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BIMCHAINED: A BLOCKCHAIN SUPPORTED DIGITAL FRAMEWORK FOR REAL-TIME CONSTRUCTION SITE MONITORING

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Abstract

The construction industry uses BIM and Common Data Environments (CDE) for coordination, nevertheless struggles with data integrity, auditability, and trusted verification for safety compliance amid fragmented processes and BIM-blockchain oracle issues. This study proposes a hybrid framework integrating BIM, Dynamo-Python automation for parameter extraction and data validation, cryptographic hashing, and QR-codes linking physical assets to blockchain-ready records. In a Rome heritage refurbishment case study on mobile scaffolding, it produced verifiable inspection registers with compliance status and traceable hashes. The key contribution is a scalable prototype enhancing BIM safety monitoring traceability, enabling blockchain anchoring and openBIM-aligned digital twin provenance.

Introduction and background

The construction industry is currently undergoing a digital transformation to address systemic inefficiencies, fragmented information flows, and high accident rates. While BIM has established a foundational infrastructure for project coordination and clash detection, it still mostly depends on manually updated models and struggles to guarantee data integrity and auditability (Ng et al., 2025). In multi-stakeholder environments, manual verification and paper-based certifications persist, while digital records remain vulnerable to unauthorized modifications, which is particularly critical for safety and regulatory compliance.

CDE facilitate centralized repositories but lack immutable audit trails to link digital models reliably with physical on-site outputs. Integration with blockchain technology offers a distributed paradigm for information management, providing tamper-resistant records and verifiable transaction histories through cryptographic verification. Recent research explores hybrid architectures where large geometric datasets remain in BIM repositories while blockchain infrastructures secure metadata and hash-based fingerprints to help reduce risks of data inconsistency (Wang & Wang, 2025).

Despite this potential, significant gaps remain in the empirical implementation of these technologies within a cohesive, governed pipeline for safety workflows. A primary technical barrier is the oracle problem, the difficulty of ensuring off-chain site data accurately reflects physical conditions before blockchain anchoring (Khuc et al., 2024). To face this, the study employs Dynamo-based computational workflows to support the traceability of physical inspections through cryptographic validation; while visual programming is well-established in BIM design, its systematic application to safety compliance verification remains underexplored. The study targets quality improvement of H&S site inspections, which are labour-intensive, inherently exposed to human error, selecting mobile scaffolding as proof-of-concept, given its role among the leading causes of workplace injuries in construction making systematic and automated compliance verification both technically relevant and practically necessary.

Methodology

The methodology consists in an enhanced integration of BIM environments, Python-based Dynamo scripts, and cryptographic algorithm techniques. The primary objective is to improve transparency and traceability by creating structured, immutable compliance records for subsequent blockchain infrastructure addressing the need for data provenance in collaborative environments where shared datasets risk being revised, overwritten, or lost.

The initial stage focuses on the data modelling layer, defining BIM requirements and safety goals through regulatory analysis, to establish key design principles for parameter selection and rule-based validation logic.

The core of the operational methodology is a BIM–Dynamo pipeline designed for automated parameter extraction and compliance checking, while further developments of the Digital Twin (DT) paradigm could enable continuous synchronization with IoT sensors and actuators to support safety monitoring and data integration (Wu & Li, 2025). Safety-related parameters are extracted directly from the digital model and processed through a Python script integrated into the visual programming environment. In the case study conducted on a heritage masonry building refurbishment project in Rome, five safety-critical parameters were systematically extracted from the BIM model and evaluated against the requirements of UNI EN 1004:2021: configured height, load class, installation context, stabilizer configuration, and guardrail status. The pipeline produced structured inspection registers in which each scaffolding configuration is associated with a compliance label, a cryptographic hash functioning as a unique digital

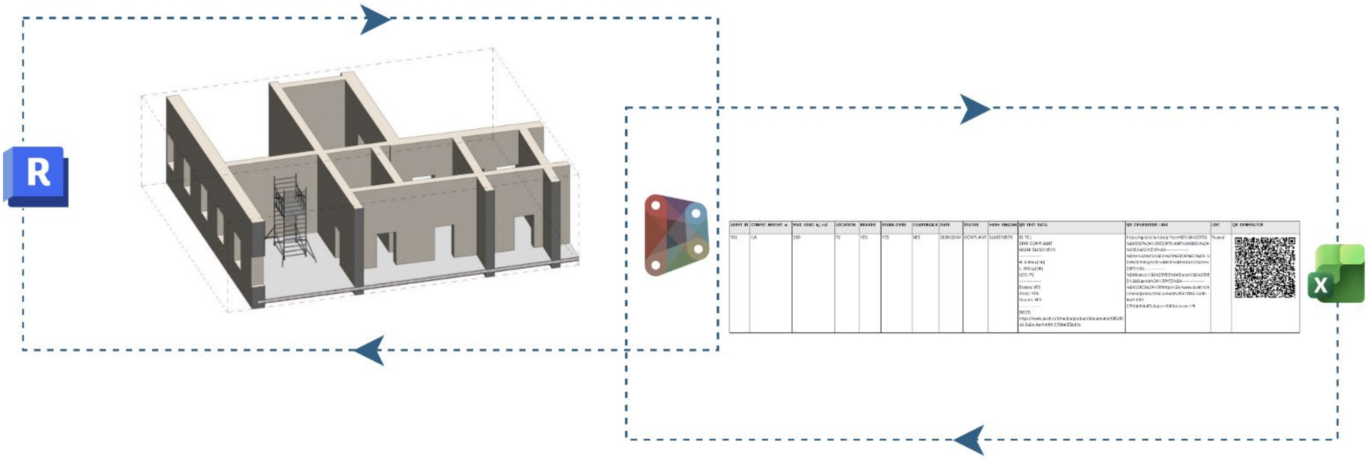

Figure 1: BIM–Dynamo workflow from Revit model to QR-coded inspection register in Excel for mobile scaffolding safety validation.

fingerprint, and a QR code enabling traceability between the physical asset and its digital record within the CDE.

This output represents a measurable improvement over conventional inspection documentation methods, reducing reliance on paper-based or informally managed records while ensuring that only validated, standardized data is prepared for subsequent blockchain checking stage.

Conclusion and discussion

The implementation of blockchain-enabled validation within BIM-based safety workflows contributes to the enhancement of data integrity and compliance documentation. By embedding validation logic directly into BIM platforms via Dynamo and Python, the system supports automated extraction of safety parameters and related compliance assessment. This configuration strengthens the reliability of inspection datasets while supporting structured documentation in multi-stakeholder environments. However, several systemic constraints persist, notably the *oracle problem*, which continues to pose challenges in establishing trusted links between physical site activities and digital verification systems. Additionally, interoperability limitations, scalability concerns, and organizational resistance remain significant barriers to sectoral adoption. Future research will focus on aligning this framework with openBIM specifications and developing more mature smart contract integration scenarios, guided by LLM capabilities integration.

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