workers to prioritize safety through incentive programs has been crucial. Incentives encouraged safe behaviors, recognized individual efforts, and fostered a collective sense of responsibility for safety. However, as discussed earlier, current incentive methodologies face challenges, including burdensome documentation requirements, delays in distribution, and resource allocation issues. Streamlining documentation processes, reducing distribution delays, and optimizing resource allocation have been essential steps to enhance the effectiveness of incentive programs.

In this study, iSafeincentive has been developed by integrating computer vision and blockchain to automate safety assessments, improving accuracy and efficiency and ensuring the integrity and immutability of safety records and incentives. Blockchain-based incentives have linked safety performance to tangible rewards, enhancing safety awareness and engagement among construction personnel. This multifaceted approach has aligned safety objectives with broader project and financial considerations, demonstrating its potential as a comprehensive strategy for improving safety conditions in the construction industry.

The safety condition analysis process from on-site images combined automated image analysis with systematic inspection strategies, ensuring regular and reliable safety assessments. Token distribution through blockchain

technology followed a systematic sequence, promoting safe behaviors and cultivating a resilient safety culture within the construction industry. Overall, these innovations held great potential for enhancing safety and productivity in construction.

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