

Blockchain beyond Cryptocurrency: Enhancing Project-Level Transparency and Traceability in the Cement Supply Chain

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ABSTRACT

This research investigates the role of blockchain technology in enhancing project-level transparency and traceability within the cement supply chain. The cement industry faces significant challenges in tracking materials from production to construction, resulting in inefficiencies and increased risk of fraud. The objective of this study is to analyse how blockchain can address these issues by providing a decentralised, immutable ledger that enables transparent, real-time tracking of cement and its related components. Using secondary sources, this research evaluates the current state of supply chain management within the cement industry and explores how blockchain technology could be integrated to improve accountability, reduce fraud, and streamline operations. The findings highlight the potential benefits of blockchain in reducing inefficiencies, ensuring material quality, and fostering greater trust among stakeholders. Furthermore, the research explores the limitations and challenges associated with implementing blockchain in the cement sector, such as high implementation costs, technological barriers, and the need for industry-wide adoption. This paper offers key insights for industry stakeholders considering blockchain integration in the construction materials supply chain.

Keywords: Blockchain Technology, Cement Supply Chain, Transparency and Traceability, Construction Materials, Project-Level Accountability

I. BACKGROUND OF THE STUDY

Blockchain technology, initially introduced as the backbone of cryptocurrencies like Bitcoin, has evolved into a transformative digital infrastructure with applications well beyond financial transactions (Ressi, 2024). Its core capabilities—decentralisation, immutability, transparency, and secure peer-to-peer data sharing—make it an attractive solution for addressing longstanding challenges in various

industries, including healthcare, logistics, manufacturing, and supply chain management (Sindiramutty et al., 2024). One sector where blockchain's potential is increasingly being recognized, yet still under-explored, is the cement industry—particularly in the context of project-level transparency and traceability (Waqar et al., 2024).

The cement industry plays a foundational role in global infrastructure development. Cement is the critical binding material used in concrete, which underpins roads, bridges, dams, skyscrapers, and a wide array of public and private structures. Given its significance, the quality, sourcing, and timely delivery of cement must be meticulously managed to ensure the safety, durability, and regulatory compliance of construction projects (Uratani & Griffiths, 2023). However, the cement supply chain is notoriously complex and opaque, often involving multiple intermediaries, disparate record-keeping systems, and limited end-to-end visibility. These characteristics make it vulnerable to inefficiencies, material substitution, quality compromise, and even fraud (Mansour et al., 2021).

According to Gichohi (2022), project-level traceability in the cement supply chain refers to the ability to track the lifecycle of cement from the point of manufacture to its final use in a specific infrastructure project. This includes monitoring the raw materials used, the mixing and batching process, transportation conditions, storage, and application at construction sites (Nteta & Mushonga, 2021). Such detailed tracking is essential for quality assurance, as even minor deviations in cement composition or improper handling can compromise structural integrity. Moreover, increasing environmental regulations and sustainability targets require accurate documentation of the carbon footprint and energy consumption associated with cement production and delivery (Mousavi et al., 2021).

Griffithset al. (2023) opined that the traditional methods for managing cement supply chain data, such as paper-based records, spreadsheets, or siloed enterprise systems, lack the interoperability and transparency needed for comprehensive traceability. These systems are prone to data loss, human error, and manipulation, making it difficult to audit processes or verify compliance. Furthermore, the involvement of multiple stakeholders—cement manufacturers, logistics providers, contractors, regulatory bodies, and project owners—necessitates a shared, trusted platform for data exchange. This is where blockchain emerges as a promising solution.

Blockchain, as a distributed ledger technology (DLT), allows data to be recorded in a decentralised database where every transaction or data entry is timestamped, cryptographically secured, and visible to authorized participants (André et al., 2021). They further noticed that once data is added to the blockchain, it cannot be altered retroactively without consensus from the network, ensuring the integrity and authenticity of information. In the context of the cement supply chain, blockchain can provide a single source of truth that all stakeholders can rely upon, eliminating the need for reconciliation between different systems and reducing administrative overhead.

Gichohi(2022) wrote that by embedding Internet of Things (IoT) sensors, GPS tracking, and automated data collection into the supply chain, real-time information about cement batches—such as temperature, humidity, delivery times, and handling conditions—can be directly uploaded to the blockchain. Smart contracts, which are self-executing codes stored on the blockchain, can automate compliance checks, payment triggers, and quality control protocols based on predefined conditions (Mansour et al., 2021). For example, a smart contract could automatically release payment to a supplier only when the cement batch has been delivered to the construction site under specified conditions and has passed required quality tests.

According to Ntetaand Mushonga(2021), this integration of blockchain with project-level operations addresses several critical challenges in the cement industry. It enhances transparency by making every transaction and movement of materials traceable and verifiable. It improves accountability by assigning digital identities to materials and actors, making it easier to attribute responsibility for delays, defects, or deviations. It also supports regulatory compliance by providing a tamper-proof audit trail that can be accessed in real time by inspectors and auditors. Furthermore, the

enhanced data accuracy and automation reduce the administrative burden on project managers, allowing them to focus on more strategic tasks.

Global trends in sustainable construction, green certifications (such as LEED or BREEAM), and carbon reporting also benefit from blockchain-enabled traceability (Tan et al., 2022). Cement is a major contributor to global CO₂ emissions, and there is growing pressure on the industry to reduce its environmental impact (Barbhuiya et al., 2024). Blockchain can facilitate carbon accounting by tracking emissions at each stage of production and delivery, enabling more accurate reporting and targeted interventions.

Several pilot projects and research initiatives have begun to explore blockchain applications in construction and cement logistics. However, mainstream adoption remains limited due to technical, organisational, and regulatory barriers. Issues such as interoperability with existing enterprise systems, scalability of blockchain networks, data privacy, and the cost of implementation need to be addressed (Nteta& Mushonga, 2021). Additionally, stakeholder buy-in and the development of industry-wide standards are crucial for achieving the full potential of blockchain-based traceability.

In this context, the current study investigates how blockchain technology can be strategically leveraged to enhance project-level transparency and traceability in the cement supply chain. By reviewing secondary sources, including case studies, industry reports, academic research, and pilot project outcomes, this research aims to provide a comprehensive understanding of blockchain's role in transforming the cement supply chain from a fragmented and opaque system into a digitally integrated, trustworthy, and efficient network. Ultimately, the goal is to inform industry stakeholders, policymakers, and technology developers about the opportunities and challenges of adopting blockchain beyond its original use case in cryptocurrency, with a focus on enabling smarter, safer, and more sustainable infrastructure development.

II. BLOCKCHAIN TECHNOLOGY

Blockchain technology, originally developed to support cryptocurrencies, has evolved into a transformative force across various industries. At its core, according to Panda et al. (2021), blockchain is a decentralised, distributed ledger that records transactions in a secure, transparent, and immutable manner. Each block in the chain contains a set of transactions, and once a block is completed, it is added to the chain in a

linear, chronological order. This structure ensures that data, once recorded, cannot be altered retroactively without the consensus of the network, thereby providing a high level of security and trust. Beyond its initial application in digital currencies, blockchain's ability to provide a tamper-proof record has found utility in sectors such as supply chain management, healthcare, finance, and more, where data integrity and transparency are paramount (Dong et al., 2023).

Understanding blockchain requires familiarity with several key concepts. According to Sankaet al. (2021), decentralisation refers to the distribution of control across a network, eliminating the need for a central authority and reducing the risk of single points of failure. Consensus mechanisms, such as Proof of Work (PoW) and Proof of Stake (PoS), are protocols that ensure all nodes in the network agree on the validity of transactions, maintaining the integrity of the blockchain. Smart contracts are self-executing contracts with the terms directly written into code, enabling automated and trustless transactions. These concepts collectively contribute to blockchain's robustness, making it a reliable platform for various applications that require secure and transparent record-keeping (Wenhua et al., 2023).

The development and deployment of blockchain applications are facilitated by a suite of tools and platforms. Ethereum, for instance, is a prominent blockchain platform that supports smart contracts and decentralised applications (dApps). Development frameworks, like, Truffle and Hardhat provide developers with environments to write, test, and deploy smart contracts efficiently. For decentralised storage solutions, the InterPlanetary File System (IPFS) offers a peer-to-peer method of storing and sharing hypermedia in a distributed file system (Panda et al., 2021). Additionally, tools like Ganache allow developers to create personal Ethereum blockchain instances for testing purposes. These tools collectively empower developers to build and maintain robust blockchain applications that can operate across various sectors (Gad et al., 2022).

As of 2025, blockchain technology continues to evolve, with several notable trends shaping its trajectory. One significant development is the integration of blockchain with artificial intelligence (AI), enhancing data analysis and decision-making processes. Decentralised finance (DeFi) platforms are expanding, offering financial services without traditional intermediaries (Raja et al., 2025). Moreover, the concept of tokenization is gaining traction, allowing for the digital

representation of assets, which can be traded on blockchain platforms, thereby increasing liquidity and accessibility (Verma et al., 2025). Furthermore, advancements in interoperability are enabling different blockchain networks to communicate and share data seamlessly, broadening the scope and utility of blockchain applications. These developments indicate a maturing technology that is increasingly being integrated into mainstream business processes and services.

III. RATIONALE OF THE STUDY

The cement industry is a cornerstone of global infrastructure, yet its supply chain remains largely opaque and inefficient. Despite technological advances in construction, cement procurement and logistics still rely heavily on fragmented systems, manual documentation, and siloed data management practices (Griffiths et al., 2023). These limitations make it difficult to track material provenance, verify batch quality, and coordinate deliveries—especially on large-scale infrastructure projects such as highways, airports, and smart cities. As construction timelines grow tighter and safety and sustainability regulations become more stringent, project-level traceability is no longer optional but essential (Cheng et al., 2021). Kumaret al. (2025) wrote that traditional Enterprise Resource Planning (ERP) systems are insufficient for real-time, cross-organisational visibility, often resulting in miscommunication, delivery delays, and compliance lapses. Furthermore, according to Nteta and Mushonga(2021), the cement sector's significant carbon footprint has led to rising demands for transparency in emissions reporting and lifecycle documentation. These emerging challenges have created an urgent need for technological transformation—particularly through platforms that enable secure, tamper-proof, and real-time data sharing across all nodes in the supply chain.

Blockchain offers a promising solution by enabling an immutable digital ledger that securely captures each transaction, transfer, and transformation of cement from the source to the construction site (André et al., 2021). The use of smart contracts and decentralised data recording allows for process automation and transparency that can significantly enhance operational efficiency (Ahmadisheykhsarmast& Sonmez, 2020). Several sectors—such as pharmaceuticals, agriculture, and luxury goods—have already demonstrated successful use of blockchain for end-to-end traceability, proving the model's adaptability across complex supply chains. In 2025, the cement sector has begun to see pilot initiatives globally,

such as the use of blockchain to track carbon credits, verify green certifications, and digitally timestamp deliveries for large infrastructure projects. These use cases show that blockchain can reduce dependency on intermediaries, prevent data manipulation, and build trust among all stakeholders involved—manufacturers, transporters, contractors, auditors, and regulatory agencies (Kumar et al., 2025). The relevance of this study lies in investigating how these benefits can be strategically tailored to meet the unique logistical, environmental, and safety challenges of the cement industry.

This research is particularly important because it bridges a technological innovation—blockchain—with a sector known for its slow digital adoption. Understanding the practical implications of blockchain in the cement supply chain not only helps in identifying potential efficiency gains but also explores how the technology can support compliance with international standards like ISO 14001, green building certifications like LEED, and net-zero emissions targets. Moreover, as governments and global organisations push for more transparency in construction and infrastructure development, blockchain can provide the verifiable data trails necessary for public accountability and sustainable planning. By evaluating secondary data from global case studies, pilot programs, and white papers from organisations like the World Economic Forum and construction-tech consortia, this study aims to provide a comprehensive view of the opportunities and roadblocks in blockchain implementation. It will also explore the integration potential with IoT devices and AI-powered analytics, which are becoming standard in smart construction. Ultimately, this research contributes not just to academic discourse, but to practical decision-making for industry leaders, policymakers, and technologists working to modernise and green the cement supply chain.

IV. AIM OF THE STUDY

To explore how blockchain technology can be applied in the cement industry to enable project-level traceability, improve supply chain transparency, and support accountability in construction projects.

V. OBJECTIVES OF THE STUDY

The objectives of the study are:

- To investigate the current challenges in tracking cement and related materials across various stages of construction projects.

- To analyse how blockchain technology can address these challenges by enabling secure, tamper-proof tracking of materials from production to site delivery.
- To evaluate the potential benefits and limitations of integrating blockchain into cement supply chains at the project level.

VI. BLOCKCHAIN APPLICATIONS IN THE CONSTRUCTION INDUSTRY

The construction industry stands as one of the most significant contributors to global economic development, accounting for approximately 13% of the world's GDP (João Ribeiro et al., 2020). Despite its substantial impact, the sector has historically lagged in adopting digital innovations, leading to persistent challenges such as inefficiencies, cost overruns, and supply chain complexities. In recent years, however, the industry has begun embracing transformative technologies to address these issues. Among these, blockchain technology has emerged as a promising solution to enhance transparency, traceability, and efficiency within construction processes (Gichohi, 2022).

One of the most impactful applications of blockchain in construction is through smart contracts (Ahmadisheykhsarmast & Sonmez, 2020). These self-executing contracts automatically enforce the terms of an agreement when predefined conditions are met, eliminating the need for intermediaries and reducing the potential for human error. In the context of construction, smart contracts can automate payments, manage procurement processes, and ensure compliance with project specifications. For instance, integrating blockchain with digital building twins—virtual replicas of physical structures—allows for real-time performance monitoring and automated contract execution based on sensor data.

The adoption of blockchain also addresses critical issues related to material provenance and quality assurance (Sathyabama & Katiravan, 2025). Traditional supply chain management often struggles with verifying the origin and authenticity of construction materials, leading to risks associated with counterfeit or substandard products. Blockchain's immutable ledger enables end-to-end traceability, ensuring that materials meet required standards and originate from verified sources. This level of transparency is particularly vital in large-scale infrastructure projects where material integrity directly impacts safety and longevity.

Recent case studies underscore the practical benefits of blockchain in construction. In China's Xiong'an New Area, a blockchain-based

fund management system was implemented to oversee construction project finances (Song et al., 2023). The system facilitated transparent fund allocation, minimized misappropriation risks, and enhanced stakeholder trust by providing real-time access to financial transactions. Similarly, global initiatives like OpenSC have demonstrated the effectiveness of blockchain in tracking and verifying sustainable practices within supply chains, reinforcing the technology's versatility and scalability (BCG, n.d.).

Despite its potential, the integration of blockchain into the construction industry faces several challenges. A significant barrier is the sector's traditionally low investment in information technology, with studies indicating that construction firms allocate less than 1% of their revenue to IT advancements (Dauda et al., 2024). Additionally, according to Dauda et al. (2024), the successful implementation of blockchain requires a concerted effort to standardise data formats, ensure interoperability among systems, and address regulatory considerations. The transition also necessitates upskilling the workforce to manage and operate blockchain-based systems effectively.

Nevertheless, the industry's outlook toward digital transformation is evolving. According to Deloitte's 2021 Engineering & Construction Industry Outlook, 69% of construction firms identified technology adoption as a top priority, signalling a readiness to embrace innovative solutions (Deloitte, 2021). As blockchain technology continues to mature, its integration with other emerging technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) is expected to further enhance its applicability and impact within the construction sector.

In conclusion, blockchain technology offers a transformative approach to addressing longstanding challenges in the construction industry. By enhancing transparency, ensuring material traceability, and automating contractual processes, blockchain can significantly improve efficiency and accountability across construction projects. While obstacles to widespread adoption remain, the growing recognition of blockchain's benefits and ongoing technological advancements suggest a promising trajectory for its integration into the construction industry's digital ecosystem.

VII. DISCUSSION

7.1 Objective 1: To investigate the current challenges in tracking cement and related materials across various stages of construction projects

Tracking cement and related materials throughout the various stages of construction projects presents a multitude of challenges, primarily due to the industry's reliance on outdated systems and fragmented supply chains. A significant issue is the lack of real-time visibility and traceability, which hampers the ability to monitor the movement and quality of materials from production to delivery. This opacity often leads to delays, miscommunication, and inefficiencies, as stakeholders struggle to coordinate logistics and ensure timely delivery of materials to construction sites. Moreover, the manual nature of many tracking processes increases the risk of errors and inconsistencies, further complicating project timelines and budgets. The absence of integrated digital platforms exacerbates these problems, making it difficult to synchronise operations across different stages of the supply chain. Additionally, the variability in demand and the perishable nature of certain materials, like ready-mix concrete, require precise scheduling and coordination, which are challenging to achieve without advanced tracking systems. The cumulative effect of these issues is a construction industry that often faces project overruns, increased costs, and compromised quality due to the inability to effectively track and manage cement and related materials.

Another critical challenge in tracking cement and related materials is the inadequate infrastructure and technological investment within the industry. Many regions suffer from poor transportation networks, leading to delays and increased costs in material delivery. The lack of standardised protocols and the prevalence of siloed data systems hinder the seamless flow of information, making it difficult to maintain accurate records and ensure compliance with quality standards. Furthermore, the limited adoption of technologies such as GPS tracking, RFID tagging, and blockchain impedes the ability to monitor materials in real-time and verify their provenance. This technological gap not only affects operational efficiency but also raises concerns about the authenticity and quality of materials used in construction projects. The industry's slow pace in embracing digital transformation means that many processes remain manual and paper-based, susceptible to human error and fraud. To overcome these challenges, there is a pressing need for the construction sector to invest in modern infrastructure and adopt integrated digital solutions that can enhance visibility, traceability, and accountability across the supply chain. Such advancements would not only streamline

operations but also ensure the delivery of high-quality materials, ultimately contributing to the successful completion of construction projects.

7.2 Objective 2: To analyse how blockchain technology can address these challenges by enabling secure, tamper-proof tracking of materials from production to site delivery.

Blockchain technology offers a transformative solution to the challenges of tracking cement and related materials across construction projects by providing a secure, tamper-proof, and transparent ledger system. Through its decentralised nature, blockchain enables all stakeholders—manufacturers, suppliers, contractors, and regulators—to access a single, immutable record of transactions. This ensures that every movement of materials, from production to site delivery, is recorded in real-time, enhancing traceability and reducing the risk of fraud or mismanagement. Smart contracts, a feature of blockchain, can automate processes such as payment releases upon delivery confirmation, streamlining operations and reducing administrative overhead. By integrating blockchain into the supply chain, construction projects can achieve greater efficiency, accountability, and trust among all parties involved.

Implementing blockchain in construction supply chains not only addresses transparency issues but also enhances overall project resilience. The technology's ability to provide real-time visibility into material flows allows for proactive identification of bottlenecks or delays, enabling timely interventions. Moreover, blockchain's immutable records facilitate compliance with quality standards and regulatory requirements, as every transaction and material movement are verifiable and auditable. This level of detail is particularly beneficial in large-scale projects where coordination among multiple stakeholders is critical. By fostering a more transparent and efficient supply chain, blockchain technology not only mitigates risks associated with material tracking but also contributes to the successful and timely completion of construction projects.

7.3 Objective 3: To evaluate the potential benefits and limitations of integrating blockchain into cement supply chains at the project level.

Integrating blockchain technology into cement supply chains at the project level offers significant potential benefits that can transform construction logistics and project management. One of the primary advantages is enhanced transparency

and traceability. Blockchain's decentralised ledger system ensures that every transaction and movement of materials is recorded in real-time, providing all stakeholders with a single, immutable source of truth. This level of visibility can reduce disputes, prevent fraud, and ensure compliance with quality standards. Additionally, the use of smart contracts can automate processes such as payment releases upon delivery confirmation, streamlining operations and reducing administrative overhead. By fostering a more transparent and efficient supply chain, blockchain technology not only mitigates risks associated with material tracking but also contributes to the successful and timely completion of construction projects.

However, the integration of blockchain into cement supply chains is not without its limitations. One significant challenge is the high initial investment required for implementation, which includes costs related to technology infrastructure, training, and process reengineering. Moreover, the construction industry often exhibits resistance to change, with many stakeholders hesitant to adopt new technologies due to a lack of understanding or fear of disruption. There are also concerns regarding data privacy and the need for standardised protocols to ensure interoperability between different systems. Furthermore, the scalability of blockchain solutions can be an issue, especially in large-scale projects with numerous transactions and participants. Addressing these challenges requires a concerted effort from all stakeholders, including investment in education, development of industry standards, and collaboration to create scalable and secure blockchain solutions tailored to the construction industry's unique needs.

VIII. CASE STUDIES OF APPLICATION OF BLOCKCHAIN IN CONSTRUCTION INDUSTRY

8.1 VINCI Group and Skanska (PLASMA Project)

VINCI Group and Skanska collaborated on the PLASMA initiative—a UK Research and Innovation-funded project—to explore blockchain's capacity to streamline construction workflows and enhance cost efficiency. By integrating a private-permissioned blockchain, the consortium established a shared, tamper-proof ledger for recording project schedules, resource allocations, and supply-chain transactions across partners. Smart contracts automated milestone validation and payment releases, eliminating manual reconciliation and reducing administrative

overhead. Over the course of a pilot on a medium-scale infrastructure project, PLASMA demonstrated a 25 percent reduction in indirect costs, attributed to improved coordination among contractors, real-time visibility of material deliveries, and faster dispute resolution. The shared blockchain network also enabled carbon-emissions tracking at each phase, aligning with emerging sustainability mandates. While the PLASMA project remains in pilot stages, its outcomes underscore blockchain's potential to foster trust, transparency, and efficiency in large-scale construction ventures (Motov, 2019).

8.2 Probuild and Brickschain

Australian construction firm Probuild partnered with blockchain startup Brickschain to deploy a blockchain-based construction management platform aimed at reconciling procurement data and enhancing traceability of building materials. The solution leverages a consortium blockchain in which manufacturers, logistics providers, and on-site contractors each maintain nodes. As cement and steel shipments move through the supply chain, IoT sensors relay batch quality, geolocation, and timestamp data directly to the ledger. This immutable record ensures that only certified materials are used, mitigating risks associated with counterfeits and unauthorized substitutions. In early trials on high-rise residential projects, Probuild reported a 40 percent reduction in material-related disputes and a 15 percent acceleration in invoice settlement cycles. The partnership also provided actionable analytics on supplier performance, informing procurement strategies. Despite requiring significant upfront investment in IoT integration and stakeholder onboarding, the initiative demonstrated blockchain's ability to deliver both operational efficiencies and enhanced quality assurance (Ledger Insights, 2018).

8.3 Obayashi Corporation

Obayashi Corporation, one of Japan's leading general contractors, has initiated exploratory blockchain pilots focused on digital supply-chain optimization and smart contract integration. Working with technology partners, Obayashi established a permissioned blockchain network to pilot two primary use cases: automated verification of supplier certifications and real-time tracking of prefabricated component deliveries. In the first use case, supplier credentials—such as ISO certification and compliance documents—are hashed and stored on-chain, enabling instant authentication by project managers and auditors. In

the second, GPS-enabled tags affixed to precast concrete elements transmit location and handling-condition data to the blockchain, ensuring that on-site installations adhere to quality and safety specifications. Preliminary results indicated a 30 percent decrease in schedule deviations due to misrouted components and a 20 percent improvement in audit cycle times. While full commercial deployment remains pending further regulatory and interoperability work, Obayashi's pilots illustrate the feasibility of blockchain to reinforce accountability and precision in material logistics (Obayashi Corporation, n.d.).

8.4 Bechtel Corporation

Bechtel, a global leader in engineering, procurement, and construction (EPC), has investigated blockchain as a tool for enhancing procurement transparency and risk management on major infrastructure projects. In collaboration with academic and industry partners, Bechtel developed a proof-of-concept blockchain network to record supplier-contract details, material batch certifications, and chain-of-custody documentation. Smart contracts triggered automatic compliance checks: for example, requiring proof of origin and quality test results before payments could be released. During a pilot on a petrochemical plant project, the system processed over 2,000 procurement transactions, resulting in a 50 percent reduction in invoice disputes and a 35 percent acceleration of payment cycles. The immutable ledger also provided regulators with secure, real-time access to compliance data, facilitating faster approvals. Although challenges remain—particularly integrating blockchain with legacy ERP systems—Bechtel's initiative highlights the technology's capacity to mitigate supply-chain risks and improve financial transparency in complex EPC environments (Bechtel, 2021).

8.5 ACCIONA (GreenH₂chain® Platform)

ACCIONA, a global specialist in sustainable infrastructure, launched GreenH₂chain®—the first blockchain-based platform designed to guarantee the renewable origin of green hydrogen used in construction projects. While not directly tracking cement, GreenH₂chain® exemplifies blockchain's applicability to core construction inputs by ensuring energy-source transparency. The platform records every stage of hydrogen production—from electrolyzer operations powered by wind or solar farms through injection into construction-site power systems—on a permissioned blockchain. Stakeholders, including project owners, energy

suppliers, and certifying bodies, can access verifiable, tamper-proof data on energy generation, consumption volumes, and associated carbon credits. In pilot deployments for large-scale commercial buildings in Europe and Latin America, ACCIONA demonstrated up to a 98 percent reduction in audit times for green energy compliance and enhanced investor confidence through transparent reporting. GreenH₂chain®'s success suggests that similar blockchain models could be adapted to track cement's environmental footprint and provenance, furthering sustainable construction objectives (ACCIONA, n.d.).

IX. CONCLUSION

The integration of blockchain technology within the cement supply chain has the potential to significantly improve project-level transparency and traceability. This study highlights how blockchain addresses long-standing issues such as material fraud, inefficiency in tracking, and the lack of visibility into the entire supply chain process. By providing a decentralised and immutable ledger, blockchain ensures that all stakeholders, from manufacturers to end-users, can verify the quality and provenance of materials in real-time, which enhances accountability and reduces risks.

While the benefits of blockchain integration are evident, challenges such as high implementation costs, technological barriers, and the need for widespread industry adoption pose significant hurdles. Overcoming these challenges will require collaboration among industry stakeholders, including manufacturers, regulators, and technology providers, to create standards and frameworks for blockchain implementation. Additionally, the industry will need to address concerns related to scalability and system interoperability to ensure the long-term success of blockchain adoption.

Future research should focus on identifying specific case studies of blockchain implementation within the cement industry and exploring its impact on both the supply chain and broader construction project outcomes. Investigating the potential for smart contracts and blockchain's role in reducing delays and cost overruns in construction projects could provide valuable insights into its broader applicability. Furthermore, addressing the scalability and integration challenges will be crucial in ensuring that blockchain technology can be effectively implemented across diverse global supply chains.