From DeFi to Intelligent Supply Chain Finance: Blockchain-Native Financial Innovation, Large Language Models, and Quantum Finance Prospects

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Abstract

This article reviews how blockchain-native finance is reshaping financial intermediation and how the next wave of digital finance is likely to be influenced by large language models (LLMs) and quantum finance research. Building on recent work on decentralized finance, blockchain implementation, supply chain finance, and emerging FinTech architectures, the study develops an integrated analytical framework that connects three layers of change: programmable settlement, intelligent decision support, and frontier computational finance. Rather than treating DeFi, blockchain-based supply chain finance, LLM applications, and quantum finance as isolated topics, the review shows that they form a continuous innovation trajectory with shared challenges in governance, interoperability, data quality, risk modeling, and institutional trust. The paper synthesizes prior findings, compares major technical and managerial mechanisms, and proposes a research agenda for resilient, explainable, and regulation-aware financial innovation. The results suggest that blockchain creates a credible record and execution layer, LLMs expand interpretive and operational intelligence, and quantum finance may eventually widen the solution space for complex risk-pricing and portfolio problems. The article concludes with practical implications for platform designers, regulators, and industry managers.

Keywords: decentralized finance; blockchain finance; supply chain finance; large language models; quantum finance

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1. Introduction

Financial innovation has entered a phase in which infrastructure, intelligence, and governance are being redesigned at the same time. During the last decade, FinTech research moved from the digitization of customer interfaces and payments to a deeper reconsideration of how financial contracts are created, executed, audited, and priced. Early studies on FinTech largely focused on platformization, data-driven service redesign, digital payment systems, crowdfunding, robo-advice, and algorithmic credit evaluation, showing that the sector was not simply adding technology to finance but reconfiguring the institutional boundaries of financial intermediation (Gomber et al., 2018; Lee & Shin, 2018; Thakor, 2020). In parallel, blockchain research developed from a discussion of cryptocurrencies into a broader architecture for trusted transactions, smart contracts, shared ledgers, and inter-organizational coordination (Conoscenti et al., 2016; Christidis & Devetsikiotis, 2016; Lu, 2018a; Lu, 2018b; Yuan & Wang, 2018). These two conversations increasingly overlap. Finance now depends not only on digital channels, but also on programmable execution, machine-verifiable records, and cross-organizational data consistency.

A major turning point in that overlap is the emergence of decentralized finance, or DeFi. DeFi extends the logic of digital finance beyond online delivery and into blockchain-native market design. In DeFi environments, financial functions such as trading, lending, collateral management, clearing, and liquidity provision are embedded in smart contracts and executed on distributed infrastructures rather than solely within conventional institutional stacks. Recent work has characterized this shift as a genuine paradigm transition inside FinTech, because it changes the source of trust, the form of market access, the role of intermediaries, and the economics of settlement (Schär, 2021; Zetzsche et al., 2020; Xu et al., 2024). Yet the DeFi debate is still uneven. Some publications treat DeFi as a disruptive replacement for mainstream finance, while others see it as a useful but partial design laboratory whose long-term contribution will depend on regulation, interoperability, and robust governance. This tension makes careful synthesis necessary.

At the same time, another stream of research has examined blockchain not as a stand-alone financial technology, but as a system-building component inside enterprise information systems, Industry 4.0 architectures, the Internet of Things, and multi-party business networks (Xu et al., 2014; Kshetri, 2018; Saberi et al., 2019; Lu, 2019; Xu et al., 2021; Chen et al., 2024). From that perspective, blockchain is valuable not only because it supports tokenized finance, but also because it creates a reliable transaction substrate for asset tracing, provenance, compliance, auditability, and cross-firm coordination. This view is particularly relevant for supply chain finance. Traditional supply chain finance suffers from persistent frictions: fragmented records, delayed information flows, weak visibility into real transactions, manual reconciliation, and asymmetry between anchor firms and smaller suppliers. A blockchain-enabled approach promises to reduce these frictions by linking commercial events, payment commitments, asset records, and contract execution within a shared logic of trusted data (Gelsomino et al., 2016; Wuttke et al., 2013; Lekkakos & Serrano, 2016; Treiblmaier, 2018; Queiroz et al., 2021). When DeFi mechanisms are connected to these enterprise settings, a broader horizon appears: the possibility of programmable, data-rich, and more inclusive supply chain finance ecosystems.

A further development now complicates and enriches this picture: the rise of large language models. LLMs do not replace blockchain, but they can materially alter how blockchain-based finance is interpreted, supervised, and operated. Blockchain systems are excellent at recording state changes, validating rules, and preserving immutable histories. They are much less capable when institutions need to explain a financing decision in natural language, summarize a counterparty's risk profile from heterogeneous evidence, draft compliance reports, respond to exceptions, or coordinate human workflows around incomplete information. LLMs address precisely these interpretive and communicative tasks. Recent studies have started to examine their potential in supply chain management and blockchain-based supply chain finance, emphasizing the role of LLMs in document intelligence, risk interpretation, scenario reasoning, conversational analytics, and decision support (Srivastava et al., 2024; Yang et al., 2025). The significance of this trend lies in the coupling of symbolic business processes, machine-readable ledgers, and language-based reasoning. Put differently, if blockchain is the execution and evidence layer, LLMs may become the cognitive layer.

Beyond this near-term transformation lies a more speculative but increasingly serious line of inquiry: quantum finance. Quantum research in finance remains early-stage compared with blockchain and AI adoption, yet recent survey work argues that quantum algorithms may eventually reshape portfolio construction, option pricing, risk simulation, optimization, and complex financial decision-making (Lu & Yang, 2024). The relevance of quantum finance to blockchain-based financial innovation is not immediate in an engineering sense, but it is conceptually important. Once finance becomes more programmable, data-intensive, and networked, the demand for more powerful methods of optimization, cryptographic resilience, and scenario exploration grows. Quantum finance therefore should not be treated as a detached frontier topic; it is better understood as the outer layer of an innovation sequence that begins with digital records, advances through programmable contracts, and expands through machine intelligence toward new computational paradigms.

Despite growing interest in each of these domains, the literature remains fragmented in at least four ways. First, blockchain review articles often stop at describing architectures, consensus mechanisms, and application domains, without fully connecting these insights to contemporary DeFi and intelligent finance debates (Yli-Huumo et al., 2016; Tschorsch & Scheuermann, 2016; Wang et al., 2018; Zhou et al., 2020). Second, FinTech reviews frequently discuss blockchain as one component within a broader technology portfolio, but do not show how blockchain-native financial design differs from centralized platform finance in terms of execution logic, governance, and risk transmission (Gomber et al., 2018; Kou & Lu, 2025). Third, supply chain finance studies often recognize the value of digital visibility, yet many still analyze SCF through traditional information-sharing and working-capital lenses rather than through programmable infrastructures and intelligent orchestration (Gelsomino et al., 2016; Bals, 2019). Fourth, recent work on LLMs and quantum finance is promising but still disconnected from established blockchain and enterprise-finance conversations. As a result, managers and scholars lack a unified account of where blockchain-native finance is heading and which combinations of technologies are likely to matter most.

This article addresses that gap by developing an integrated review of blockchain-native financial innovation across four linked themes: DeFi, blockchain-based supply chain finance, LLM-enabled financial intelligence, and quantum finance prospects. The paper does not argue that all financial activity will migrate to public blockchains, nor that every intelligent finance application requires LLMs or quantum methods. Instead, it asks a more grounded question: how do these technologies combine to reconfigure the design space of financial intermediation? The answer matters for theory and practice alike. For scholars, it helps connect work in information systems, operations, financial innovation, and AI governance. For practitioners, it clarifies where real operational value is emerging, where hype exceeds current capability, and which institutional conditions determine whether experimentation becomes scalable transformation.

The remainder of this paper is organized as follows. Section 2 explains the review design and introduces the analytical framework used in the study. Section 3 revisits the foundations of blockchain-native financial innovation and clarifies how DeFi extends the FinTech trajectory. Section 4 examines blockchain-based supply chain finance as a domain where enterprise integration and programmable finance meet. Section 5 discusses the role of LLMs as an intelligence layer for blockchain-enabled finance. Section 6 turns to quantum finance and identifies its most plausible intersections with the blockchain-finance agenda. Section 7 develops an integrated research agenda and managerial implications. Section 8 concludes the article.

2. Review Design and Analytical Framework

This paper adopts an integrative review design rather than a narrow bibliometric or purely technical survey. The purpose is not to provide a mechanical count of keywords, but to synthesize how different streams of scholarship collectively explain the transition from digital finance to blockchain-native, AI-assisted, and computationally intensified finance. The review therefore combines conceptual comparison, thematic synthesis, and managerial interpretation. Sources were selected from peer-reviewed studies in information systems, operations and supply chain management, finance, industrial informatics, and technology management. Priority was given to articles that made one of four contributions: clarifying the architectural logic of blockchain systems, explaining the evolution of FinTech and DeFi, examining the redesign of supply chain finance, or discussing intelligent and frontier computational methods relevant to future financial infrastructures. The resulting corpus is structured around problems, not merely around technologies.

The review logic follows three principles. First, technologies are interpreted as institutional design mechanisms rather than as isolated tools. A blockchain ledger matters because it changes auditability, asset verification, and cross-party trust. A DeFi protocol matters because it embeds financial rules in executable code and reassigns some functions of intermediation. An LLM matters because it reshapes how complex financial evidence is translated into decisions, reports, and oversight. A quantum algorithm matters because it may enlarge the tractable space for simulation and optimization. This institutional reading helps move beyond a feature-by-feature description and toward a more realistic account of why organizations adopt, reject, or hybridize these systems. Second, the review emphasizes complementarities. The main contribution of recent innovation is not any single technology in isolation, but the possibility of combining credible records, programmable transactions, and adaptive intelligence. Third, the review maintains a governance perspective. Financial infrastructures are shaped not only by speed, efficiency, and automation, but also by explainability, accountability, legal enforceability, and systemic resilience.

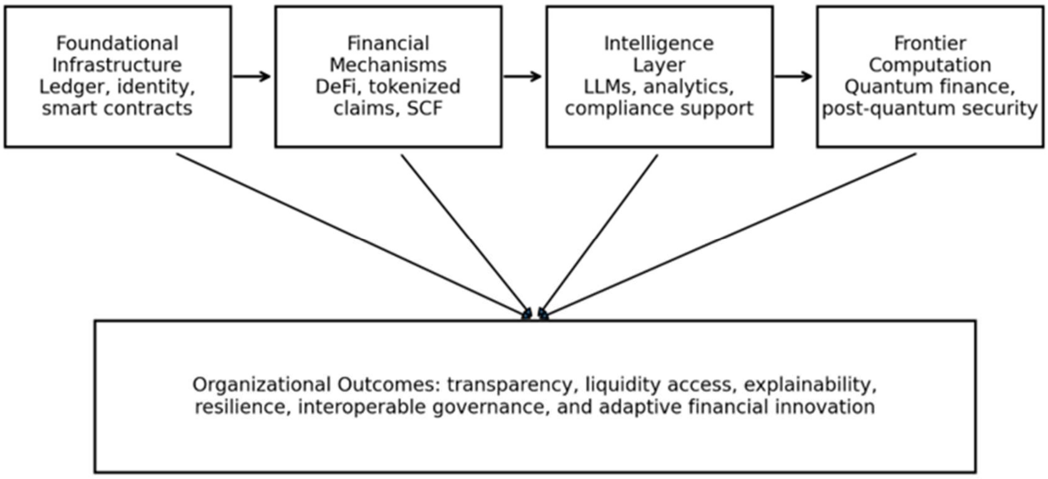

Figure 1. Integrated Analytical Framework of Blockchain-Native Financial Innovation

To operationalize this perspective, the paper uses a four-layer analytical framework shown in (Figure 1). The first layer is foundational infrastructure. This includes distributed ledgers, tokenization logic, smart contracts, data standards, identity systems, and interoperability arrangements. Research in this layer asks how trusted execution and shared records are established and how technical design choices influence scalability, security, and institutional fit (Croman et al., 2016; Luu et al., 2016; Dinh et al., 2018; Zhou et al., 2020). The second layer is financial mechanism design. Here the focus shifts from infrastructure to application logics such as payments, trading, liquidity pools, collateralization, invoice financing, asset provenance, and working-capital coordination. DeFi and blockchain-enabled supply chain finance belong primarily to this layer because they redesign how value claims are originated, transferred, and settled (Schär, 2021; Xu et al., 2024). The third layer is intelligent augmentation. This layer involves AI, especially LLM-based capabilities for document interpretation, exception handling, policy compliance, market analysis, and conversational decision support (Srivastava et al., 2024; Yang et al., 2025). The fourth layer is frontier computation and strategic adaptation. Quantum finance is located here because it is likely to matter first in advanced optimization, simulation, cryptography-sensitive environments, and strategic scenario analysis rather than in routine transaction processing (Lu & Yang, 2024).

The framework also clarifies the article's central propositions. Proposition 1 is that blockchain-native finance creates the most value when financial claims depend on verifiable multi-party events, because the ledger reduces information asymmetry and the smart contract reduces execution ambiguity. Proposition 2 is that DeFi should be interpreted less as a universal replacement for institutions and more as a modular design space whose elements may be recombined with enterprise finance and regulatory systems. Proposition 3 is that LLMs increase the practical value of blockchain-based finance when they are connected to trustworthy structured records, because language intelligence is most useful when grounded in reliable transactional evidence. Proposition 4 is that quantum finance is unlikely to displace existing systems in the near term, but it expands the strategic horizon of financial innovation by improving computational approaches to complexity, uncertainty, and optimization. These propositions do not function as econometric hypotheses in the way they would in a panel-data study. Instead, they provide a structured logic for comparing and synthesizing prior work.

Table 1. Main Streams Covered in the Review

Stream	Core focus	Representative references	Managerial significance
Foundational blockchain research	Consensus, smart contracts, security, scalability, and systems architecture	Conoscenti et al. (2016); Christidis & Devetsikiotis (2016); Croman et al. (2016); Zhou et al. (2020)	Establishes trusted execution and auditable records
FinTech and DeFi	Digital financial ecosystems, programmable intermediation, composability, governance	Gomber et al. (2018); Thakor (2020); Schär (2021); Xu et al. (2024)	Explains how financial products move from digitized delivery to coded execution
Supply chain finance	Working capital, information asymmetry, receivable finance, platform coordination	Wuttke et al. (2013); Gelsomino et al. (2016); Bals (2019); Queiroz et al. (2021)	Shows where real-economy financing can benefit from trusted multi-party data
Intelligent and frontier finance	LLMs, document intelligence, AI-enabled coordination, quantum finance	Srivastava et al. (2024); Yang et al. (2025); Lu & Yang (2024)	Extends blockchain finance toward explainability, adaptive decisions, and advanced computation

(Table 1) summarizes the main streams covered in this review. The table is important because it shows that the current literature is no longer adequately described by the old distinction between "traditional finance" and "digital finance." What emerges instead is a layered transition. FinTech introduced digitized interfaces, alternative delivery channels, and data-intensive customer management. Blockchain introduced trusted shared execution and recordkeeping. DeFi intensified programmability and automated market logic. LLMs introduced language-based interpretation and coordination across complex business contexts. Quantum finance represents a possible future step toward deeper computational decision support. When these developments are viewed together, a more coherent picture of financial innovation becomes visible.

A final methodological note concerns scope. This paper deliberately avoids two extremes. It does not reduce blockchain finance to cryptocurrencies and token speculation, because the enterprise and infrastructural applications are now too substantial to ignore (Kshetri, 2018; Lei & Ngai, 2023). Nor does it treat every AI tool as equivalent to LLM-based intelligence. Many earlier finance technologies relied on machine learning for prediction, classification, and anomaly detection, but LLMs differ because they can directly mediate between formal data structures and natural-language institutional work. That distinction matters in supply chain finance, where decisions depend not only on transaction records, but also on contracts, invoices, correspondence, policy terms, and human explanations. The review therefore centers on applications in which blockchain, finance, and advanced AI intersect in ways that reshape organizational routines.

3. FinTech and the Rise of Blockchain-Native Finance

The contemporary discussion of blockchain finance makes more sense when placed within the broader trajectory of FinTech. FinTech did not begin with cryptocurrencies. It emerged from a longer wave of digitization that changed how financial services were delivered, monitored, and personalized. Studies on the FinTech revolution consistently argue that the core shift involved more than technological efficiency; it involved new ecosystem structures, new competitive boundaries, and new relationships among incumbents, platforms, regulators, and users (Gomber et al., 2018; Lee & Shin, 2018; Thakor, 2020). Digital payments, peer-to-peer lending, crowdfunding, robo-advisory services, open banking, and algorithmic risk assessment all illustrate this transformation. However, these innovations generally remained within an architecture of centralized control. The provider still owned the data environment, the platform still defined market access, and institutional trust still depended heavily on organizational authority.

Blockchain changed the terms of that arrangement. The early literature described it as a distributed ledger capable of creating tamper-resistant, time-stamped records without requiring a single central authority to maintain the canonical database (Haber & Stornetta, 1991; Tschorsch & Scheuermann, 2016; Yli-Huumo et al., 2016). Subsequent work expanded the discussion by linking blockchain to smart contracts, consensus mechanisms, tokenized incentives, and multi-party systems design (Christidis & Devetsikiotis, 2016; Croman et al., 2016; Luu et al., 2016). From an information-systems perspective, this mattered because blockchain redefined the architecture of trust. Data validation, process execution, and auditability could now be embedded into a shared technological substrate rather than being coordinated only through contracts, reconciliations, and institutional reputation. Review studies by Lu (2018a, 2018b, 2019, 2022), Zheng and Lu (2022), and Lei and Ngai (2023) collectively show how this shift opened a rich agenda spanning system implementation, business process redesign, governance, and platform integration.

Yet blockchain alone does not produce financial transformation. It creates a new infrastructural possibility, but the form of financial innovation depends on how that infrastructure is combined with market design. This is where the idea of blockchain-native finance becomes useful. Blockchain-native finance refers to financial arrangements whose core logic depends on programmable settlement, tokenized claims, or smart-contract execution rather than on the ledger serving merely as a supporting database. In other words, blockchain is not just back-end plumbing; it becomes a constitutive part of the financial product. DeFi is the clearest example. Liquidity pools, automated market makers, on-chain collateralization, algorithmic yield mechanisms, and token-governed protocols are not conventional financial products digitized after the fact. They are products whose existence depends on the blockchain environment. This distinction explains why DeFi deserves separate analytical treatment rather than being subsumed under a generic "blockchain in finance" category.

Recent review work on FinTech and DeFi helps sharpen this distinction. Kou and Lu (2025) describe FinTech as an umbrella field that includes digital payments, blockchain, AI, wealth technology, insurtech, regtech, and data-driven financial infrastructures. Xu et al. (2024) argue that DeFi marks a paradigm shift because it alters the technical and institutional grammar of finance. Instead of relying on balance-sheet intermediation and organizational gatekeeping, DeFi protocols rely on code-based rules, transparent state transitions, public verification, and composable financial building blocks. Zetzsche et al. (2020) similarly frame DeFi as a challenge to conventional legal and regulatory categories, because functions that were once bundled within firms become distributed across protocols, token holders, liquidity providers, governance arrangements, and oracle systems. Schär (2021) adds that the real analytical novelty lies in composability: financial services can be stacked, recombined, and reused in an open architecture, creating both innovation and contagion.

This open architecture produces several benefits that explain DeFi's appeal. First, programmability lowers some transaction and coordination costs. Financial rules can be encoded and automatically executed when conditions are met. Second, transparency increases because protocol logic and transaction histories are often publicly auditable. Third, modularity encourages experimentation. Developers can create new financial services by integrating existing components such as wallets, liquidity pools, oracles, and collateral contracts. Fourth, accessibility may improve for some users because open protocols can reduce dependence on traditional onboarding channels. These benefits are not merely technical. They influence who can participate, how quickly products evolve, and where value migrates inside the financial ecosystem. That is why DeFi has become central to current debates on digital financial innovation.

Still, DeFi also exposes several structural weaknesses. Smart contracts may be transparent, but they are not automatically safe. Vulnerabilities in contract logic can trigger irreversible losses, a concern that has remained visible since early work on smart contract security (Luu et al., 2016). Market transparency may increase, but governance can still be opaque when token distribution is concentrated or when protocol changes depend on poorly understood voting structures. Open access may widen participation, but it can also increase exposure to volatile collateral, oracle manipulation, unstable incentive schemes, and rapid contagion across protocols. Moreover, the claim that DeFi eliminates intermediaries is often overstated. In practice, users still depend on exchanges, wallets, developer teams, infrastructure providers, legal wrappers, and interfaces that shape how protocols are accessed and governed. A realistic reading of DeFi therefore requires balancing innovation against operational fragility.

Table 2. Comparison of Major Digital-Finance Models

Model	Trust basis	Execution logic	Transparency	Typical strengths	Typical risks
Traditional institutional finance	Licensed institutions and legal contracts	Manual-plus-digital process control	Selective and organization-bound	Scale, legal clarity, systemic support	Slow settlement, fragmented data, heavy reconciliation
Centralized platform finance	Platform governance and proprietary data	API-driven but centrally administered	High internal visibility, limited external auditability	Fast customer service and ecosystem integration	Concentration risk, opacity, dependence on platform owner
DeFi	Smart contracts, protocol rules, on-chain verification	Programmable and composable execution	High protocol transparency	Rapid innovation, modularity, open participation	Code exploits, governance fragility, contagion
Blockchain-based SCF	Shared business evidence plus institutional governance	Programmable finance tied to trade events	Selective shared auditability	Better receivable verification, faster approvals, improved	Onboarding errors, interoperability limits, legal ambiguity

				inclusion potential	

This balance becomes clearer when DeFi is compared with other forms of digital finance. Centralized platform finance typically excels in customer acquisition, integrated service delivery, and regulatory legibility. Traditional bank-centered finance excels in scale, institutional confidence, legal enforceability, and systemic support. DeFi excels in programmability, transparency of protocol logic, and composability. Blockchain-based enterprise finance, including supply chain finance, occupies a hybrid position. It generally does not seek radical disintermediation. Instead, it uses blockchain to improve the quality of information, automate trusted coordination, and enable more responsive financing arrangements in multi-party business networks. (Table 2) compares these models in terms of trust basis, execution logic, data transparency, governance structure, and main risks.

A key implication of this comparison is that the future of finance is likely to be hybrid. The binary question—will DeFi replace traditional finance?—is analytically weaker than a more nuanced question: which functions migrate to programmable infrastructures, which remain institutionally anchored, and which are redesigned through hybrid combinations? The literature increasingly suggests that hybridization is the dominant path. Enterprise applications often require identifiable counterparties, contractual enforceability, privacy controls, and compliance integration, which means permissioned or semi-open blockchain models may be more practical than fully public, anonymous architectures in many business settings (Khan & Salah, 2018; Ali et al., 2021; Chen et al., 2024). At the same time, DeFi contributes valuable design patterns: tokenized incentives, automated settlement logic, modular services, and transparent execution. The most promising innovations may therefore arise not from wholesale institutional displacement, but from selective recombination.

That recombination is especially relevant for supply chain finance. Unlike speculative retail DeFi, supply chain finance is anchored in trade relationships, invoices, procurement cycles, shipment data, and payment obligations. It depends on credible business events rather than only on token economics. This makes it a suitable domain for testing whether blockchain-native logic can produce durable operational value. If DeFi demonstrates how finance can be encoded and composably executed, blockchain-based supply chain finance demonstrates where programmable finance may matter most in the real economy: settings in which multiple organizations need to trust the same evidence, respond to the same business events, and price risk with more granularity than legacy systems allow.

4. Blockchain-Based Supply Chain Finance: From Visibility to Programmable Coordination

Supply chain finance has long been treated as an information problem as much as a funding problem. Conventional SCF mechanisms such as reverse factoring, receivables finance, dynamic discounting, and inventory-backed lending rely on the timely exchange of credible information among buyers, suppliers, logistics providers, and financiers. When that information is fragmented, delayed, or disputable, risk perception rises and financing becomes more expensive or less inclusive. The literature has therefore repeatedly emphasized that SCF performance depends on information quality, relational structure, and the distribution of bargaining power inside the supply network (Wuttke et al., 2013; Gelsomino et al., 2016; Lekkakos & Serrano, 2016; Bals, 2019). Smaller suppliers are especially disadvantaged because they often possess weaker informational credibility even when their underlying commercial performance is sound.

Blockchain changes this setting by improving how supply-chain events are recorded, shared, and verified. In a blockchain-enabled SCF environment, purchase orders, shipment confirmations, quality checks, warehouse receipts, delivery events, invoice approvals, and payment commitments can be anchored to a shared transaction layer. This does not eliminate the need for governance, but it reduces repeated reconciliation and creates a more credible evidentiary trail. Studies on blockchain adoption in operations and supply chain management suggest that this feature is one of the strongest motives for adoption: firms want to reduce opportunism, increase traceability, and improve cross-organizational coordination in environments where no single database is fully trusted by all parties (Treiblmaier, 2018; Queiroz et al., 2021; Saberi et al., 2019). From a financing perspective, better event visibility can improve risk assessment, speed up receivables validation, and support more dynamic liquidity arrangements.

The operational value of blockchain in SCF can be described through three mechanisms. The first is evidentiary integrity. Financiers frequently hesitate because they cannot easily verify whether an invoice corresponds to a genuine commercial event, whether goods were delivered as stated, or whether the same receivable has already been pledged elsewhere. A blockchain-based record can reduce these ambiguities by linking financing claims to verifiable transaction histories. The second is process synchronization. In legacy systems, each party often maintains its own version of the transaction, which creates delays in approval and payment. A shared ledger can shorten these cycles by aligning event recognition and by enabling smart-contract triggers tied to predefined milestones. The third is programmability. Once key business events are reliably digitized, financing logic can become conditional, modular, and responsive. Payment acceleration, collateral release, discount recalculation, and covenant enforcement can all be partially automated. These mechanisms move SCF from passive digitization toward active coordination.

This transition is analytically important because it clarifies what blockchain contributes beyond ordinary database modernization. Ordinary digitization can improve visibility within a firm or platform, but it does not automatically solve the cross-boundary trust problem. Blockchain matters most when parties need a common, auditable, and resistant record without fully surrendering control to a dominant intermediary. In that sense, blockchain is not just an efficiency tool; it is an inter-organizational governance technology. The same point has been made in broader blockchain and enterprise information systems research, which shows that implementation success depends on whether the technology addresses real coordination frictions rather than being adopted as a symbolic innovation (Lu, 2022; Lei & Ngai, 2023). For SCF, the real friction is seldom the absence of data in an absolute sense. It is the absence of mutually trusted, timely, and finance-usable data.

The next question is whether DeFi concepts add anything meaningful to this enterprise setting. The answer is yes, but with qualification. DeFi contributes a repertoire of programmable financing designs that can be adapted to SCF, even when the application is not fully decentralized in the public-chain sense. Tokenized claims can represent receivables, warehouse assets, or structured rights to payment. Smart-contract logic can govern collateral thresholds, dynamic pricing, milestone-based disbursement, and distribution rules. Liquidity pools can be reinterpreted as permissioned or semi-permissioned financing pools linked to verified trade data. Governance mechanisms from DeFi may inform how multiple parties participate in shared financing infrastructures, especially when platforms involve anchor firms, financiers, insurers, logistics actors, and technology providers. What matters is not ideological decentralization, but the selective transfer of useful design principles.

The user-provided literature supports this view from several angles. Xu et al. (2024) show that DeFi's main significance lies in the redesign of financial intermediation rather than in the simple use of tokens. Yang et al. (2025) specifically argue that blockchain-based supply chain finance is now moving toward a more intelligent and modular stage in which advanced digital intelligence can support document review, risk interpretation, and financing orchestration. Lu (2022) demonstrates that blockchain implementation in information systems should be evaluated through organizational fit, governance logic, and process redesign rather than through technological novelty alone. Zheng and Lu (2022) likewise note that the future trajectory of blockchain depends on how research and practice confront scalability, interoperability, and application grounding. Together these works imply that the most credible path forward for blockchain-based SCF is neither a replication of speculative DeFi nor a mere digitization of conventional bank processes. It is a hybrid architecture in which trade evidence, programmable contracts, and adaptive intelligence interact.

However, important barriers remain. One barrier is data onboarding. Blockchain is only as trustworthy as the interfaces that connect physical or organizational events to digital records. If invoice data, shipment confirmations, or quality certifications are inaccurate before they reach the ledger, immutability can preserve errors instead of resolving them. This is a classic "garbage in, immutable forever" problem. A second barrier is legal and accounting recognition. For tokenized or smart-contract-based SCF to scale, firms and financiers need clarity on ownership, enforceability, insolvency treatment, and reporting obligations. A third barrier is interoperability across enterprise systems. SCF participants commonly use heterogeneous ERP, logistics, banking, and customs systems. Without data standards and process alignment, the ledger becomes another silo rather than a coordination backbone. A fourth barrier is governance. Even permissioned blockchains require agreement on access rights, validation rules, dispute resolution, and update procedures. These are managerial problems, not merely technical details.

The lesson, then, is that blockchain-enabled SCF creates the most value when it is embedded in a broader capability stack. Trusted data capture, shared process standards, financing logic, legal enforceability, and user-facing decision support all need to be aligned. This is why recent scholarship has moved beyond asking whether blockchain can be used in finance and toward asking how it should be combined with AI, analytics, and platform governance. (Figure 2) illustrates this layered architecture. The base layer contains transaction evidence and shared ledgers. The next layer contains tokenized claims, receivable representations, and smart-contract execution. The third layer contains analytics and language-based intelligence. The top layer contains governance, compliance, and strategic adaptation. Seen in this way, blockchain-based SCF is not a narrow financing application. It is a microcosm of next-generation enterprise finance.

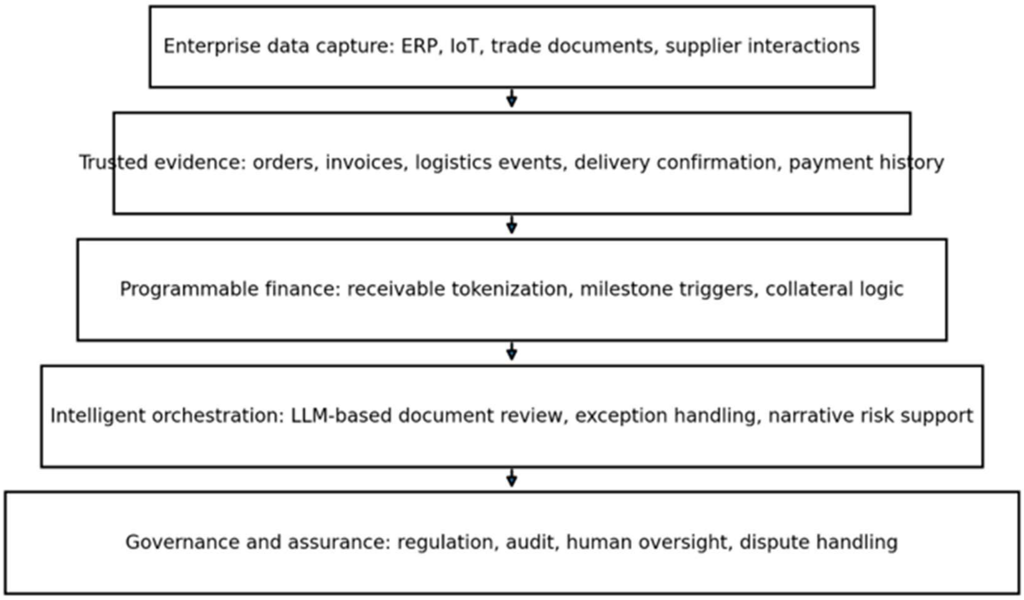

Figure 2. Layered Architecture for Blockchain-Enabled Supply Chain Finance

The practical implications are substantial. For anchor firms, blockchain-based SCF can improve supplier visibility, shorten payment cycles, and strengthen resilience by supporting smaller suppliers that would otherwise face expensive working-capital constraints. For financiers, it can improve risk pricing, reduce fraud exposure, and support more responsive credit structures. For suppliers, it can increase financing access if the system is designed to recognize verified performance rather than only balance-sheet strength. For regulators and standard setters, it creates an opportunity to support more transparent and inclusive financial infrastructures while also raising new questions about governance, data rights, competition, and systemic dependence on shared platforms. These issues point directly to the next stage of the discussion: the role of LLMs as a cognitive layer for blockchain-enabled finance.

A closely related lesson comes from the blockchain-IoT integration literature. Reviews have shown that end-to-end traceability depends not only on ledger design, but also on sensors, tagging systems, event authenticity, and secure edge connectivity (Fernández-Caramés & Fraga-Lamas, 2018; Viriyasitavat et al., 2019; Latif et al., 2021; Golpira et al., 2021). Studies of food and industrial supply chains further warn that the connection between "what happened" and "what is written on-chain" remains precarious when data capture is weak or strategically manipulated (Powell et al., 2022). For supply chain finance, this means that trustworthy financing does not start at the bank interface. It starts at the quality of operational events entering the system. The stronger the linkage between physical flow, commercial documentation, and shared digital records, the more credible the financing layer becomes.

5. Large Language Models as the Intelligence Layer of Blockchain Finance

Blockchain systems are highly effective at preserving ordered transaction histories and executing machine-readable rules, but financial work is not reducible to state transitions on a ledger. Real financial operations involve interpretation, explanation, negotiation, anomaly handling, policy translation, contract review, and the synthesis of structured and unstructured evidence. This is precisely where LLMs matter. The recent wave of work on LLMs in supply chain management argues that these models can create value by converting heterogeneous documents and contextual information into usable operational intelligence (Frederico, 2023; Srivastava et al., 2024). In the context of blockchain-based finance, the importance of that capability is even greater, because many adoption barriers are caused not by the absence of data, but by the gap between machine-validated records and institutionally meaningful decisions.

Yang et al. (2025) provide one of the clearest bridges between these conversations by examining the potential of LLMs in blockchain-based supply chain finance. Their argument is not that LLMs should replace financial judgment. Rather, LLMs can extend the reach of digital finance by improving how financing applications are interpreted, summarized, and coordinated across complex business settings. This includes reading invoices and contracts, identifying discrepancies across trade documents, drafting financing rationales, explaining credit decisions to human users, summarizing transaction histories for auditors, and supporting intelligent exception management when something in the financing workflow deviates from expectation. In other words, LLMs can reduce the translation cost between structured records and managerial action.

This point is often underappreciated in the blockchain literature. Much blockchain research has focused on security, consensus, scalability, and system design (Tschorsch & Scheuermann, 2016; Zhou et al., 2020; Ali et al., 2021). These topics remain essential, but they do not fully explain how organizations actually use financial infrastructure. Managers and financing officers work through narratives as much as through data tables. They need to understand why a financing request was flagged, what changed in a supplier's shipment pattern, whether a contract clause affects collateral enforceability, how a discrepancy should be escalated, and what a regulator or board member needs to know about the system's decision logic. LLMs are particularly suitable for this layer because they generate, compare, summarize, and contextualize language at scale. When grounded in trustworthy ledgers and enterprise data, they can make blockchain finance more usable rather than merely more automated.

The potential applications are broad. One application is document intelligence. Supply chain finance often depends on invoices, purchase orders, delivery notes, customs documents, financing agreements, and correspondence. These documents are heterogeneous in format and quality. LLMs can extract relevant clauses, compare versions, detect inconsistencies, and produce structured summaries for review. A second application is risk narration. Predictive systems may generate scores or anomaly flags, but human decision makers frequently need a defensible explanation. LLMs can transform signals from ledger data, procurement histories, and payment behavior into concise risk narratives that are easier to scrutinize and communicate. A third application is compliance orchestration. Regulations on anti-money laundering, sanctions, fraud, disclosure, and data handling generate complex rule environments. LLMs can assist by mapping transaction patterns and documents against policy templates, surfacing likely issues for human validation. A fourth application is user interaction. Conversational interfaces can make financing platforms easier to use for suppliers who lack specialized financial or technical expertise. (Table 3) outlines these application areas and the corresponding risks.

Table 3. Representative LLM Applications in Blockchain-Based Supply Chain Finance

Application area	Example task	Main value	Key caution
Document intelligence	Compare invoices, contracts, and shipment records	Reduces review time and highlights inconsistencies	Requires evidence grounding and human validation
Risk narration	Translate ledger signals into readable case summaries	Improves managerial understanding and audit communication	Narratives may become overconfident or incomplete
Compliance support	Map transaction patterns to policy templates and red flags	Improves monitoring and escalation efficiency	Does not replace legal judgment
Conversational user support	Explain financing options and onboarding requirements to suppliers	Lowers cognitive barriers and improves usability	Needs access controls and careful prompt governance

Those risks should not be minimized. LLMs can hallucinate, oversimplify, inherit bias from training data, or produce plausible but incorrect explanations. In finance, such errors can be costly. A mistaken summary of a receivables contract, an overconfident explanation of a risk signal, or an inaccurate compliance recommendation could distort decisions and expose firms to liability. This is why the most credible deployment model is not autonomous language-driven finance, but human-supervised, evidence-grounded augmentation. Blockchain can contribute to that grounding by providing a reliable evidentiary base. The more faithfully the LLM is linked to transaction records, smart-contract outputs, and verified enterprise data, the lower the risk that language generation floats away from operational reality. Put differently, blockchain can help anchor LLMs, while LLMs can help make blockchain finance intelligible.

Another challenge concerns architecture. Many firms are tempted to treat LLMs as plug-in assistants layered on top of existing platforms. That may produce short-term productivity gains, but it rarely addresses core process redesign. The more meaningful question is architectural: where should language intelligence sit in the workflow? In a blockchain-enabled SCF platform, LLMs can be positioned at several points. They can support onboarding by helping interpret supplier documents and KYC materials. They can support underwriting by summarizing trade evidence and highlighting unusual dependencies. They can support execution by handling exceptions, amendments, and conversational confirmations. They can support governance by generating auditable summaries for risk committees, auditors, and regulators. Each of these roles requires different controls, permissions, and model-evaluation criteria. A one-size-fits-all deployment strategy is therefore unlikely to work.

There is also a strategic implication. LLMs may widen participation in supply chain finance by lowering the cognitive and linguistic barriers faced by smaller firms. Many SCF systems implicitly favor large organizations because they have specialized legal, procurement, treasury, and compliance teams. Smaller suppliers often struggle not only with access to capital but also with access to the procedural knowledge needed to navigate financing systems. An LLM-enabled interface can partly reduce that asymmetry by explaining requirements, drafting responses, and helping users understand financing options. This does not solve structural power imbalances, but it can reduce friction and improve usability. In that sense, the social value of LLMs in blockchain finance may be as important as the efficiency value.

The emerging literature therefore suggests a simple but powerful principle: the practical future of blockchain finance depends not only on trusted execution, but on intelligible execution. Systems that can record and automate financial events but cannot explain them will struggle to scale in regulated and relational environments. Systems that can explain but lack credible evidence will struggle to earn trust. Combining blockchain with LLMs offers a path toward both operational rigor and interpretive accessibility. The open research question is how to make that combination safe, explainable, and robust enough for mainstream enterprise use.

This question leads naturally to the final frontier considered in this paper. If blockchain provides trusted execution and LLMs provide grounded interpretation, what role might new computational paradigms play in future financial innovation? Quantum finance does not answer today's operational problems in the way that LLMs might, but it enlarges the strategic horizon of what programmable finance could become.

The broader AI and operations literature supports this interpretation. Recent reviews of AI in supply chain and operations management suggest that the field is moving from predictive analytics toward more interactive, generative, and human-facing forms of intelligence (Cannas et al., 2024; Aghaei et al., 2025). Research at the intersection of AI and supply chain finance also indicates that intelligent systems can improve risk visibility, capital coordination, and resilience when they are embedded in process design rather than added as isolated tools (Olan et al., 2022). These findings reinforce the idea that LLMs will create the most value when they are combined with structured enterprise data, grounded evidence, and clear governance boundaries.

6. Quantum Finance and the Outer Horizon of Financial Innovation

Quantum finance is still an emerging field, and it would be misleading to present it as an immediate operational solution for today's digital-finance challenges. Yet dismissing it as irrelevant would also be a mistake. The most persuasive recent survey in this area argues that quantum approaches deserve serious attention because finance increasingly depends on high-dimensional optimization, simulation under uncertainty, complex combinatorial search, and secure information processing (Lu & Yang, 2024). These are domains in which classical methods already face scale and complexity limits. As financial systems become more data-rich and more programmable, the demand for advanced computational methods is likely to grow rather than shrink.

To understand the relevance of quantum finance in the present context, it is useful to distinguish between operational immediacy and strategic adjacency. Operational immediacy refers to technologies that can be deployed now to improve financial processes. Blockchain and LLMs fall into this category, albeit at different levels of maturity. Strategic adjacency refers to technologies that are not yet mainstream in operations but are conceptually adjacent to emerging needs. Quantum finance belongs here. A blockchain-based SCF platform that captures granular transaction flows, tracks asset states, and supports dynamic financing decisions will eventually generate complex optimization problems: how to allocate liquidity across suppliers, how to price contingent claims under uncertain trade patterns, how to simulate network-level disruptions, or how to optimize collateral structures under multiple constraints. Quantum methods may become relevant as these problems grow harder and more interconnected.

The current finance literature identifies several plausible application areas. One is portfolio optimization, especially when decision spaces become combinatorially large. Another is option pricing and Monte Carlo simulation, where quantum approaches may accelerate certain classes of stochastic computation. A third is risk analytics in complex networks, where correlated exposures and cascading dependencies challenge conventional models. A fourth is cryptography-related preparedness. If quantum computing evolves to a point where existing cryptographic assumptions are weakened, blockchain systems and digital financial infrastructures will need post-quantum security strategies. Even before full-scale quantum advantage arrives, this issue already matters strategically because long-lived financial infrastructures cannot ignore future cryptographic threats. The link between blockchain and quantum finance therefore runs in two directions: quantum may strengthen advanced financial computation, and it may also pressure financial infrastructures to rethink security.

In the context of blockchain-native finance, the strongest near-term contribution of quantum thinking may actually be conceptual rather than computational. It encourages researchers and designers to ask whether current financial architectures are being built for a future in which complexity, data density, and simulation intensity continue to rise. Many current digital-finance platforms are optimized for transaction throughput or interface convenience, but not necessarily for long-range adaptive intelligence. If finance is moving toward a stack that includes programmable claims, continuous data ingestion, AI-assisted interpretation, and dynamic optimization, then computational extensibility becomes a design concern today. In that sense, quantum finance is less a separate field than a reminder that financial infrastructure should be designed with future computational layers in mind.

Still, it is important to remain disciplined. The path from quantum research to deployable enterprise finance is uncertain, and the history of digital innovation contains many cases in which technically elegant possibilities arrived far later than expected. A realistic assessment therefore places quantum finance at the strategic edge of the framework rather than at its operational center. It is a field to monitor, shape, and integrate conceptually, not one to overpromise in the present. The implication for research is clear: blockchain and LLM-enabled finance should be studied in ways that remain compatible with future computational advances, but practical implementation priorities should remain grounded in today's organizational problems of governance, explainability, risk control, and interoperability.

7. Integrated Discussion, Research Agenda, and Managerial Implications

The review points to a broad but coherent conclusion: the future of financial innovation is neither purely decentralized nor purely intelligent. It is layered. Blockchain contributes credible execution and shared evidence. DeFi contributes modular financial design and programmable market logic. Supply chain finance provides a real-economy domain in which those capabilities can solve concrete inter-organizational problems. LLMs contribute interpretive and communicative intelligence that makes digital finance more usable and governable. Quantum finance extends the horizon of computational possibility. The technologies differ in maturity and purpose, but together they reveal an important shift: finance is becoming a coordination system that integrates code, data, language, and adaptive decision support. This is a deeper transformation than channel digitization or process automation.

One implication is theoretical. Research on financial innovation should move beyond single-technology explanations. Many studies still ask whether blockchain adoption improves transparency, whether AI improves prediction, or whether FinTech enhances inclusion. Those questions remain useful, but they are too narrow for the next phase of digital finance. What increasingly matters is the interaction among technologies and institutions. For example, blockchain may improve the credibility of data, but the value of credible data depends on whether financing mechanisms can use it. LLMs may improve interpretability, but their practical reliability depends on the quality of the evidence they are grounded in. DeFi may expand the design space of intermediation, but its real-world impact depends on governance, legal fit, and organizational adoption. Future theory therefore should emphasize complementarities, sequencing, and boundary conditions rather than isolated net effects.

A second implication concerns research method. The field would benefit from more work that bridges technical, organizational, and financial levels of analysis. Technical papers often optimize protocol or model performance while abstracting from institutional friction. Organizational papers often study adoption or perception while abstracting from technical design constraints. Finance papers often emphasize pricing, risk, or market outcomes while abstracting from enterprise workflow and data provenance. This fragmentation limits cumulative knowledge. A more useful research agenda would combine system design, process observation, case analysis, and where appropriate, empirical evaluation of platform performance. For example, researchers could examine how ledger quality affects financing decisions, how LLM interfaces influence supplier participation, or how tokenized SCF arrangements alter bargaining power and liquidity distribution across a supply network.

Several substantive research questions emerge. First, under what conditions does blockchain materially improve financing inclusion for smaller suppliers rather than merely strengthening the information advantage of already powerful anchor firms? The answer likely depends on governance design, data-sharing rules, and whether financiers are willing to price risk from verified trade performance rather than from conventional collateral alone. Second, what forms of hybrid architecture are most effective? Public-chain DeFi, permissioned enterprise blockchain, and platform-mediated arrangements each embody different trade-offs in transparency, privacy, speed, and legal clarity. Comparative studies are needed to identify which models fit which SCF contexts. Third, how should LLMs be evaluated in blockchain finance? Standard accuracy metrics are insufficient when the model is producing explanations, compliance suggestions, or risk summaries that affect real financial decisions. Evaluation should include grounding quality, stability, explainability, escalation design, and user trust. Fourth, how can intelligent finance systems be audited when decision making is distributed across ledgers, smart contracts, analytical models, and language interfaces? Fifth, what governance structures can prevent concentration of power in nominally decentralized ecosystems?

Table 4. Research Agenda for Next-Generation Blockchain Finance

Research domain	Illustrative question	Promising methods	Expected contribution
Infrastructure and interoperability	How can enterprise and public-chain components exchange trusted financing data?	Architecture analysis, case studies, design science	Improves realistic deployment models
SCF market design	When do tokenized or programmable claims	Field studies, simulation, archival platform data	Clarifies value creation and inclusion effects

	improve liquidity access for suppliers?		
LLM governance	How should evidence grounding, escalation, and explanation quality be audited?	Experimentation, human-AI workflow studies	Supports safe intelligent finance
Frontier computation	Which financing problems are likely to benefit first from quantum-inspired or quantum methods?	Optimization experiments, scenario analysis	Connects present infrastructure design with long-term computational strategy

(Table 4) organizes these questions into a forward-looking research agenda. The table differentiates between infrastructure research, market-design research, organizational adoption research, and governance research. This distinction is important because many current debates become confused when different levels are mixed together. Concerns about smart-contract security, for example, are not the same as concerns about equitable access to financing. Questions about the scalability of blockchains are not the same as questions about whether suppliers understand LLM-generated financing explanations. Questions about quantum advantage are not the same as questions about present-day cryptographic transition planning. A layered research agenda helps keep these levels visible while still showing how they connect.

The managerial implications are equally significant. For firms, the first lesson is to avoid technology-first implementation. Organizations should begin with a financing friction that is costly, recurring, and multi-party in nature. Typical examples include invoice verification delays, trade-document inconsistencies, poor supplier visibility, manual exception management, and weak explainability in financing decisions. Blockchain becomes valuable when it addresses the shared-evidence problem, not when it is introduced as a branding device. LLMs become valuable when they reduce interpretation cost, improve user interaction, or strengthen oversight, not when they merely generate text around unchanged processes. Managers therefore should map the workflow before they choose the stack.

Second, firms should design for hybrid governance from the beginning. The literature makes clear that many blockchain and DeFi failures are governance failures as much as technical failures (Luu et al., 2016; Zetzsche et al., 2020; Xu et al., 2024). In enterprise finance, governance includes participant roles, update rights, model supervision, dispute resolution, data access, and accountability for automated actions. Hybrid systems involving blockchain and LLMs also require decision-right clarity. Who is responsible when an LLM-generated explanation is incomplete? Who can override a smart-contract trigger? Which events must be manually confirmed before financing is released? These questions should be answered as part of system design, not after deployment.

Third, capability building matters as much as platform building. A technically elegant system can still fail if organizations lack data discipline, legal coordination, AI oversight capability, or change-management capacity. Cross-functional teams are therefore essential. Finance professionals, procurement specialists, compliance officers, technology architects, and operations managers need to work from a shared process view. This is especially true in supply chain finance, where commercial, logistical, and financial events are deeply intertwined. The most effective projects will likely be those that treat blockchain finance as an enterprise transformation problem rather than a narrow IT deployment.

Fourth, regulators and standard setters have a constructive role to play. The goal should not be to force all innovation into old categories or to exempt new platforms from scrutiny. A more productive approach is to clarify standards for digital claim representation, smart-contract enforceability, model accountability, data rights, and post-quantum transition planning. The literature on FinTech and DeFi repeatedly shows that uncertainty around legal status and governance can slow useful experimentation just as much as overregulation can (Gomber et al., 2018; Thakor, 2020; Schär, 2021). Clearer standards would help distinguish legitimate infrastructure development from unsustainable hype.

Finally, the review suggests a strategic lesson for scholars and practitioners alike. The enduring value of digital financial innovation will not come from the most spectacular technology in isolation. It will come from architectures that combine trustworthy records, usable intelligence, appropriate governance, and real economic relevance. DeFi offered an important proof that financial services can be rebuilt as programmable modules. Supply chain finance shows where such programmability can be tied to the real economy. LLMs show how these systems can become interpretable and accessible. Quantum finance reminds us that computational complexity will remain part of the long-term agenda. The challenge now is not to choose one of these paths, but to design how they fit together.

8. Conclusion

This article has argued that blockchain-native financial innovation should be understood as a layered transition rather than as a sequence of disconnected technology trends. FinTech established the broader shift toward data-driven and digitally mediated financial services. Blockchain introduced a new architecture of trusted records and programmable execution. DeFi expanded that architecture into a new design space for financial intermediation. Blockchain-based supply chain finance demonstrated how these ideas can be applied to real-economy coordination problems in which visibility, trust, and timing are central. LLMs added a cognitive and communicative layer that can make blockchain-enabled finance more interpretable, usable, and responsive. Quantum finance, while still emerging, points to the next horizon of computationally intensive financial innovation.

The review also showed that the strongest future for these technologies is likely to be hybrid rather than absolutist. Public and permissioned blockchain models, institutional finance and protocol-based finance, machine execution and human oversight, predictive analytics and language-based reasoning, classical computation and quantum experimentation all have roles to play. The central managerial task is therefore not to pursue technological novelty for its own sake, but to align architecture with real financing frictions and governance needs.

In this sense, the future of finance is not simply decentralized, intelligent, or quantum. It is increasingly programmable, explainable, and interconnected. The firms and institutions that understand this layered logic will be better positioned to build financial systems that are not only more efficient, but also more trustworthy and more adaptive.

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