A Review of Blockchain-based Quality Information Management Systems in Shipbuilding Industry

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Summary

Quality management in manufacturing faces persistent challenges related to transparency, traceability, and data integrity across complex, multi-stakeholder production environments. This paper presents a systematic literature review investigating the potential of blockchain technology as a foundation for decentralized, trust-enhancing information systems in quality control and quality management in shipbuilding industry. By analyzing 55 peer-reviewed publications from Web of Science and Scopus databases, the study identifies key thematic clusters in current research, including supply chain traceability, smart contract automation, and the integration of blockchain within Industry 4.0 quality frameworks. Based on these insights, the paper proposes a conceptual framework for a blockchain-based quality management architecture tailored to the operational and regulatory needs by the manufacturing industry with the focus on shipbuilding. The system design emphasizes permissioned access, tamper-proof quality records, and programmable compliance through smart contracts. While the review affirms the conceptual feasibility of such systems, it also highlights areas for further research, particularly regarding system governance, interoperability, and implementation. This work provides a theoretical foundation for future development of a proof-of-concept platform aimed at validating blockchain-driven quality control and lifecycle compliance in shipbuilding.

Ključne riječi: *blockchain, smart contracts, quality control, quality management, shipbuilding*

1. Introduction

The manufacturing sector, and shipbuilding in particular, is undergoing a profound transformation catalyzed by the Fourth Industrial Revolution, characterized by the convergence of cyber-physical systems, data analytics, and automation under the term of Industry 4.0 (Tambare et al., 2022). Within this shifting industrial landscape, quality management has emerged as a domain undergoing redefinition in Quality 4.0 (Bankoff et al., 2023). As manufacturing processes become increasingly distributed, multi-tiered, and technologically complex, ensuring product integrity, regulatory compliance, and customer satisfaction demands a shift in how quality is monitored, managed, and assured across the whole value chain.

For the background and context, quality management practices have historically heavily relied on centralized information systems, manual inspection logs, and trust-based supplier relationships. While these approaches have supported the industry for decades, their limitations are becoming increasingly evident. In manufacturing sectors, where precision, regulation, and traceability are non-negotiable, existing quality control systems often fall short in ensuring transparency, data integrity, and end-to-end traceability (AlKhader et al., 2020). Information asymmetry, a key driver of communication risk which happens when one party in a communication exchange knows more than the other while their interests aren't aligned (Ceric, 2021), along with the data fragmentation, and susceptibility to manipulation or omission, continue to challenge quality assurance across multiple phases. At the same time, the supply chain, comprising multiple specialized suppliers, subcontractors, and service providers, exemplifies a setting where seamless, immutable, and verifiable data sharing is essential. The integration of blockchain technology may offer a response to these structural and operational deficits by enabling decentralized, tamper-proof recording of quality events where blockchain introduces trust by design, creating a single version of verified truth accessible to all permitted stakeholders (Sahoo, 2024; Westphal et al., 2023). Furthermore, smart contracts which are programmable blockchain elements, allow for the automatic enforcement of quality thresholds, compliance rules, and technical specifications that can reduce human error, bias, and delay in quality assurance processes (AlKhader et al., 2023). Further distinctions and detailed elaborations on the terms Quality Management, Quality Control, and Quality Management System, including their differences and implications, will be clearly addressed and defined in subsequent sections of this paper.

1.1. Rationale and Problem Statement

The challenges in quality management in manufacturing lies in the lack of trustworthy, interoperable, and real-time quality information. Existing digital systems are often fragmented and developed in isolation by contractors or departments, with little incentive or capacity for cross-organizational integration (Brandín & Abrishami, 2024; Wang et al., 2024). The reliance on human mediation in quality workflows, from paper-based inspection logs to third-party audits, introduces delays and increases the risk of fraud, omission, or inconsistency.

As highlighted in recent literature, the fragmentation of quality data across the manufacturing ecosystem leads to systemic inefficiencies and undermines transparency (Wang et al., 2017; Ali et al., 2022; Li et al., 2020). These inefficiencies become particularly problematic when products and components traverse global value chains and involve sequential assembly stages, each with its own quality checkpoints.

To build a common conceptual foundation, the following section defines key terms and frameworks relevant to the paper's analytical focus. These definitions are drawn from contemporary literature and framed in relation to the shipbuilding and advanced manufacturing contexts. Quality Management refers to the structured set of activities and principles aimed at ensuring that products or services meet defined performance, safety, and compliance standards. It encompasses strategic and operational processes, ranging from policy development and resource allocation to inspections, audits, and continuous improvement cycles (ISO 9001:2015). Within manufacturing, quality management has evolved from reactive defect detection to proactive, data-driven assurance processes integrated across the entire product lifecycle (Tambare et al., 2022). The emerging Quality 4.0 paradigm extends traditional quality principles by integrating digital technologies such as artificial intelligence, the Internet of Things (IoT), and blockchain. In this view, quality is not a final checkpoint, but an embedded, real-time dynamic process guided by data, automation, and machine-level intelligence (Bankoff et al., 2023; Kodumuru et al., 2025).

Quality control (QC) refers specifically to the inspection and testing activities designed to detect defects and ensure that outputs conform to specifications. While traditionally associated with final-stage inspection, modern QC systems are integrated throughout the production chain, using real-time sensors, automated testing routines, and feedback loops. The effectiveness of QC is heavily dependent on the accuracy, integrity, and timeliness of data. Recent research emphasizes the vulnerability of QC systems to data tampering, omission, and inconsistent documentation, particularly in settings where subcontractors and external suppliers manage key quality checkpoints (Ng et al., 2023).

A Quality Management System (QMS) is a formalized framework that outlines policies, procedures, and responsibilities for achieving quality objectives. The ISO 9001 standard remains the dominant global benchmark, focusing on customer satisfaction, process improvement, and risk-based thinking. However, modern QMS platforms face limitations in multi-party environments due to their centralized design and lack of native support for distributed verification. Blockchain-enhanced QMS, sometimes referred to as decentralized quality networks, introduce transparency, immutability, and traceability into quality documentation and governance. These systems can track not only non-conformance reports or corrective actions but also the complete audit trail of all quality-related decisions and data entries (Ali et al., 2022; Ahmad et al., 2023).

Supply chain management (SCM) involves the coordination of materials, information, and financial flows across suppliers, manufacturers, logistics providers, and customers. In industries such as shipbuilding, where hundreds or thousands of components and raw materials converge in tightly regulated assembly sequences, traceability becomes an essential function not only for logistics but also for quality verification, warranty compliance, and legal accountability. Traceability allows stakeholders to track the origin, movement, processing, and transformation of every component and while blockchain technologies offer a decentralized ledger for tracking assets, capturing events such as material inspections, transit conditions, handover confirmations, and supplier certifications with immutable timestamps (Yu et al., 2021; Sahoo, 2024). Smart contracts can further enhance SCM by automating supplier validation, delivery acceptance, and regulatory notifications. At its core, blockchain is a cryptographically secured, distributed ledger system. It stores transaction records across a network of nodes in a structure that is immutable and verifiable. In manufacturing, blockchain can be used to securely record quality control results, supplier certifications, material handling events, and audit logs without relying on a central authority (Wang et al., 2024). This decentralized architecture that allows trust in environments where stakeholders may have conflicting interests or limited visibility into each other's processes, which is particularly relevant for shipbuilding, blockchain ensures that quality records are not retroactively altered and that all entries are attributable and auditable by design. Blockchain frameworks that support smart contracts, which are automated protocols that execute specific actions when predefined conditions are met can be used to automatically flag non-conforming inspection results, approve shipments only upon certificate validation, or trigger corrective workflows based on sensor input anomalies. They reduce reliance on manual approval chains and ensure consistent, rule-based compliance (Shahbazi & Byun, 2021). Also, in the industrial contexts, consortium blockchains, as a specific type of permissioned blockchain, offer a balance between openness and control. Unlike public blockchains, which allow unrestricted access, consortium chains restrict participation to known, vetted organizations, making them ideal for regulated environments such as aerospace, automotive, and shipbuilding. This model enables manufacturers, subcontractors, classification societies, and clients to participate in a shared quality governance system with role-based permissions and distributed consensus (Matenga & Mpofu, 2022).

The aim of this review paper is to systematically examine the literature at the intersection of blockchain technology, quality management practices, and traceability within manufacturing and/or shipbuilding sectors. The goal is not merely to assess technical feasibility, but to develop a conceptual foundation for designing blockchain-enabled Quality in shipbuilding that can be validated in subsequent proof-of-concept implementations. The literature review conducted herein serves for identifying key themes, recurring issues, and implementation pathways and designs in industries as observed in recent academic and applied research.

2. Methodology

This paper follows a systematic literature review (SLR) methodology to critically examine the academic contributions at the intersection of blockchain technology, quality control/management, and industrial/manufacturing applications, with a particular emphasis on the shipbuilding sector. The primary objective of this review is to assess the viability and scholarly foundation for blockchain-based solutions to address long-standing challenges in quality management regarding transparency, traceability, and trust across extended manufacturing and supply chains and to check for the foundations of designing a blockchain-enabled quality information management framework in the shipbuilding industry. The review process was designed to ensure a comprehensive, unbiased, and replicable exploration of relevant literature, encompassing recently published research seeking to answer following research questions:

RQ1: How has blockchain technology been conceptualized and applied in the domain of quality control and quality management across industrial contexts?

RQ2: What are the documented benefits and limitations of blockchain-based solutions in enhancing traceability, data integrity, and transparency in supply chains?

RQ3: Is there empirical or conceptual support in the literature for implementing blockchain in shipbuilding-related quality processes?

Two well-established academic databases were used to identify relevant peer-reviewed articles, Web of Science (WoS) Core Collection and Scopus, where the search strategies were crafted using Boolean logic to capture relevant intersections between blockchain, quality management/control, and industrial applications. To ensure the relevance and quality of studies, peer-reviewed articles and reviews were chosen, published after 2021 with an explicit mention of blockchain in the context of quality management, quality control, or traceability. The specific query in both databases was ("quality control" OR "quality management") AND blockchain AND (industry OR industries OR manufacturing OR shipbuilding) AND PUBYEAR >= 2021 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")). Abstracts were read to check for the domains of applications within manufacturing, industrial processes or shipbuilding. Exclusion criteria involved papers focused solely on financial or cryptocurrency applications, articles without abstracts or full-text availability and duplicates between database results which were taken care of manually and programmatically based on titles and DOIs. A total of 55 unique records were retained after cleaning and formed the basis for analysis. The papers' quality was assumed based on their inclusion in reputable, peer-reviewed journals that are indexed in before mentioned databases but was not assessed using formal quality appraisal criteria. Later, the study employed a narrative synthesis approach, emphasizing conceptual clustering and thematic mapping of the literature published to categorize papers based on primary focus: quality control, quality management, supply chain traceability, blockchain frameworks, smart contracts, and industrial implementation to identify recurring patterns, such as technological architectures, benefits and reported challenges and to trace sector-specific applications, especially in construction, aerospace, pharmaceutical, and indirectly related heavy industries to draw parallels to shipbuilding contexts as the empirical research focused explicitly on blockchain applications in shipbuilding was very scarce. For the limitations, this review is limited by the scope of its search terms and database selection. Some relevant work may reside in grey literature or domain-specific engineering databases not included.

In the next chapter, we present the results of the systematic review by synthesizing cross-sectoral findings from the literature and critically analyzing how blockchain applications are evolving within quality and manufacturing contexts, specifically organized into thematic clustering, domain mapping of industrial examples, and implications found for shipbuilding.

3. Systematic Literature Review

3.1. Thematic Taxonomy of Application Areas

To better understand the landscape of research on blockchain applications in quality-related industrial domains, the identified literature was classified using a thematic clustering approach. Abstracts from 55 unique publications were analyzed for keyword frequency and semantic patterns. For text preprocessing, all abstracts were converted to lowercase, punctuation and special characters were removed using a regular expression, and words were tokenized and then lemmatized to their base forms using NLTK's WordNetLemmatizer. Using a combination of CountVectorizer for term extraction with parameters stop_words='english', min_df=5, max_df=0.8, ngram_range=(1, 2) with default analyzer "word" and lowercase=True. PCA was used for dimensionality reduction with the following parameters: n_components=0.85, random_state=42 and KMeans clustering with tha parameters k-means++, run with n_init=10, max_iter=500 and random_state=42, where four distinct thematic groups emerged with the following distribution of papers:

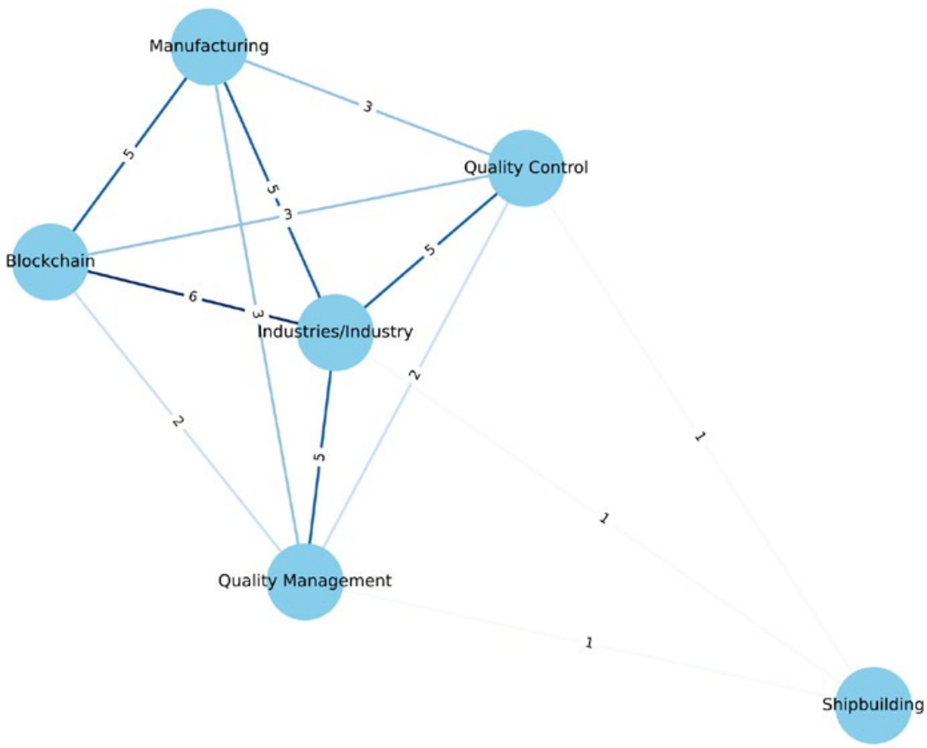
Table 1. Distinct thematic groups from keyword frequency and semantic patterns

Cluster ID	Dominant Theme	Representative Topics	No. of Papers
Cluster 0	Blockchain Integration with AI & IoT for Quality	AI-enhanced inspections, IoT for real-time data, blockchain-enabled automation	16
Cluster 1	Traceability and Supply Chain Transparency	Supply chain integration, digital traceability, multi-tier manufacturing logistics	24
Cluster 2	Smart Contracts in Quality Compliance	Compliance verification, digital certification, regulatory auditing, rules enforcement	2
Cluster 3	Quality Management Frameworks in Industry 4.0	QMS modernization, organizational models, strategic quality systems with digital layers	13

These themes offer strong conceptual overlaps with the objectives of this study, particularly Clusters 1 and 2, which address traceability and compliance which are central concerns in the shipbuilding industry. To further validate, a curated set of domain-relevant keywords: "blockchain", "industry/industries", "shipbuilding", "manufacturing", "quality control", and "quality management" with the exemption of generic and high-frequency academic terms such as "study", "technology", "data", or "proposed", "paper" were intentionally excluded in text preprocessing for keyword frequency analysis. Then, a co-occurrence matrix was constructed to quantify how often each pair of keywords appeared together in the same abstract. Terms were considered co-occurring if they appeared within the same abstract, regardless of proximity. The matrix was transformed into a network graph with edge weights proportional to co-occurrence frequency showing in Figure 1.

The frequency analysis revealed that "blockchain" was the most dominant term, underscoring its centrality in current research narratives around quality systems. This was followed by "manufacturing" and "industry/industries", which together reflected the broader context within which quality management systems are being explored. The terms "quality control" and "quality management" appeared moderately across the corpus, while "shipbuilding" was less frequent but present, indicating a niche and underexplored application area. The co-occurrence network graph offers valuable structural insights as linkages were observed between "blockchain" and both "manufacturing" and "quality management", suggesting a thematic focus on digital traceability and quality assurance mechanisms within industrial environments. Interestingly, "shipbuilding" exhibited notable co-occurrence primarily with "quality management" and "blockchain", reinforcing its relevance as a high-integrity domain where immutable records and decentralized control can provide significant value.

Figure 1. Keyword co-occurrence network graph



3.2. Research papers across different industrial domains

To provide a structured perspective of blockchain application across various industrial domains, domain mapping was performed by categorizing the analyzed papers based on their explicit mention of specific industry contexts. The following table illustrates the quantitative distribution and representative titles from each identified domain, offering a clear overview of current research emphasis and practical implementations of blockchain-based quality management solutions across diverse industrial landscapes again showing limited direct empirical research in shipbuilding.

The domain mapping underscores the dominance of research efforts in general manufacturing, food, pharmaceutical, and construction industries, reflecting their early adoption and exploration of blockchain technology. Notably, specific studies directly addressing shipbuilding remain scarce, emphasizing an important research gap. Consequently, insights from the aerospace, construction, and pharmaceutical sectors, known for stringent regulatory requirements and complex quality management systems like shipbuilding, are used extensively as analogies throughout this review. Recognizing sectoral differences, future research specifically tailored to shipbuilding's unique regulatory, operational, and technical environments is essential to validate the transferability of these findings.

Table 2. Distribution of reviewed literature across different industries with selected titles

Industrial Domain	Number of Papers	Representative Titles
General Manufacturing	17	"Blockchain-Enabled Open Quality System for Smart Manufacturing: Applications and Challenges" (Ali et al., 2022); "Integrating Lean Six Sigma with blockchain technology for quality management - a scoping review" (Ahmad et al., 2023); Integration of Blockchain, IoT and Machine Learning for Multistage Quality Control and Enhancing Security in Smart Manufacturing (Shahbazi et al., 2021);
Logistics and Supply Chain	13	Value and Design of Traceability-Driven Blockchains (Cui et al., 2023); Blockchain-enabled traceability systems for supply chain quality management: empirical insights from manufacturers (Sahoo, 2024); Blockchain-based Supply Chain System for Traceability, Regulation and Anti-counterfeiting (Lau et al., 2021); Application of IoT and blockchain technology in the integration of innovation and industrial chains in high-tech manufacturing (Li et al., 2025)
Food & Agriculture	9	Industry 4.0 digital transformation: Shaping the future of food quality (Bisht et al., 2025); Blockchain-based fresh food quality traceability and dynamic monitoring: Research progress and application perspectives (Yu et al., 2024); Integrating AI with detection methods, IoT, and blockchain to achieve food authenticity and traceability from farm-to-table (Liu et al., 2025); Enhanced Food Quality by Digital Traceability in Food Processing Industry (Verna et al., 2025);
Pharmaceutical	6	Smart Pharmaceutical Manufacturing: Ensuring End-to-End Traceability and Data Integrity in Medicine Production (Leal et al., 2021); Artificial Intelligence and Internet of Things Integration in Pharmaceutical Manufacturing: A Smart Synergy (Kodumuru et al., 2025); Blockchain Applications for Improving Track and Trace Process on Pharmaceutical Supply Chain (Lahjouji et al., 2022);
Construction	3	"IoT-BIM and blockchain integration for enhanced data traceability in offsite manufacturing" (Brandín & Abrishami, 2024); Quality Control for Offsite Construction: Review and Future Directions (Liu et al., 2022); Blockchain-enabled platform for the quality management of the ready-mixed concrete supply chain (Wang et al., 2024);
Aerospace, Aviation, Automotive	6	"Blockchain-Based Process Quality Data Sharing Platform for Aviation Suppliers" (Cao et al., 2023); Application of IoT and blockchain technology in the integration of innovation and industrial chains in high-tech manufacturing (Li et al., 2025); Development and Implementation of Autonomous Quality Management System (AQMS) in an Automotive Manufacturing using Quality 4.0 Concept - A Case Study (Singh et al., 2022)
Shipbuilding	1	"Digital Twin of Shipbuilding Process in Shipyard 4.0" (Iwańkowicz & Rutkowski, 2023)

3.3. Recognized shipbuilding implications

The collected literature centers around traceability in supply chains, where blockchain is positioned as a foundational technology to enhance data visibility and transactional trust. The studies consistently emphasize the fragmented nature of supply chain quality data and the inability of traditional systems to maintain consistent, tamper-proof records across organizational boundaries. For instance, Ali et al. (2022) propose a blockchain-enabled open quality system designed for smart manufacturing environments, demonstrating how decentralized data architectures can ensure that quality records remain consistent and verifiable across suppliers and regulators. The system described shows how immutable recording of inspection and compliance events can streamline stakeholder trust and reduce auditing overheads. This framework strongly parallels the challenges in shipbuilding, where certification authorities, component manufacturers, and shipyards must synchronize quality documentation across a complex product lifecycle. Yu et al. (2024) explore how traceability mechanisms enabled by blockchain enhance food quality assurance by establishing clear provenance data, a concept directly translatable to shipbuilding for tracking materials and compliance from source to final product. Although their study is grounded in the food industry, the implementation of layered blockchain architecture to trace input origin and transformation closely mirrors the structure of a distributed manufacturing chain in shipbuilding. Additionally, Matenga and Mpofu (2022) introduce a blockchain-based cloud manufacturing system (BCMaaS) in railcar manufacturing, particularly for sheet metal parts which is also very common in shipbuilding. Their system supports real-time analytics, provenance tracking, and decentralized collaboration among SMEs. This directly informs the vision for a blockchain-based shipbuilding QMS that captures every quality-critical event across procurement, fabrication, logistics, and commissioning.

Next studies contribute to valuable insights into how programmable rules embedded in blockchain can actively monitor and regulate processes that traditionally require human oversight. KorkusuzPolat and Baran (2024) propose a blockchain-based Quality 4.0 model. Focused on the post-procurement storage process, the model emphasizes traceability, control, and sustainability of quality across technology, processes, and workforce. When applied to a sheet metal and profile warehouse, the BC-based system outperformed the traditional system in effectiveness and comprehensiveness ensuring real-time product tracking, restricting unauthorized access, and supporting decision-making for quality sustainability, thus providing a scalable blueprint for digitized, secure quality control systems.

Tambare et al. (2022) showcase how companies like Rolls-Royce and Scania have operationalized these models to achieve efficiency and quality gains. Quality 4.0, characterized by digital tools and data analytics, is shown to enhance competitiveness and adaptability. However, the review calls for deeper, systematic analysis and statistical validation of these frameworks across industries to ensure their effective implementation and to facilitate broader adoption of smart manufacturing practices. Similarly, Shahbazi and Byun (2021) propose a smart manufacturing framework integrating blockchain technology and machine learning to enhance data security, reliability prediction, and quality control. Using the Hyperledger Fabric platform, the system addresses challenges such as fake datasets and data management inefficiencies. Machine learning models, particularly hybrid and non-linear approaches, are employed for fault diagnosis and quality evaluation, while big data techniques support system scalability and performance. The approach demonstrates high accuracy in quality control prediction.

On a more conceptual note, several studies explore the broader digital transformation of quality management systems in industrial contexts. These works provide the theoretical scaffolding necessary to position blockchain not simply as a technology stack for quality governance. Bisht et al. (2025) highlight the transformative role of Industry 4.0 in the agri-food sector, emphasizing how Quality 4.0 leverages advanced digital technologies to meet growing global demands for food quality. It outlines the integration of artificial intelligence, big data analytics, food printing, digital twins, smart sensors, and blockchain as essential tools in modernizing and enhancing quality monitoring systems. Positioned within the broader context of digital transformation, these technologies collectively aim to revolutionize quality management across diverse segments of the food industry. Kodumuru et al. (2025) examine the convergence of artificial intelligence (AI) and the Internet of Things (IoT) in pharmaceutical manufacturing, highlighting its transformative role in bridging digital and physical systems. Through AI-enabled IoT sensors, real-time analysis, predictive maintenance, and automation are achieved, enhancing quality control and operational efficiency. Their review also explores supporting technologies like cloud computing and data analytics while discussing recent innovations such as AI in drug discovery and blockchain for traceability. Despite notable benefits, the integration faces challenges related to data interoperability, ethical concerns, and regulatory compliance, necessitating robust frameworks for future implementation.

Cao et al. (2023) present a blockchain-based quality data-sharing platform tailored for aviation suppliers to address issues of data silos and information credibility in traditional manufacturing processes. By integrating blockchain technology with supply chain quality management, the platform enables real-time, secure, and transparent sharing of manufacturing process data. It introduces architectural elements such as data block packaging models, secure storage mechanisms, and supplier evaluation tools. Applied in a real-world aircraft industrial park, the platform demonstrates its capacity to streamline supplier collaboration and enhance the reliability of product quality data across aviation manufacturing networks. Liu et al. (2025) focus on AI-based detection technologies such as spectroscopy and sensor systems, the study explores how integrating these with IoT and blockchain contributes to transparent, automated, and secure traceability frameworks.

Given the scarcity of direct empirical research focused explicitly on blockchain applications in shipbuilding, the studied literature draws significantly on analogies from sectors with comparably strict regulatory environments, such as aerospace, pharmaceutical, and construction industries. Nonetheless, the transferability of these conclusions to shipbuilding must be viewed cautiously. Specific regulatory constraints, organizational complexities, and unique technical challenges inherent in multi-year shipbuilding projects limit the universality of solutions proven effective in other industries.

This synthesis affirms that a rich foundation may already exists in literature to inform the conceptualization of a blockchain-based quality management system tailored to shipbuilding. The review reveals not only technological enablers and barriers but also theoretical and operational models that can guide future implementation efforts.

4. Toward Blockchain-Based Quality Information Systems in Shipbuilding

The shipbuilding industry stands as one of the most quality-sensitive manufacturing domains. It requires close coordination between hundreds of suppliers, subcontractors, engineering teams, and classification societies over extended production timelines and within strictly regulated frameworks. Ensuring quality and compliance throughout this complex ecosystem is a challenge. This section proposes a conceptual design for a blockchain-based quality information system tailored to the specific needs of shipbuilding, integrating the principles and structure of the Hyperledger Fabric blockchain framework.

4.1. Conceptual design objective

The proposed system framework must overcome key limitations of conventional QMS implementations in shipbuilding by introducing several foundational enhancements such as decentralization of quality data governance that enables each stakeholder (shipyard, suppliers, classification and certification societies and customers) to verify quality events without depending on a central authority. Immutability and traceability of quality records should be ensured once an inspection reports, material or workers certificates, or non-conformance events are logged and cannot be altered or deleted for full immutability. Smart contract-based compliance enforcement should allow automated validation of quality events against predefined technical and regulatory criteria which can later be assessed with a secure, role-based access control, providing tailored visibility for each stakeholder depending on their contractual role and regulatory authority. These goals are tightly aligned with the challenges documented in the reviewed literature, which highlight the critical need for trust, visibility, and verifiability in complex industrial value chains.

While the proposed system design offers clear advantages in decentralization and immutability, several practical challenges must be acknowledged. Integrating blockchain into an existing shipyard's digital environment requires addressing interoperability with legacy systems, allocating sufficient budgets for infrastructure and long-term maintenance, and managing potential institutional resistance to decentralized record-keeping. Effective implementation also depends on training stakeholders to correctly handle digital certifications, interact with smart contracts, and manage secure identities within the consortium.

4.2. System architecture overview

The architecture of the proposed framework is based on the Hyperledger Fabric[1] platform, a modular, permissioned blockchain framework designed for enterprise consortia (Hyperledger Fabric Docs Main Documentation, n.d.). Hyperledger Fabric was selected for its channel-based privacy architecture, pluggable consensus model, and support for various access control policies (Thummavet, 2023). These features make it particularly well-suited for shipbuilding environments, where multiple stakeholders require both data confidentiality and cross-party verification.

Zhong et al., (2020) prototype on construction industry practices, used Hyperledger Fabric consortium blockchain platform and can similarly be used as foundational layer for a shipbuilding system. Their framework demonstrates how blockchain can provide immutable, traceable, and transparent records of quality-related activities, while also enabling automated compliance checking through smart contracts. This system architecture can be adapted to the shipbuilding context, where trust among contractors, suppliers, inspectors, and regulators is critical, and where compliance with certification standards must be verifiable and audit-proof, featuring role-based information permissions and lifecycle governance, allowing each actor in the shipbuilding process (e.g., material suppliers, transporters, shipyards, certification agencies and end clients) to access, validate, or append quality data within their predefined scope. A consensus mechanism native to the Hyperledger Fabric platform ensures that all transactions (e.g., build, quality inspections, part certifications, or test results) are cryptographically verified before inclusion on the ledger. Smart contracts automatically rule-check against design specifications or regulatory criteria such as inspection records for welds or structural integrity tests can be automatically validated against predefined parameters before progressing to the next production phase providing quality enforcement and audit trails that are accessible and verifiable across the entire chain.

Hence, the conceptual framework should be structured around a consortium network which is a system governed by a permissioned consortium of entities including shipyards, suppliers, regulatory authorities, classification societies, certification and inspection organizations and clients where each participant operates a peer node that maintains a local copy of the ledger and executes smart contracts (called chaincodes in Hyperledger Fabric). Hyperledger Fabric enables the creation of private channels, where only relevant parties have access to the transactions and data. For example, a shipyard and steel supplier might share one channel for procurement traceability, while the shipyard and a classification society operate on another for regulatory inspections. Smart contracts (chaincode) that can be written in Golang, Java, or Node.js, enforce quality compliance logic which for instance a contract might require that a welding process has passed certified inspection before the next process (e.g., painting) can be validated. The ordering service component ensures transaction consistency and deterministic ordering across the network. Fabric supports multiple consensus mechanisms to verify, order, and record transactions in a decentralized manner. To define the identity management and authentication policies for each organization, ensuring that only authorized entities can submit or verify quality events, a membership service providers (MSP) should exist for every stakeholder. Lastly, client applications should be developed as interfaces used by users (e.g., quality inspectors, project managers, auditors) to record events, retrieve documentation, and visualize lifecycle compliance dashboards

The quality management lifecycle in shipbuilding includes numerous milestones such as technical design validation, supplier certification, material acceptance, assembly inspections, testing protocols, and final product handover. In the

1 Introduction - Hyperledger Fabric Docs main documentation. (n. d.). https://hyperledger-fabric.readthedocs.io/en/release-2.5/whatis.html#hyperledger-fabric

proposed system design, each of these events need to be recorded on the blockchain as digitally signed, timestamped transactions. Considering a scenario of material procurement, when a supplier delivers certified steel plates, a digital certificate is issued and recorded on a shared channel with the shipyard and classification or certification body. This certificate is linked to the batch number and includes specifications, origin, and test data. Inside assembly and fabrication, as the hull structure is assembled, each weld is inspected by a certified inspector whose identity is verified via the MSP. The results are entered via a secure client interface and validated through a smart contract that checks qualification compliance. Inspection processes and non-conformance handling, for example a weld defect, a deviation report should be logged that automatically triggers a remediation workflow defined in the chaincode. At the final handover phase, once the ship is completed, a final compliance certificate is generated, aggregating all prior transactions into a verifiable quality trail. This dataset or document can be made accessible to clients, port authorities, and insurers through permissioned views.

4.3. Consensus mechanisms

In the following section, we examine the consensus mechanisms that govern trust and validation in blockchain system for the consistency and legitimacy of shared data across distributed nodes. Unlike traditional databases, where a centralized authority manages updates and enforces integrity, blockchain networks rely on consensus mechanisms to verify, order, and record transactions in a decentralized manner. The effectiveness of a blockchain-based quality management system in shipbuilding, therefore, depends not only on the structure of smart contracts or data models but also on the reliability and performance of its underlying consensus protocol (Zhang et al., 2021; Westphal et al., 2023).

In the context of enterprise and permissioned networks, such as the one proposed for the shipbuilding sector, the consensus process differs substantially from public blockchain platforms like Bitcoin or Ethereum. Permissioned systems do not require energy-intensive proof-of-work or permissionless participation; instead, they rely on a known set of authorized participants and focus on fault tolerance, performance, and governance. This approach has been emphasized in multiple studies exploring blockchain for manufacturing and regulated industrial applications (Battisti et al., 2023; Zhang et al., 2021).

The proposed system architecture adopts the Raft consensus algorithm[2], which is natively supported in Hyperledger Fabric, Raft is a crash fault tolerant (CFT) consensus protocol designed to provide a balance between operational efficiency and consistency. It works by electing a leader among ordering nodes, which is responsible for proposing the sequence of transactions. Other nodes (followers) then replicate and validate these blocks. In the event of a leader failure, a new one is elected to continue the process with minimal disruption (Ongaro, 2014; Thummavet, 2023). Raft offers several key advantages that make it well-suited for the quality assurance environment in shipbuilding. It supports low-latency transaction finality, which ensures that inspection records, test results, and certifications are committed to the ledger quickly that is essential for dynamic manufacturing workflows. Raft provides deterministic ordering of transactions, which is critical when the sequence of quality events (such as inspections or approvals) must be preserved for regulatory or legal reasons.

Importantly, consensus in this architecture is decoupled from the execution of smart contracts and endorsement of transactions. Hyperledger Fabric's execute-order-validate model ensures that each transaction is first simulated and endorsed by a specified set of peers, then ordered by the consensus layer, and finally validated and committed across the ledger. This separation enhances performance and modularity while preserving deterministic results which is a requirement when compliance rules are encoded in chaincode and must be uniformly applied across all peer organizations (Hyperledger Foundation, 2024). From an implementation perspective, shipyards and certification agencies could operate ordering nodes to co-maintain the integrity of the network. This shared control over the consensus process would align with existing regulatory hierarchies and

2 Raft is a consensus algorithm for managing a replicated log, https://raft.github.io/raft.pdf

stakeholder relationships, enhancing trust in the system's impartiality and reliability. Suppliers and subcontractors, while not responsible for ordering, would participate as endorsing and committing peers, submitting quality data and receiving confirmations.

While the use of the Raft algorithm aligns with the permissioned nature of a shipbuilding consortium, it is important to clarify its trust model and compare it to possible Byzantine Fault Tolerant (BFT) alternatives. Søgaard et al. (2023) explain that crash fault tolerance (CFT) assumes that if a node fails, it does so by simply ceasing to function, it crashes but does not behave unpredictably or maliciously. Raft, as a CFT ordering protocol, is designed to ensure the system continues operating as long as most nodes remain available and honest. This is generally sufficient in a private, regulated industrial consortium where participants such as shipyards, classification societies, and regulatory agencies are known, vetted, and share aligned incentives to maintain trustworthy operations. However, CFT alone does not protect against intentional misbehavior by insider nodes. BFT, by contrast, extends fault tolerance to include arbitrary or malicious faults, providing consensus even when some nodes act dishonestly. This is particularly relevant when a distributed ledger must resist intentional data tampering or collusion among untrusted or partially trusted participants. Authors from the same study also note that BFT systems, such as PBFT or Tendermint, achieve this enhanced trust by requiring additional message exchanges to establish consensus, ensuring that even if a fraction of nodes acts maliciously, the system remains secure, and the ledger stays consistent but these stronger trust guarantees come at a cost. They found that CFT-based blockchains like Hyperledger Fabric using Raft (or its older Kafka variant) deliver significantly higher peak throughput than comparable BFT architectures under identical hardware and network conditions. Their testing showed that BFT protocols introduce substantial performance overhead due to the extra communication and verification required to guard against Byzantine faults. In large-scale or high-frequency transaction environments, such as national or transnational e-business systems, this performance cost can limit scalability or require more robust infrastructure to maintain acceptable response times.

For the shipbuilding industry's context, this means that while a Raft-based CFT model remains practical and efficient for a relatively small, permissioned consortium of known participants, trade-offs must be recognized. If the network expands to include more autonomous suppliers, subcontractors, or cross-border parties where trust is lower or the risk of insider misconduct is greater, adopting a BFT-capable consensus, even at higher computational cost, could become justifiable. The performance penalty may be acceptable if the added layer of distributed trust is critical for safeguarding high-value, long-lifecycle assets and immutable quality records.

Consequently, any real-world deployment should plan for resilience against the limitations of Raft, such as vulnerability to network partitions and the need for stable leader election. Robust fallback and monitoring procedures for leader node failures should be integrated. Likewise, if the project scope evolves to include less regulated or geographically dispersed participants, system architects should evaluate whether transitioning to a BFT consensus layer or a hybrid approach combining CFT with BFT elements for critical workflows, would better balance operational trust and performance requirements.

4.4. Use case scenarios for shipbuilding quality processes

To contextualize the proposed blockchain-based quality information system framework, this section outlines several use case scenarios relevant to key quality assurance processes in the shipbuilding lifecycle. These scenarios are presented not as implementation guides, but as illustrations of how blockchain can support traceability, compliance, and process transparency across interdependent actors and workflows in shipbuilding. Together, they serve as a theoretical foundation for future implementation and validation efforts.

Each of the following scenarios also corresponds to thematic concerns identified in the literature review: for example, procurement traceability and supply chain transparency directly address challenges in Cluster 1, smart contract-based compliance automation aligns with Cluster 2, and the integration of inspection and audit data into Quality 4.0 frameworks resonates with Clusters 0 and 3.

In traditional shipbuilding workflows, the procurement of raw materials and components such as steel plates, propulsion systems, valves, pumps or electronic modules involves a complex chain of suppliers. Each tier of this chain may provide its own documentation and certification, which are later manually aggregated or validated by the shipyard, certification organizations or a classification society. Blockchain-based system transforms this process by recording procurement events as immutable transactions. When a supplier dispatches a batch of certified material, a digital certificate is generated and registered on the blockchain. This certificate includes material specifications, batch identifiers, compliance codes, and links to original test data. It is digitally signed by the supplier's private key and verifiable by any authorized party on the network. In this way, the blockchain acts as a shared source of truth across supplier tiers, preventing document tampering or duplication, and allowing the shipyard to verify material authenticity prior to acceptance or usage. Moreover, in cases where regulatory bodies require long-term verification of part origin, the blockchain provides a permanent and accessible audit trail (Regueiro & Urquizu, 2024).

The shipbuilding process involves an array of inspections across various stages: dimensional checks during hull fabrication, weld quality control, coating inspections, system integration testing, and sea trials. Typically, these inspections are recorded in isolated logs and sometimes non-interoperable systems. With a blockchain-based approach, inspection events can be recorded as individual transactions, each tied to a specific quality activity. These records are submitted by authorized inspectors whose credentials are cryptographically verified via the system's membership service provider. Once submitted, the inspection outcome, time, and responsible party are fixed on the ledger and validated by smart contract logic to check conformity to process or regulatory standards (Ali et al., 2022; Cui et al., 2023).

This mechanism supports the real-time aggregation of inspection results across subsystems and timeframes meaning that a project engineer can query the ledger to view the inspection status of a hull block, subsystem, or the entire vessel, thus, the system can also provide automated compliance summaries during project handover or certification audits, reducing the administrative burden traditionally associated with these phases.

In conventional systems, the identification and resolution of non-conformities (e.g., component failures, missed tolerances, process deviations) often involve multi-party communication, documentation delays, and versioning issues. These bottlenecks can be exacerbated in shipbuilding projects where external certification authorities or subcontractors are required to validate quality issues. The blockchain system introduces an approach in which a non-conformance report might be issued as a smart contract-triggered event, automatically linked to the process or inspection step that identified the issue. The record includes supporting documents, timestamps, and the party responsible for follow-up. The resolution process can be governed by another set of smart contracts that require corrective action validation from independent authorities before closing the issue which creates a transparent chain of accountability (Kuhn et al., 2018; Hariyani et al., 2025). Each step (issue identification, corrective proposal, verification, and closure) are time-stamped and linked to authenticated users, reducing the risk of undocumented fixes or post-hoc justifications. In doing so, the blockchain system contributes to a culture of continuous, auditable quality assurance across all stakeholders in cross-organizational non-conformance management.

The final handover and delivery phase of a shipbuilding project is traditionally administrative-heavy, relying on manual collation of quality documents, inspection records, and regulatory approvals and is marked by a culmination of certification, verification, and documentation consolidation for compliance archiving. Within the blockchain-enabled quality information system, all prior events, from component procurement to final testing, already exist on-chain in verifiable form. During handover, a smart contract can be triggered to generate a composite compliance report that aggregates all relevant transactions, digitally signs it, and anchors it as a final block in the vessel's quality history. That kind of report serves as a digital twin of compliance, an immutable, distributed archive that can be accessed by classification societies, clients, port authorities, certification authorities or insurers. Such framework also supports post-delivery lifecycle quality assurance, such as warranty claims or refit projects, where historical inspection records and part provenance may be needed years after commissioning (Bisht et al., 2024; Brandín & Abrishami, 2024; Zhang et al., 2021).

To improve clarity, Table 3. outlines the stakeholders in the shipbuilding blockchain consortium, describing their typical access rights and quality-related responsibilities.

Table 3. System Components for the Blockchain-Based Shipbuilding Quality Information System

Stakeholder	Primary Role and Responsibilities	Relevant Quality Events	Access Rights
Shipyard	Oversees project execution, coordinates suppliers, subcontractors, manages inspections and quality records	Technical design validation, assembly inspections, non-conformance management, compliance certification	Full access to record, verify, append, and audit all project quality events
Suppliers	Provide raw materials, components, and documentation; supply certificates for delivered items	Material procurement certification, batch quality documentation	Write and read access to their own supply data; view relevant inspection outcomes
Classification Societies	Independent verification and certification of compliance with maritime standards	Approval of inspection reports, certification of critical processes	Verify inspection and compliance records; append final certificates
Certification & Inspection Bodies	Conduct detailed inspections, witness tests, verify corrective actions	Inspection reports, non-conformance findings, corrective action approvals	Submit inspection results; verify compliance with regulatory frameworks
Regulatory Authorities	Ensure compliance with legal and international maritime standards; issue final approvals	Final audits, compliance oversight, regulatory reporting	Read access to complete quality trails; verification authority for compliance records
Clients/ Owners	Commission and receive the final vessel; require proof of compliance for warranty, insurance, and operational licensing	Final handover certificate, quality documentation archive	Read access to final aggregated compliance reports and relevant certification records
IT Administrators (Consortium Operators)	Manage network nodes, oversee smart contract deployment, maintain system security and identity management	System configuration, MSP updates, access control management	Full administrative rights to manage technical aspects but no direct control over quality data

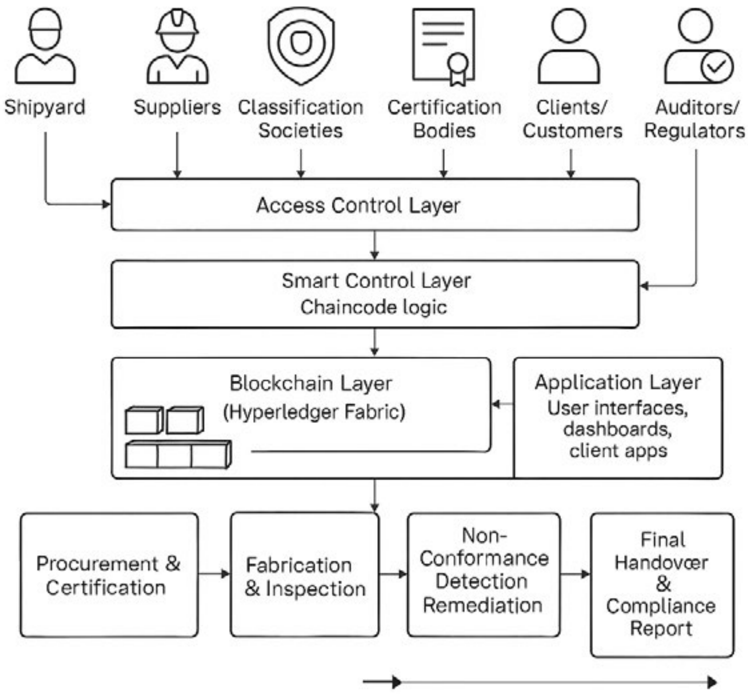
Also, Table 4. summarizes the key system components, their functionalities, and associated technologies with notes and together, with Table 3. helps to visualize how decentralized governance, differentiated permissions, and smart contract rules are distributed across the shipbuilding quality lifecycle.

Table 4. System Components for the Blockchain-Based Shipbuilding Quality Information System

System Component	Description of Functionality	Technological Element	Notes
Stakeholder Identity	Verifies the identity of users, suppliers, inspectors, and regulatory bodies via digital certificates	Membership Service Provider (MSP)	Each stakeholder operates under strict role-based identity management; credentials verified before transactions are recorded.
Smart Contracts	Automate rule-based quality checks, trigger events for inspections, approvals, or non-conformance remediation	Chaincode (written in Go, Java, or Node.js)	Example: A welding inspection smart contract blocks progress until certification is validated. Non-conformance reports automatically trigger corrective workflows.
Access Management	Ensures different stakeholders can only access data relevant to their contractual and regulatory roles	Role-Based Access Control (RBAC)	Shipyard has full write/read, suppliers have limited write, regulators and classification societies have read/verify privileges.
Immutable Data Recording	Stores all quality-related records, including inspection logs, material certificates, test results, and final handover documents	Hyperledger Fabric Ledger	Transactions are digitally signed, time-stamped, and permanently stored.
Consensus Mechanism	Guarantees data consistency across all nodes by validating transactions in an agreed sequence	Raft (Crash Fault Tolerant) or optional Byzantine Fault Tolerant (BFT) module for higher trust guarantees	Raft is suitable for small, trusted shipbuilding consortia; PBFT could be applied if stakeholder trust is weaker or more malicious faults are anticipated.
Private Communication Channels	Enables confidential data sharing between defined parties	Hyperledger Fabric Channels	Channels: *Material Ordering Channel* (shipyard ↔ supplier); *Work Orders and Inspections Channel* (shipyard ↔ classification society); *Final Certification Channel* (shipyard ↔ regulator ↔ client).
Data Visualization	Provides stakeholders with dashboards to track real-time quality status, compliance progress, and audit trails	Client Apps (Web Interfaces, APIs, Mobile Apps)	Project managers monitor inspection status; clients view final compliance certificates; inspectors submit results via secure user portals.
Ordering Service	Manages the ordering and final commitment of transactions into the ledger	Hyperledger Fabric Ordering Service	Operated by shipyards and certification societies to ensure trustworthy sequencing and ledger consistency, aligned with the chosen Raft or BFT consensus module.

As a result of all fore-mentioned components of a proposed concepts in this chapter, Figure 2 illustrates the conceptual architecture of the proposed blockchain-based quality information system framework.

Figure 2. Conceptual quality information system architecture



The proposed system integrates key stakeholders, core system layers, and the shipbuilding quality lifecycle. The three-tiered structure captures the interaction between actors (e.g., shipyards, suppliers, regulatory bodies), the blockchain infrastructure (including access control, smart contracts, and Hyperledger Fabric ledger), and quality management activities such as procurement certification, inspections, and final handover.

This visualization supports the theoretical framework presented in this study and demonstrates how decentralized data governance can be operationalized across interdependent phases of shipbuilding quality assurance.

While these use cases demonstrate significant potential, it is important to acknowledge that practical deployment may face obstacles such as stakeholder alignment, compliance with evolving data privacy regulations, smart contract audits and technical scaling limits, which will need to be validated through all future implementations.

4.5. Critical Challenges and Limitations in Implementing Blockchain in Shipbuilding

The adoption of blockchain technology within the shipbuilding industry promises considerable improvements in traceability, data integrity, and transparency. However, the implementation faces significant practical challenges and inherent limitations that must be critically addressed to realize its full potential as technical complexities may constitute a barrier to blockchain deployment. Issues such as interoperability with legacy systems, integrations with Enterprise Resource Planning (ERP) and Product Lifecycle Management (PLM) systems, which are typically proprietary or customized. Integrating blockchain solutions into such environments requires substantial adjustments and careful design to ensure seamless data exchange and prevent disruptions to existing workflows (Brandín & Abrishami, 2024; Westphal et al., 2023). Furthermore, maintaining data consistency across these platforms and managing large, dynamically evolving datasets raises additional difficulties, particularly when considering blockchain's immutable nature and the need for accurate initial data entry (Karaduman & Gülhas, 2025). Cybersecurity concerns add another layer of complexity. Despite blockchain's inherent security benefits, vulnerabilities persist, especially when blockchain integrates with external technologies such as IoT devices, RFID tags, and sensors commonly used in shipbuilding logistics and quality management processes (Karaduman & Gülhas, 2025). Devices transmitting erroneous or deliberately manipulated data could severely compromise the integrity of blockchain records, undermining trust and transparency, essential elements that blockchain seeks to enhance. Addressing these vulnerabilities requires robust encryption, secure communication protocols, and rigorous validation mechanisms to ensure data authenticity and accuracy.

Another significant limitation arises from blockchain consensus mechanisms themselves. Consortium blockchains may typically employ consensus algorithms such as Raft or Byzantine Fault Tolerance (BFT). Although Raft provides operational efficiency suitable for smaller, trusted consortia, it does not offer resilience against malicious nodes or more sophisticated faults, limiting its effectiveness in broader or less regulated collaborations. On the other hand, BFT-based algorithms, while providing greater security against malicious behavior, introduce notable performance penalties in terms of latency, throughput, and computational overhead (Søgaard et al., 2023). Balancing security, performance, and scalability thus becomes critical in selecting the appropriate consensus model. Technical hurdles, such as latency, limited data formats, and the complex consensus processes inherent in consortium blockchains, further complicate their integration into existing industrial practices (Zhong, 2020; Cao et al., 2023).

Ethical and regulatory challenges further complicate blockchain adoption in shipbuilding. Given the international regulatory framework governed by bodies such as the International Maritime Organization (IMO) and classification societies, ensuring blockchain implementations meet certification standards and statutory compliance becomes crucial. Standards like ISO 9001 for quality management, ISO 14001 for environmental management, ISO 45001 for occupational safety, and ISO 3834 for welding quality must be integrally reflected within blockchain designs, requiring extensive cross-disciplinary collaboration (ISO standards documentation; International maritime organization's (IMO) that sets policies for international shipping like regulations on safety, security, and environmental best practices. Ethical considerations, including data privacy, equitable stakeholder participation, and transparency in data handling, also require careful governance frameworks to avoid misuse or monopolization of data access within consortium-based blockchains.

Operational and organizational challenges should also be explicitly recognized. Blockchain solutions require significant upfront investments, not only financially but also in terms of stakeholder training and organizational adaptation to decentralized governance models. Institutional resistance to decentralized data management, common in industries with traditionally centralized quality control structures, may pose significant hurdles to acceptance and successful deployment. Moreover, ongoing maintenance costs and evolving regulatory landscapes require blockchain systems to maintain flexibility, adaptability, and resilience in the face of inevitable technological and regulatory changes.

In conclusion, while blockchain technologies offer compelling benefits to the shipbuilding sector, addressing these identified challenges and limitations is critical for successful real-world implementation. Future research must focus on developing robust, scalable, and secure blockchain architectures, ensuring regulatory compliance, ethical governance, and seamless integration with legacy systems and processes. Such informed approach should support the effective translation of blockchain's theoretical benefits into tangible operational improvements within the complex shipbuilding environment.

5. Discussion

Specifically for the shipbuilding sector, direct research on blockchain implementation remains scarce, with more available insights from comparably strict and regulated sectors, such as aviation and construction which are also required to quality standards and special regulations. Aviation industry experiences, characterized by highly complex processes, stringent security requirements, and pronounced data privacy concerns, might provide relevant analogies for shipbuilding's similarly complex and tightly regulated environments (Cao et al., 2023). Likewise, construction sector studies highlight barriers like stakeholder agreement difficulties, privacy concerns, lack of established regulatory frameworks, and significant initial costs, issues equally pertinent to shipbuilding due to its long-term project cycles, regulatory rigor, standards conformity, extensive multi-tiered supplier networks, and critical long-term data archival requirements (Zhong, 2020; Brandín & Abrishami, 2024). These features may be suited for shipbuilding, where documentation of quality milestones is critical not only for regulatory compliance but also for commercial and legal clarity. Thus, while blockchain provides powerful tools for enhancing transparency and trust, its benefits are not automatically guaranteed and require careful planning, design, and resource allocation for these features to be particularly suited for shipbuilding, where quality is critical.

Synthesizing the insights from recent peer-reviewed literature, this paper proposes a conceptual framework that shows how quality data may be governed, shared, and validated across industrial networks or across various domains such as pharmaceuticals, aerospace, and food processing. In shipbuilding, where products are uniquely complex and quality failures can have regulatory or safety-critical implications, these attributes are not simply desirable, they are essential. These findings try to justify blockchain not just as a technical tool, but as a potential foundation for building trust and coordination in multi-actor manufacturing environments. This study identifies conceptual feasibility, not commercial maturity. Questions around consortium governance, identity management, privacy-preserving architectures, and integration with existing digital shipbuilding platforms still require technical, organizational and legal refinement. From a practical standpoint, the actual design and implementation of a blockchain-based quality management platform tailored to a shipbuilder and its cooperating stakeholders will involve rigorous experimentation. The framework proposed in this review presents a foundational blueprint, but it will need to be translated into smart contract logic, permission policies, and application interfaces which raise important future research directions, not just in systems engineering and cybersecurity, but also in human-centered design, interoperability with enterprise resource planning (ERP) or product lifecycle management (PLM) systems, and standards development for blockchain-based quality data.

Another important limitation relates to the adaptability of the system when consortium membership changes over time. In dynamic industrial collaborations, new suppliers may join, or regulatory partners may be replaced. Updating membership service policies, access rights, and smart contract logic securely and without disruption will require robust governance mechanisms and operational protocols, which still need practical validation in production settings. Additionally, while this paper demonstrates conceptual feasibility, it does not address production-grade user interfaces or middleware necessary to handle multi-channel data fragmentation, as real implementations will likely demand greater granularity of data privacy alongside full end-to-end traceability.

6. Conclusion

This work has undertaken a systematic exploration of the intersections between blockchain technology and quality management systems (QMS) within industrial and manufacturing contexts, with a particular emphasis on the shipbuilding sector. Through a structured review of 55 peer-reviewed publications sourced from the Web of Science and Scopus databases, the analysis addressed three core research questions pertaining to the conceptualization, benefits and constraints, and sector-specific applicability of blockchain in quality control and assurance domains. This synthesis was guided by a combination of qualitative narrative analysis and computational methods, including principal component analysis (PCA) and KMeans clustering. The thematic taxonomy derived from these methods revealed clear quantitative trends: among the 55 reviewed studies, the largest thematic cluster relates to general manufacturing (17 papers), followed by logistics and supply chain (13), food and agriculture (9), pharmaceutical contexts (6), aerospace, aviation, and automotive (6), construction (3), and a single direct study in shipbuilding. These distributions support the claim that, while direct shipbuilding research is limited, conceptual overlaps with other highly regulated, complex manufacturing domains justify the proposed adaptation.

In response to the first research question, the review demonstrates that blockchain technology has been increasingly conceptualized not merely as a secure data repository but as a distributed governance mechanism embedded within broader Quality 4.0 paradigms. Across diverse industrial applications, including pharmaceuticals, food logistics, aerospace, and smart manufacturing where blockchain is a foundational infrastructure that supports traceability, decentralized verification, and rule-based automation through smart contracts. The literature indicates a shift from traditional centralized quality architectures toward distributed systems of trust that facilitate cross-organizational transparency and compliance enforcement.

Second research question focused on the advantages and limitations of blockchain-based quality systems. The empirical and conceptual findings across the reviewed literature underscore multiple documented benefits: improved traceability across multi-tier supply chains, immutable recording of quality events, reduced auditing overhead through automated compliance validation, and enhanced stakeholder accountability. These outcomes are particularly relevant in industries marked by regulatory intensity and subcontractor fragmentation. At the same time, the review highlights several limitations, including integration complexities with legacy enterprise systems, a lack of standardized frameworks for quality data exchange, scalability concerns, and challenges in operationalizing smart contract governance in real-world industrial settings. Nonetheless, the adoption of permissioned blockchain models, particularly those based on Hyperledger Fabric, emerges as a prevalent mitigation strategy, offering access control, privacy-preserving mechanisms, and consortium-level governance structures.

Regarding the third research question, the literature provides conceptual justification for the implementation of blockchain solutions in shipbuilding-specific quality processes. Despite its relatively underexplored presence in shipbuilding publications, the thematic parallels between shipbuilding and other high-complexity manufacturing domains offer substantial support for its applicability. The sector's reliance on extensive supplier networks, compliance requirements and certifications, and long-lifecycle documentation workflows mirrors many of the structural challenges that blockchain has addressed in other contexts.

Building on these findings, this paper proposed a conceptual framework for a blockchain-based quality information system tailored to shipbuilding based on the architectural capabilities of Hyperledger Fabric, which introduces a permissioned, consortium-led ledger infrastructure capable of governing quality data across diverse stakeholders, shipyards, suppliers, regulators, classification societies, certification authorities and clients. Key features of the framework include immutability of inspection records, smart contract-based enforcement of technical and regulatory compliance, and secure role-based access to quality data. The framework supports decentralized documentation of quality-critical milestones such as material certification, process inspections, non-conformance reports, and final product handover, all recorded as cryptographically verifiable transactions on-chain. In doing so, the proposed design aligns directly with the systemic needs of the shipbuilding sector, where quality management is not only operationally central but legally and commercially consequential. However, the conceptual framework's practical implementation in real shipbuilding conditions may face technical and operational challenges that require deeper validation. All technical aspects will need careful engineering to align the blockchain's architectural promise with shipbuilder day-to-day operational realities.

The findings of this review reinforce the argument that blockchain technologies may offer not only the technical affordances but also the architectural paradigms that have the potential to support a new generation of quality management systems. In the context of shipbuilding, where quality failures can have significant economic, regulatory, and safety repercussions, the introduction of immutable, auditable, and decentralized quality records may enable an incremental but potentially transformative shift in how assurance is executed across the value chain. This review also acknowledges that the proposed solution remains conceptual in nature and must be subjected to further empirical validation. Issues such as system interoperability with digital shipbuilding platforms (e.g., PLM and ERP systems), human-system interaction design, performance benchmarking under production conditions, and compliance with maritime regulatory frameworks require comprehensive investigation. Moreover, questions of governance, liability, and standardization in consortium-based blockchain networks call for interdisciplinary engagement across technical, legal, and organizational domains. In conclusion, this paper provides an academic foundation and forward-looking design framework to guide future implementation efforts aimed at integrating blockchain into quality management systems within shipbuilding not only as isolated digital tools, but as integral elements of resilient, transparent, and trusted quality ecosystems in the era of Industry 4.0. Future work should continue to strengthen the quantitative and empirical basis for these design directions, integrating broader industry data, explicit comparative benchmarks, and demonstrations under real shipyard operating conditions.

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Pregled sustava upravljanja informacijama o kvaliteti temeljenih na blockchainu u brodogradnji

Sažetak

Upravljanje kvalitetom u proizvodnji suočava se s trajnim izazovima vezanima uz transparentnost, sljedivost i integritet podataka u složenim proizvodnim okruženjima s više dionika. Ovaj rad predstavlja sustavni pregled literature kojim se istražuje potencijal blockchain tehnologije kao temelja za decentralizirane informacijske sustave koji unaprjeđuju povjerenje u području kontrole i upravljanja kvalitetom u brodograđevnoj industriji. Analizom 55 recenziranih publikacija iz baza podataka Web of Science i Scopus, studija identificira ključne tematske skupine u suvremenim istraživanjima, uključujući sljedivost u opskrbnom lancu, automatizaciju putem pametnih ugovora te integraciju blockchaina unutar okvira upravljanja kvalitetom u sklopu Industrije 4.0. Na temelju dobivenih spoznaja, rad predlaže konceptualni okvir za arhitekturu sustava upravljanja kvalitetom temeljenog na blockchainu, prilagođenog operativnim i regulatornim zahtjevima proizvodne industrije, s posebnim naglaskom na brodogradnju. Predloženi dizajn sustava naglašava ovlašteni pristup, nepromjenjive zapise o kvaliteti te programiranu usklađenost putem pametnih ugovora. Iako pregled potvrđuje konceptualnu izvedivost takvih sustava, ističe i potrebu za daljnjim istraživanjima, osobito u područjima upravljanja sustavom, interoperabilnosti i implementacije. Ovaj rad pruža teorijsku osnovu za budući razvoj platforme u fazi dokazivanja koncepta, s ciljem validacije kontrole kvalitete i usklađenosti tijekom životnog ciklusa proizvoda u brodogradnji.

Ključne riječi: *blockchain, pametni ugovori, kontrola kvalitete, upravljanje kvalitetom, brodogradnja*