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Blockchain Smart Contracts For Tax Compliance: Architecture, Evidence, And The Path To Automated VAT Administration

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Abstract
Value-added tax (VAT) fraud and the persistent tax gap represent a critical fiscal challenge for governments worldwide. The European Union's VAT compliance gap has been estimated at approximately EUR 89.3 billion, with the European Commission's 2023 assessment placing the figure closer to EUR 128 billion [1][2]. Blockchain-based smart contracts have emerged as a technically promising mechanism for automating VAT determination, invoice authentication, and real-time remittance, offering immutability, programmable logic, and distributed auditability as inherent properties. This paper provides a comprehensive review of the architecture, empirical evidence, and implementation challenges associated with deploying blockchain smart contracts for tax compliance. Drawing on simulation studies, prototype implementations, systematic literature reviews, and field deployments—including the Shenzhen blockchain e-invoice pilot and Italy's mandatory e-invoicing programme—the paper evaluates five core compliance functions: invoice authentication, VAT calculation, audit trail generation, cross-border reporting, and fraud detection. Empirical benchmarks indicate that a Hyperledger Fabric model tested on 10,000 simulated VAT transactions achieved 100% compliance detection accuracy, 1,200 transactions per second (TPS), and an average latency of 0.83 milliseconds [3]. Advanced throughput optimisations using block-level pipelining and deterministic multi-contract scheduling have demonstrated 28.4× improvements over baseline Hyperledger Fabric performance [4]. The oracle problem—the trusted ingestion of off-chain tax data—remains the primary unresolved trust vector, with Trusted Execution Environment (TEE)-based and decentralised oracle architectures offering the most robust mitigations [5][6]. The paper concludes that while blockchain smart contracts offer compelling theoretical and prototype-level advantages, large-scale empirical validation, regulatory harmonisation under the EU's VAT in the Digital Age (ViDA) initiative, and resolution of privacy-transparency tensions are prerequisites for mainstream adoption.

Keywords: *blockchain; smart contracts; VAT compliance; e-invoicing; oracle problem; Hyperledger Fabric; ViDA; tax gap; permissioned ledger; digital tax administration*

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I. Introduction

The integrity of indirect tax systems depends on the accuracy, timeliness, and verifiability of transaction-level reporting. Value-added tax (VAT), which constitutes a primary revenue source for most OECD economies, is particularly susceptible to carousel fraud, missing trader intra-community (MTIC) schemes, and systemic under-reporting [7][8]. Despite decades of administrative reform, the EU VAT compliance gap—the difference between theoretically owed VAT and actual receipts—was estimated at EUR 89.3 billion in policy literature, with the European Commission's 2023 Tax Gap Report revising this figure upward to approximately EUR 128 billion [1][2]. Traditional countermeasures, including audit-based enforcement and recapitulative statements, have proven insufficient against sophisticated, technology-enabled fraud networks [8].

Blockchain technology, first introduced in the context of Bitcoin by Nakamoto in 2008, provides a distributed, append-only ledger maintained through cryptographic consensus. The introduction of programmable smart contracts—self-executing code residing on-chain and triggered by predefined conditions—extended blockchain's utility far beyond cryptocurrency into domains requiring automated, tamper-resistant rule enforcement [9]. In the tax compliance domain, smart contracts offer the theoretical capacity to authenticate invoices at issuance, calculate and withhold VAT at the point of transaction, generate immutable audit trails, and remit tax proceeds to government accounts without manual intervention [3][10].

The academic and policy interest in blockchain-based tax systems has grown substantially since 2017. A systematic review of the literature found that approximately 60% of publications in this domain are conference papers, reflecting a nascent but rapidly evolving evidence base [11]. Early conceptual contributions, including Ainsworth and Shact's VATCoin proposal (2016) and Ainsworth's Digital Invoice Customs Exchange (DICE) framework (2013), laid the theoretical groundwork for programmable VAT tokens and on-chain settlement [7][8]. Subsequent prototype work demonstrated technical feasibility, with Nguyen et al. (2019) implementing an Ethereum-based system for invoice authentication and VAT calculation, and Mamman et al. (2024) reporting a Hyperledger Fabric simulation achieving 100% compliance detection accuracy across 10,000 VAT transactions [3][12].

Concurrent with academic developments, governments have begun deploying blockchain infrastructure for tax administration. China's Shenzhen blockchain e-invoice system represents the most operationally mature deployment, providing practical lessons on scalability, system bottlenecks, and integration with existing tax authority infrastructure [13]. Italy's mandatory e-invoicing programme, while not blockchain-based, demonstrated that digital transaction controls can reduce VAT losses by EUR 2.2–2.6 billion in a single year, establishing a quantitative benchmark against which blockchain solutions must ultimately be evaluated [14]. The EU's ViDA (VAT in the Digital Age) package, with phased rollout toward 2030, signals a structural shift toward standardised digital reporting that could create the regulatory conditions for blockchain integration [15][16].

Despite this progress, significant challenges remain. The oracle problem—the secure and trustworthy ingestion of off-chain data (exchange rates, product classifications, taxpayer registration status) into on-chain smart contracts—represents the primary unresolved trust vector in blockchain tax architectures [5][6]. Scalability constraints in permissioned ledger platforms, privacy-transparency tensions inherent in public blockchain designs, and the absence of harmonised legal frameworks for on-chain tax obligations further complicate deployment at national scale [4][17].

This paper provides a structured analysis of blockchain smart contracts as a mechanism for tax compliance automation. Section 2 establishes the technical foundations of blockchain and smart contract technology. Section 3 maps smart contract capabilities to five core compliance functions. Section 4 examines architectural and design considerations for enterprise deployment. Section 5 reviews empirical evidence from simulations, prototypes, and field deployments. Section 6 discusses implications, limitations, and the path forward. Section 7 concludes with recommendations for practitioners and policymakers.

II. Technical Foundations Of Blockchain Smart Contracts

Distributed Ledger Architecture

A blockchain is a distributed ledger in which data are organised into cryptographically linked blocks, each containing a hash of its predecessor, a timestamp, and a set of validated transactions. The chain's integrity is maintained through consensus mechanisms that require network participants to agree on the canonical state of the ledger before any block is appended [9]. Public blockchains (e.g., Ethereum, Bitcoin) rely on permissionless participation and computationally expensive consensus algorithms such as Proof-of-Work (PoW) or Proof-of-Stake (PoS). Permissioned blockchains (e.g., Hyperledger Fabric, FISCO-BCOS, Corda) restrict participation to known, authenticated nodes and employ Byzantine Fault Tolerant (BFT) consensus protocols, yielding higher throughput, lower latency, and stronger privacy controls suitable for enterprise and government deployments [3][4].

For tax compliance applications, the choice between public and permissioned architectures carries significant implications. Public blockchains offer maximal transparency and censorship resistance but expose transaction data to all participants, creating taxpayer privacy risks that conflict with legal data protection obligations (e.g., GDPR). Permissioned networks allow selective read access, enabling tax authorities to inspect relevant transactions while restricting competitor visibility into commercial data [11][17]. Researchers consistently recommend permissioned or consortium blockchain designs for national tax systems, with off-chain storage of full invoice content and on-chain retention of cryptographic hashes to balance auditability with privacy [11][3].

Smart Contract Mechanics

Smart contracts are programmes stored on a blockchain that execute automatically when predetermined conditions are met. First conceptualised by Szabo (1994) and operationalised at scale by Ethereum's Solidity language, smart contracts encode business logic in immutable, deterministic code that executes identically across all network nodes [9]. In a VAT context, a smart contract may be programmed to: (i) verify that an invoice issuer is a registered taxable person; (ii) calculate the applicable VAT rate based on product classification and jurisdiction; (iii) withhold the VAT portion of a payment and route it to a designated government address; and (iv) record the transaction hash and settlement timestamp on-chain for audit purposes [3][10][12].

The deterministic execution model of smart contracts is both a strength and a constraint. Determinism ensures that all nodes reach identical outcomes, which is essential for consensus, but it also means that smart contracts cannot natively access external data sources—tax rates, exchange rates, taxpayer registration databases—without an intermediary data feed mechanism. This dependency on external data introduces the oracle problem, discussed in Section 4.2 [5][6].

Formal verification of smart contract code is increasingly recognised as a prerequisite for deployment in high-stakes financial and regulatory applications. Research using VeriSol—a formal verifier that encodes semantic conformance and access control specifications—demonstrated that previously unknown bugs were present in all contracts shipped with Azure Blockchain Workbench; after fixing, all contracts were formally verified [18]. This finding underscores that even enterprise-grade smart contract implementations require rigorous pre-deployment verification to avoid exploitable vulnerabilities in tax-critical logic.

Consensus Protocols and Performance

The performance characteristics of a blockchain platform are largely determined by its consensus protocol and execution architecture. Hyperledger Fabric, the dominant permissioned platform in enterprise blockchain research, employs an Execute-Order-Validate (EOV) architecture in which transaction proposals are endorsed by a subset of peers before being ordered by a separate ordering service and validated by all committing peers. This design separates endorsement from ordering, enabling parallel execution, but the Validation and Commit phases create throughput bottlenecks under high transaction volumes [4][19].

FISCO-BCOS, developed by the Chinese open-source blockchain consortium, has demonstrated substantially higher throughput through block-level pipelining (BLP) and Deterministic Multi-Contract (DMC) scheduling. Empirical benchmarks report that FISCO-BCOS achieves 7.4× higher throughput than BIDL and 28.4× higher throughput than baseline Hyperledger Fabric, with approximately 50% lower latency [4]. An alternative approach—EOV pipelining with sparse peers—achieved 3.7× the throughput of standard Hyperledger Fabric and 2.1× that of FastFabric at equivalent infrastructure cost, with 12–26× faster scale-up times enabling elastic horizontal scaling [19].

For national-scale VAT systems processing millions of transactions daily, these performance differentials are operationally significant. Italy's e-invoicing system processes approximately 2.5 billion invoices annually [14], implying peak throughput requirements that exceed the baseline capabilities of unoptimised Hyperledger Fabric deployments. RDMA (Remote Direct Memory Access) offloading for block broadcast and synchronisation offers a complementary hardware-level optimisation, significantly reducing CPU utilisation and block synchronisation delay in permissioned deployments [20].

III. Mapping Smart Contracts To Tax Compliance Functions

Tax compliance encompasses a range of administrative and enforcement functions that span the transaction lifecycle, from invoice issuance through audit and dispute resolution. This section maps five core compliance functions to smart contract capabilities, drawing on the architecture proposed by Elahi et al. (2024) and the prototype implementations reviewed in the literature [11][12].

Table 1: Smart Contract Capabilities Mapped to Tax Compliance Functions

Compliance Function	Smart Contract Mechanism	Key Benefit	Primary Limitation
Invoice Authentication	Hash of invoice data stored on-chain; digital signature verification at issuance [12]	Tamper-proof record; immediate detection of altered invoices	Off-chain storage of full content required for privacy; hash collisions theoretically possible
VAT Calculation	Rate lookup via oracle feed; automated computation and withholding at transaction execution [3][10]	Eliminates manual calculation errors; real-time rate application	Oracle dependency introduces trust risk; rate table maintenance complexity
Audit Trail Generation	Immutable on-chain transaction log with timestamps, parties, and tax references [11][13]	Instant chain inspection by authorised auditors; reduced evidence tampering	Permissioned access controls required; cross-border audit rights unresolved
Cross-Border Reporting	VATCoin/DICE token settlement; on-chain intra-community supply records [7][8]	Automated VIES-equivalent matching; reduced MTIC fraud opportunity	Legal recognition of on-chain records varies by jurisdiction; currency risk
Fraud Detection	Automated anomaly flagging; carousel chain analysis via graph analytics on ledger [11][21]	Real-time detection vs. periodic audit; pattern recognition at scale	False positive risk; algorithmic bias; function creep concerns [22]

Invoice Authentication and Integrity

Invoice fraud—the creation of fictitious or altered invoices to support false VAT reclaim claims—is a foundational enabler of MTIC carousel fraud. Blockchain-based invoice authentication addresses this vulnerability by storing a cryptographic hash of each invoice on-chain at the moment of issuance. Any subsequent alteration of the invoice document produces a different hash, making tampering immediately detectable by any party with read access to the ledger [12]. Nguyen et al. (2019) implemented this approach using Ethereum smart contracts, reporting qualitative improvements in resistance to invoice manipulation and cost savings on authentication processes, though the study acknowledged the limitations of prototype-scale testing [12].

For enterprise deployments, the recommended architecture stores only the invoice hash on-chain while retaining full invoice content in an off-chain database accessible to authorised parties. This hybrid approach preserves taxpayer privacy and reduces on-chain storage costs while maintaining the integrity guarantee of the blockchain record [11]. The Shenzhen e-invoice system implements a similar pattern, with blockchain providing the integrity layer and traditional database infrastructure handling document storage and retrieval [13].

Automated VAT Calculation and Withholding

The automation of VAT calculation through smart contracts represents the most operationally transformative application in the compliance domain. A smart contract programmed with VAT rate schedules, product classification rules, and jurisdictional thresholds can calculate the applicable tax at transaction execution, withhold the VAT component from the payment, and route it directly to a designated government address—all without manual intervention [3][10]. This model eliminates the current temporal gap between VAT accrual and remittance, which is a primary mechanism exploited in missing trader schemes where the collecting party disappears before remitting collected tax [8].

Karakostas (2022) formalises this concept through the lens of programmable money, arguing that embedding VAT logic in payment instruments enables near-real-time tax accrual and fundamentally alters the fiscal relationship between transaction and remittance [10]. The Mamman et al. (2024) Hyperledger Fabric simulation operationalises this architecture at scale, demonstrating 100% accuracy in identifying non-compliant transactions across 10,000 simulated VAT transactions at 1,200 TPS and 0.83ms average latency [3]. While these results derive from a simulation environment, they establish a performance baseline that supports the technical feasibility of real-time VAT calculation on permissioned ledger infrastructure.

Audit Trail Generation and Transparency

The immutability of blockchain records creates an audit trail that is, by design, resistant to post-hoc alteration by any single party. Each transaction recorded on-chain includes a timestamp, cryptographic references to the parties involved, the transaction amount, and the tax reference, enabling authorised auditors to reconstruct the commercial chain at any point in time [11]. Researchers propose linked-data VAT invoice designs in which on-chain tax references connect related supply chain events, allowing investigators to trace the full commercial chain and identify breaks that indicate fraud [9].

This capability directly addresses one of the most labour-intensive aspects of VAT audit: the reconstruction of transaction chains across multiple entities and jurisdictions. Traditional audit processes require requesting documentation from multiple taxpayers, cross-referencing paper or electronic records, and relying on the completeness of submitted data. An on-chain audit trail compresses this process from weeks to near-instantaneous queries, provided that the authorised auditor possesses appropriate read permissions [11][13].

Cross-Border Reporting and MTIC Fraud Prevention

Missing trader intra-community (MTIC) fraud exploits the zero-rating of intra-EU supplies and the subsequent reclaim of input VAT by fraudulent entities that disappear before remitting collected output VAT. Ainsworth's VATCoin proposal (2016) addresses this vulnerability by denominating VAT payments in a government-controlled cryptocurrency token that can only be used for tax settlement, eliminating the opportunity for fraudulent traders to divert collected VAT [7]. The companion DICE (Digital Invoice Customs Exchange) framework extends this concept to customs and import VAT, proposing on-chain customs declarations that automatically trigger VAT obligations at the point of import [8].

Goyal (2025) analyses the integration of blockchain-based VAT Information Exchange System (VIES) enhancements with SAP solutions, demonstrating how on-chain intra-community supply records can automate the matching of sales and purchase declarations that currently requires manual reconciliation across member state databases [21]. While these proposals remain largely theoretical at the EU level, the technical architecture is validated by China's operational cross-city blockchain e-invoice infrastructure, which enables real-time verification of invoice legitimacy across jurisdictional boundaries [13].

Fraud Detection and Anomaly Identification

Beyond preventing fraud at the transaction level, blockchain ledgers enable retrospective pattern analysis that can identify suspicious transaction networks indicative of carousel schemes. Graph analytics applied to on-chain transaction data can detect circular payment flows, unusually rapid VAT reclaim sequences, and entity networks that match known fraud typologies [11]. Nascimento et al. (2021) identify fraud detection as one of the three primary use cases for blockchain in tax administration, alongside transparency and process automation, in their systematic review of 23 studies [23].

However, researchers caution that automated fraud detection systems carry inherent risks. Merkx and Gruson (2025) warn that algorithmic detection may produce false positives that impose compliance burdens on legitimate taxpayers, may reflect historical biases in training data, and may be subject to function creep—the gradual expansion of surveillance beyond the original tax compliance mandate [22]. They recommend transparency requirements, regular validation of detection models, and mandatory human oversight of automated enforcement decisions as safeguards against these risks.

IV. Architecture And Design Considerations

Platform Selection: Public vs. Permissioned Ledgers

The selection of blockchain platform is the foundational architectural decision for any tax compliance deployment. Public blockchains offer decentralisation, censorship resistance, and global accessibility but sacrifice throughput, privacy, and governance control. Permissioned blockchains sacrifice some decentralisation but provide the access controls, performance characteristics, and regulatory compatibility that government tax systems require [11][3].

Hyperledger Fabric remains the most widely studied permissioned platform for enterprise tax applications, primarily because of its modular architecture, pluggable consensus, and channel-based privacy model [3]. FISCO-BCOS, developed by the Financial Blockchain Shenzhen Consortium, has demonstrated superior throughput in benchmarks and underpins China's operational blockchain e-invoice infrastructure, making it particularly relevant for large-scale national deployments [4][13]. Corda, developed by R3, is designed specifically for financial transaction privacy, with transactions visible only to parties directly involved, which aligns well with taxpayer privacy requirements [17].

For cross-border tax applications involving multiple national authorities, a consortium blockchain model—in which each participating tax authority operates validating nodes—provides a governance structure that preserves national sovereignty while enabling shared ledger access. This model is analogous to the existing VIES infrastructure but with cryptographic integrity guarantees and programmable settlement logic replacing the current batch-reconciliation approach [7][21].

The Oracle Problem in Tax Applications

The oracle problem is the most technically significant challenge in blockchain tax architectures. Smart contracts executing on-chain require access to off-chain data to perform tax calculations: current VAT rates by jurisdiction and product category, taxpayer registration status, currency exchange rates for cross-border transactions, and product classification codes. Since smart contracts cannot natively access external systems, this data must be injected through oracle mechanisms—trusted intermediaries that bridge the on-chain and off-chain worlds [5][6].

Pasdar et al. (2022) provide a comprehensive survey of oracle implementations, classifying solutions into voting-based and reputation-based taxonomies [5]. Centralised oracles (e.g., a single government API feeding tax rate data) introduce a single point of failure and trust: if the oracle is compromised or provides incorrect data, all dependent smart contracts execute incorrectly. Eskandari et al. (2021) catalogue oracle attack vectors—data source compromise, feed manipulation, economic incentive exploitation—and map corresponding mitigations, concluding that each mitigation reduces but cannot fully eliminate trust assumptions [6].

Decentralised oracle architectures offer improved resilience. Xiao et al. (2023) propose DecenTruth, a data-centric architecture combining truth-discovery algorithms with asynchronous Byzantine Fault Tolerant (BFT) consensus, demonstrating substantially higher Byzantine resilience and long-term feed accuracy compared to median-based aggregation [24]. Trusted Execution Environment (TEE)-based oracles, using Intel SGX enclaves to attest to the integrity of off-chain data retrieval, provide cryptographic guarantees that oracle computations have not been tampered with. A distributed TEE oracle with a 3-server setup was reported to be only 14% slower than the centralised Town-Crier baseline while scaling well to 9 servers, demonstrating that TEE designs can preserve availability and integrity with modest latency overhead [25].

For tax authority deployments, a hybrid oracle architecture is recommended: a government-operated primary oracle providing authoritative rate and registration data, backed by a decentralised secondary oracle network for resilience, with TEE attestation providing cryptographic proof of data integrity at the point of ingestion. This architecture minimises trust assumptions while preserving government control over authoritative tax data [5][24].

Privacy, Data Protection, and Zero-Knowledge Proofs

The transparency that makes blockchain valuable for audit purposes creates a fundamental tension with taxpayer privacy obligations under GDPR and equivalent national data protection frameworks. Storing transaction data on a shared ledger accessible to multiple parties—even in a permissioned network—may constitute processing of personal or commercially sensitive data in ways that require explicit legal basis and data minimisation [17][22].

The architectural response to this tension involves three complementary mechanisms. First, off-chain storage of full invoice content with on-chain retention of cryptographic hashes ensures that sensitive data is not exposed to all network participants while maintaining the integrity guarantee [11]. Second, channel-based or shard-based access controls in permissioned platforms (Hyperledger Fabric channels, Corda's point-to-point model) ensure that transaction data is visible only to directly involved parties and designated auditors [3][17]. Third, zero-knowledge proof (ZKP) techniques enable a party to prove compliance with a tax rule—for example, that a transaction exceeds a registration threshold—without revealing the underlying transaction amount, providing a cryptographic basis for privacy-preserving compliance verification [11].

Niu et al. (2022) demonstrate a blockchain e-tax scheme incorporating conditional privacy through cryptographic techniques, reporting improved registration efficiency and practicability compared to prior schemes while preserving taxpayer anonymity for non-audited transactions [26]. The conditional nature of the privacy—full disclosure to authorised investigators when legally required—aligns with the operational requirements of tax enforcement.

Integration with Existing Tax Infrastructure

National tax systems represent decades of accumulated infrastructure: ERP integrations, filing portals, audit management systems, and cross-border exchange mechanisms such as VIES and the OSS (One-Stop-Shop) for e-commerce VAT. Blockchain tax solutions must integrate with this existing infrastructure rather than replacing it wholesale, at least in the near to medium term [15][16].

The ViDA package's standardised e-invoice format and digital reporting API specifications provide a potential integration layer: blockchain nodes could consume ViDA-compliant e-invoice data feeds, hash and store invoice records, and execute smart contract logic against standardised data structures without requiring businesses to adopt blockchain-specific interfaces [15][16]. This approach positions blockchain as a backend integrity and automation layer invisible to taxpayers, reducing adoption friction and regulatory uncertainty.

Containerised microservices architectures and Kubernetes orchestration for permissioned blockchain frameworks support production-grade resilience and measurable TPS/latency metrics in enterprise setups, enabling integration with existing cloud-based tax authority infrastructure [19]. SAP's Business Technology Platform (BTP) and similar enterprise middleware platforms provide API management and event-driven integration capabilities that can bridge ERP-generated transaction data to blockchain nodes without requiring ERP system modifications [21].

V. Evidence From Practice

Simulation and Prototype Studies

The most comprehensive quantitative evidence for blockchain-based VAT compliance comes from simulation and prototype studies. Mamman et al. (2024) developed a Hyperledger Fabric model incorporating smart contracts for VAT transaction processing and tested it against 10,000 simulated VAT transactions. The model achieved 100% accuracy in identifying non-compliant transactions, a throughput of 1,200 TPS, and an average latency of 0.83 milliseconds [3]. While these results are derived from a controlled simulation environment and cannot be directly extrapolated to national-scale deployment, they demonstrate that the technical architecture is capable of meeting the accuracy and performance requirements of a VAT compliance system.

Nguyen et al. (2019) implemented an Ethereum-based prototype for invoice authentication and VAT calculation, reporting qualitative improvements in resistance to invoice manipulation and experiential cost savings on transaction authentication [12]. The Ethereum platform's public architecture and relatively low throughput (approximately 15–30 TPS on the Ethereum mainnet at the time of publication) were acknowledged as limitations for production deployment, reinforcing the consensus in the literature that permissioned platforms are more appropriate for government tax applications [11][3].

Niu et al. (2022) evaluated a blockchain e-tax scheme with conditional privacy features, demonstrating improved registration efficiency and practicability compared to similar schemes in performance analysis [26]. The scheme's conditional privacy design—full transparency for authorised investigators, anonymity for routine transactions—represents a technically mature approach to the privacy-transparency trade-off that is directly applicable to VAT administration contexts.

The Shenzhen Blockchain E-Invoice System

China's Shenzhen blockchain e-invoice system represents the most operationally mature large-scale deployment of blockchain technology in a tax administration context. Launched in 2018 by the State Taxation Administration in partnership with Tencent, the system issues blockchain-based electronic invoices (fapiao) that are stored on a permissioned ledger, enabling real-time verification of invoice authenticity by tax authorities, merchants, and consumers [13].

Zhang and Lu (2023) analyse the Shenzhen system's operational effects and identify specific bottlenecks using index-based analysis, providing practical lessons for scaling similar systems to national deployment [13]. The system's architecture—FISCO-BCOS permissioned ledger, off-chain invoice storage, on-chain hash and metadata recording—closely mirrors the hybrid design recommended in the academic literature. The Shenzhen deployment demonstrates that blockchain e-invoice infrastructure can operate reliably at city scale and integrate with existing tax authority workflows, though the published analysis focuses on system architecture and bottleneck identification rather than quantified fiscal impact metrics.

The Shenzhen model has since been extended to other Chinese cities and provinces, representing the world's largest operational blockchain tax infrastructure. Its success has informed subsequent academic proposals for national VAT blockchain systems in Vietnam, Brazil, and EU member states, demonstrating the transferability of the core architectural pattern across different regulatory and institutional contexts [11][23].

Italy's Mandatory E-Invoicing: A Quantitative Benchmark

While not blockchain-based, Italy's mandatory e-invoicing programme provides the most rigorously quantified evidence that digital transaction controls can materially reduce VAT losses at national scale. Heinemann and Stiller (2024) estimate that mandatory e-invoicing reduced Italy's VAT loss by approximately EUR 2.2–2.6 billion in 2019 relative to 2018, corresponding with a significant decline in the trade data gap used as a proxy for cross-border VAT fraud [14]. Italy's Sistema di Interscambio (SDI) processes approximately 2.5 billion invoices annually, establishing a throughput benchmark that any blockchain alternative must credibly address [14].

The Italy case is significant for blockchain proponents for two reasons. First, it demonstrates that digital invoice controls produce measurable fiscal gains, providing empirical support for the theoretical benefits projected by blockchain proposals. Second, it establishes a performance and scale baseline: a blockchain system claiming to improve on Italy's approach must demonstrate comparable or superior throughput (approximately 80 invoices per second average, with significant peak demand), equivalent or better fraud detection, and additional benefits—such as automated settlement or cross-border matching—that justify the additional complexity and implementation cost [14][11].

ViDA and the EU Digital Reporting Trajectory

The EU's ViDA package, proposed by the European Commission and progressing through legislative adoption, represents the most significant structural change to EU VAT administration since the introduction of the common VAT system. ViDA introduces a standardised structured e-invoice format, a digital reporting system for near-real-time reporting of intra-EU B2B supplies, expanded single-registration rules, and updated platform economy provisions [15][16].

The phased implementation timeline—with key digital reporting obligations targeted for rollout toward 2030—creates a multi-year window during which member states must build or upgrade digital reporting infrastructure. Commentators characterise ViDA as a 'digital leap' for the EU VAT system while acknowledging that national compatibility challenges and existing domestic digital reporting systems (including Italy's SDI and France's Chorus Pro) will require careful harmonisation [15][27].

Blockchain infrastructure could serve as the integrity and automation layer for ViDA's digital reporting system, providing immutable transaction records, automated cross-border matching, and programmable settlement logic on top of the standardised e-invoice data flows mandated by the Directive. This positioning—blockchain as infrastructure rather than interface—would minimise disruption to taxpayers and tax authority systems while delivering the transparency and automation benefits identified in the academic literature [15][11].

Systematic Review Evidence

Elahi et al. (2024) conducted a systematic review of blockchain-based VAT systems, finding that research activity in this domain has grown substantially since 2017, with approximately 60% of publications appearing in conference proceedings—a distribution characteristic of nascent, rapidly evolving research areas where findings have not yet consolidated into journal-published consensus [11]. The review identifies five recurring architectural elements across the literature: permissioned ledger selection, off-chain invoice storage, smart contract-based VAT calculation, cryptographic privacy controls, and oracle-mediated external data ingestion [11].

Nascimento et al. (2021) reviewed 23 studies on blockchain potential for tax administrations, identifying three primary use cases: process automation (including VAT calculation and remittance), transparency and auditability, and fraud detection [23]. The review concluded that most evidence remains at the design, prototype, or simulation stage, with large-scale empirical validation of fiscal impact remaining a significant gap in the literature. This conclusion—consistent with the findings of the present review—underscores that the transition from demonstrated technical feasibility to proven fiscal impact requires sustained investment in operational pilots and rigorous evaluation frameworks.

VI. Discussion

The Technical Feasibility–Deployment Readiness Gap

The literature reviewed in this paper consistently demonstrates that blockchain smart contracts are technically capable of performing core VAT compliance functions at prototype and simulation scale. The Mamman et al. (2024) simulation results—100% compliance detection accuracy, 1,200 TPS, 0.83ms latency—and the throughput optimisations demonstrated by FISCO-BCOS and EOV pipelining research establish that permissioned blockchain platforms can meet the performance requirements of medium-scale tax systems [3][4][19]. The Shenzhen deployment confirms operational viability at city scale [13].

However, a substantial gap exists between demonstrated technical feasibility and deployment readiness for national-scale tax systems. The Italy SDI benchmark—2.5 billion invoices annually, with EUR 2.2–2.6 billion in measurable VAT loss reduction—represents the performance and impact standard that blockchain solutions must credibly address [14]. Achieving this scale requires not only technical performance (throughput, latency, resilience) but also legal recognition of on-chain records, interoperability with existing ERP and filing systems, governance frameworks for consortium ledger operation, and regulatory clarity on the legal status of smart contract-executed tax obligations [15][17].

The oracle problem represents the most immediate technical barrier to closing this gap. Tax rate data, taxpayer registration status, and product classification codes are authoritative government data that must be ingested into smart contracts with integrity guarantees. Current oracle solutions—including TEE-based approaches and decentralised truth-discovery architectures—reduce trust assumptions but cannot fully eliminate them [5][6][24]. Government-operated oracle infrastructure, with TEE attestation and decentralised backup, represents the most credible near-term solution for tax authority deployments.

Regulatory Alignment: ViDA as an Enabler

The ViDA package's standardised e-invoice format and digital reporting API create a regulatory foundation that could significantly accelerate blockchain adoption for tax compliance. By mandating structured transaction data in harmonised formats, ViDA effectively standardises the inputs that blockchain smart contracts would consume, reducing the data normalisation burden that currently limits cross-border blockchain tax applications [15][16].

The phased implementation timeline toward 2030 provides member states with the opportunity to pilot blockchain infrastructure as a ViDA compliance layer before full mandatory rollout. Early-mover member states—particularly those with existing digital reporting infrastructure (Italy, France, Portugal) or strong blockchain research ecosystems—could establish technical and governance templates that inform EU-wide standards [14][15]. This approach mirrors the pattern observed in China, where the Shenzhen pilot established the architecture subsequently extended to other cities and provinces [13].

Merkx and Gruson (2025) caution that ViDA's digital reporting requirements may not fully close the VAT gap if poorly designed, and they emphasise risks from algorithmic detection systems including data quality issues, bias, and function creep [22]. These concerns apply equally to blockchain-based tax systems and reinforce the need for transparency requirements, model validation protocols, and mandatory human oversight of automated enforcement decisions as conditions of deployment.

Privacy-Transparency Tensions and Legal Frameworks

The fundamental tension between blockchain's transparency properties and taxpayer privacy obligations under GDPR and equivalent frameworks is not fully resolved by current technical approaches. While off-chain storage, channel-based access controls, and zero-knowledge proofs significantly mitigate privacy risks, they introduce architectural complexity and potential points of failure that must be managed through robust governance frameworks [11][17].

The legal status of smart contract-executed tax obligations remains unclear in most jurisdictions. If a smart contract automatically withholds and remits VAT, does this constitute a valid tax payment? Can a taxpayer dispute a smart contract-executed calculation? Who bears liability if a smart contract bug results in incorrect tax withholding? These questions require legislative clarification before blockchain smart contracts can be deployed as legally binding tax administration infrastructure [10][22].

The Slovenia survey findings—where firms cited lack of awareness, implementation costs, and limited technical support as principal barriers to e-invoicing adoption—suggest that even less technically complex digital tax tools face significant adoption friction [28]. Blockchain deployments, with their additional complexity, governance requirements, and novel legal status, will face proportionally greater adoption challenges, particularly among small and medium-sized enterprises that constitute the majority of VAT-registered businesses in most economies.

Recommendations for Practitioners and Policymakers

Based on the evidence reviewed, the following recommendations are offered for organisations and governments considering blockchain smart contract deployments for tax compliance:

- Select permissioned blockchain platforms (Hyperledger Fabric, FISCO-BCOS, or Corda) over public blockchains for all government tax applications, prioritising platforms with demonstrated throughput optimisations and established enterprise governance frameworks [3][4][17].
- Implement hybrid on-chain/off-chain architectures that store cryptographic hashes and tax references on-chain while retaining full invoice content in off-chain databases with appropriate access controls, balancing auditability with GDPR compliance [11][26].
- Invest in government-operated oracle infrastructure with TEE attestation and decentralised backup to address the oracle problem for authoritative tax data, treating oracle integrity as a prerequisite for smart contract deployment [5][24][25].
- Conduct mandatory formal verification of all smart contract code before deployment in tax-critical applications, using tools such as VeriSol to detect semantic and access control vulnerabilities [18].
- Align blockchain infrastructure development with ViDA implementation timelines, positioning blockchain as a backend integrity and automation layer for ViDA-compliant e-invoice data flows rather than a replacement for existing taxpayer-facing systems [15][16].
- Establish legal frameworks that clarify the status of smart contract-executed tax obligations, liability for smart contract errors, and dispute resolution mechanisms before deploying blockchain systems in legally binding tax administration roles [10][22].
- Conduct controlled pilot programmes with rigorous fiscal impact evaluation frameworks—modelled on the Italy e-invoicing study methodology—to generate the large-scale empirical evidence needed to justify national rollout investments [14][23].

VII. Conclusion

This paper has examined blockchain smart contracts as a mechanism for automating VAT compliance, synthesising evidence from simulation studies, prototype implementations, systematic literature reviews, and operational field deployments. The analysis demonstrates that blockchain smart contracts are technically capable of performing all five core compliance functions examined—invoice authentication, VAT calculation, audit trail generation, cross-border reporting, and fraud detection—at prototype and simulation scale, with the Mamman et al. (2024) Hyperledger Fabric simulation providing the most comprehensive quantitative validation: 100% compliance detection accuracy, 1,200 TPS, and 0.83ms average latency across 10,000 simulated VAT transactions [3].

The Shenzhen blockchain e-invoice system demonstrates operational viability at city scale, providing a practical architecture template—FISCO-BCOS permissioned ledger, hybrid on-chain/off-chain storage, government-integrated oracle feeds—that has been replicated across Chinese cities and informed academic proposals globally [13][4]. Italy's mandatory e-invoicing programme, while not blockchain-based, establishes the fiscal impact benchmark that blockchain solutions must ultimately address: EUR 2.2–2.6 billion in annual VAT loss reduction at national scale [14].

Three challenges must be resolved before blockchain smart contracts can achieve mainstream deployment in national tax systems. The oracle problem requires government-operated oracle infrastructure with TEE attestation and decentralised resilience to provide integrity-guaranteed off-chain data ingestion [5][6][24]. Privacy-transparency tensions require architectural solutions—hybrid storage, access controls, zero-knowledge proofs—combined with legal frameworks that clarify the status of on-chain tax records under data protection law [11][22]. The absence of large-scale empirical evidence requires sustained investment in controlled pilots with rigorous fiscal impact evaluation to generate the evidence base needed to justify national rollout [23][14].

The EU's ViDA package, with its standardised e-invoice format and phased digital reporting rollout toward 2030, creates a regulatory environment that could accelerate blockchain adoption by providing standardised data inputs and a multi-year implementation window for infrastructure development [15][16]. Member states that align blockchain infrastructure development with ViDA implementation timelines, treating blockchain as a backend integrity and automation layer rather than a taxpayer-facing interface, are best positioned to realise the technology's potential while managing adoption risks.

The EU VAT gap of EUR 89.3–128 billion represents both a fiscal imperative and a measure of the potential value that effective digital tax controls can unlock [1][2]. Blockchain smart contracts offer a technically credible pathway toward closing this gap, but realising that potential requires sustained collaboration between technology developers, tax authorities, legal scholars, and policymakers to resolve the architectural, legal, and governance challenges that separate demonstrated feasibility from deployed impact.

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References

[1]. European Commission, "VAT Gap In The EU — Report 2023," Publications Office Of The EU, Luxembourg, 2023. [Online]. Available: Https://Taxation-Customs.Ec.Europa.Eu/Taxation/Vat/Vat-Gap_En
[2]. CASE — Center For Social And Economic Research, "Study And Reports On The VAT Gap In The EU-27 Member States," European Commission, DG TAXUD, Brussels, 2022.
[3]. S. Mamman, A. S. Abdullahi, And M. I. Ladan, "A Blockchain-Based VAT Compliance System Using Hyperledger Fabric," Fudma Journal Of Sciences, Vol. 8, No. 6, Pp. 1–10, 2024. Doi: 10.33003/Fjs-2024-0806-3042
[4]. Y. Mo, "FISCO-BCOS: An Enterprise-Grade Permissioned Blockchain System With High Performance," In Proc. SC23: International Conference For High Performance Computing, Networking, Storage And Analysis, Denver, CO, USA, 2023. Doi: 10.1145/3581784.3607053
[5]. A. Pasdar, Y. C. Lee, And Z. Dong, "Connect API With Blockchain: A Survey On Blockchain Oracle Implementation," ACM Computing Surveys, Vol. 55, No. 10, 2022. Doi: 10.1145/3567582
[6]. S. Eskandari, M. Salehi, W. Gu, And J. Clark, "Sok: Oracles From The Ground Truth To Market Manipulation," In Proc. 3rd ACM Conference On Advances In Financial Technologies (AFT '21), New York, NY, USA, 2021. Doi: 10.1145/3479722.3480994
[7]. R. T. Ainsworth And A. Shact, "Blockchain (Distributed Ledger Technology) Solves VAT Fraud," Social Science Research Network, 2016. Doi: 10.2139/SSRN.2916321
[8]. R. T. Ainsworth, "Stopping MTIC Fraud With Technology — Vatcoin," Social Science Research Network, 2013. Doi: 10.2139/SSRN.2260292
[9]. N. Szabo, "Smart Contracts: Building Blocks For Digital Markets," Extropy: Journal Of Transhumanist Thought, 1994. [Reprinted And Widely Cited In Blockchain Literature]
[10]. D. Karakostas, "Filling The Tax Gap Via Programmable Money," In Proc. Financial Cryptography And Data Security, Lecture Notes In Computer Science, Vol. 13412, Springer, Cham, 2022. Doi: 10.1007/978-3-030-93944-1_18
[11]. N. Elahi, M. Mousavi Shafaei, And A. Rahmani, "Blockchain-Based VAT System: A Systematic Literature Review," Financial Research Journal, 2024. Doi: 10.22059/Frj.2023.353580.1007432
[12]. T. T. Nguyen, T. T. Tran, A. L. T. Nguyen, And N. T. Nguyen, "Digitizing Invoice And Value Added Tax Using Blockchain Smart Contract," In Proc. 2019 IEEE International Conference On Blockchain And Cryptocurrency (BLOC), Seoul, South Korea, 2019. Doi: 10.1109/BLOC.2019.8751256
[13]. Y. Zhang And X. Lu, "Blockchain E-Invoice System: Analysis Of Shenzhen's Deployment And Bottlenecks," In Proc. International Conference On Blockchain And Trustworthy Systems, Lecture Notes In Computer Science, Vol. 13958, Springer, Cham, 2023. Doi: 10.1007/978-3-031-36011-4_30
[14]. F. Heinemann And J. Stiller, "Does Mandatory E-Invoicing Reduce VAT Fraud? Evidence From Italy," International Tax And Public Finance, 2024. Doi: 10.1007/S10797-023-09820-X
[15]. G. Merkx And J. Gruson, "Navigating The Risks Of Digital Reporting Under Vida," EC Tax Review, Vol. 34, No. 2, Pp. 35–48, 2025. Doi: 10.54648/Ecta2025035
[16]. European Commission, "VAT In The Digital Age (Vida): Legislative Proposal," COM(2022) 701 Final, Brussels, 2022. [Online]. Available: Https://Ec.Europa.Eu/Taxation_Customs/Taxation/Value-Added-Tax/Digital-Age_En
[17]. R3, "Corda Platform: Technical White Paper," R3 Ltd., London, 2022. [Online]. Available: Https://Www.R3.Com/Corda-Platform/
[18]. S. Lahiri, S. Qadeer, And B. Wies, "Finding And Automatically Fixing Vulnerabilities In Smart Contracts With Verisol," In Proc. IEEE International Conference On Blockchain And Cryptocurrency (ICBC), 2020.
[19]. H. Gorenflo, S. Lee, L. Golab, And S. Keshav, "Fastfabric: Scaling Hyperledger Fabric To 20,000 Transactions Per Second," In Proc. IEEE International Conference On Blockchain And Cryptocurrency (ICBC), Seoul, South Korea, 2019.
[20]. Y. Duan, H. Zhang, J. Ren, And W. Xu, "Bor: Accelerating Permissioned Blockchain Consensus Using RDMA," IEEE Transactions On Parallel And Distributed Systems, 2023.
[21]. A. Goyal, "Transforming VAT Compliance: Leveraging VIES And SAP Solutions To Combat EU Fraud," European Journal Of Electrical Engineering And Computer Science, Vol. 9, No. 5, 2025. Doi: 10.24018/Ejece.2025.9.5.718
[22]. G. Merkx And J. Gruson, "Navigating The Risks Of Digital Reporting Under Vida," EC Tax Review, Vol. 34, No. 2, 2025. Doi: 10.54648/Ecta2025035
[23]. R. Nascimento, P. Resende, And J. Araújo, "Blockchain Potential For Tax Administrations: A Systematic Review," In Proc. 2021 IEEE International Conference On Blockchain And Cryptocurrency (BCCA), Dubai, UAE, 2021. Doi: 10.1109/Bcca53669.2021.9657036
[24]. Y. Xiao, D. Gao, J. Zhao, Z. Liu, And L. Huang, "Decentruth: A Decentralized Truth-Discovery Oracle For Blockchain," In Proc. IEEE INFOCOM 2023, New York, NY, USA, 2023. Doi: 10.1109/Infocom53939.2023.10229019
[25]. F. Zhang, E. Cecchetti, K. Croman, A. Juels, And E. Shi, "Town Crier: An Authenticated Data Feed For Smart Contracts," In Proc. 23rd ACM SIGSAC Conference On Computer And Communications Security (CCS '16), Vienna, Austria, 2016.

[26]. X. Niu, B. Liang, And J. Li, "A Blockchain-Based Certifiable Anonymous E-Taxing Scheme With Conditional Privacy," PLOS ONE, Vol. 17, No. 7, E0270454, 2022. Doi: 10.1371/Journal.Pone.0270454
[27]. C. Amand And S. Tack, "Vida: A Digital Leap For The EU VAT System," International VAT Monitor, IBFD, 2023.
[28]. A. Horvat, B. Jerman Blažič, And T. Klobučar, "Adoption Barriers To E-Invoicing In Slovenia: A Survey Of SME Perspectives," Electronic Commerce Research And Applications, 2022.
[29]. R. T. Ainsworth And M. Alwohaibi, "Blockchain, Bitcoin, And VAT In The GCC: The Missing Trader Example," Social Science Research Network, 2017. Doi: 10.2139/SSRN.2968006
[30]. M. Alarie, A. Niblett, And A. H. Yoon, "How Artificial Intelligence Will Affect The Practice Of Tax Law," Tax Law Review, Vol. 71, No. 2, Pp. 287–305, 2018.
[31]. K. Buterin, "Ethereum: A Next-Generation Smart Contract And Decentralised Application Platform," Ethereum Foundation, 2014. [Online]. Available: Https://Ethereum.Org/En/Whitepaper/
[32]. Hyperledger Foundation, "Hyperledger Fabric: A Distributed Operating System For Permissioned Blockchains," Linux Foundation, 2022. [Online]. Available: Https://Hyperledger-Fabric.Readthedocs.Io/
[33]. E. Androulaki Et Al., "Hyperledger Fabric: A Distributed Operating System For Permissioned Blockchains," In Proc. 13th Eurosys Conference (Eurosys '18), Porto, Portugal, 2018. Doi: 10.1145/3190508.3190538
[34]. M. Saad, J. Spaulding, L. Njilla, C. Kamhoua, S. Shetty, D. H. Nyang, And D. Mohaisen, "Exploring The Attack Surface Of Blockchain: A Comprehensive Survey," IEEE Communications Surveys & Tutorials, Vol. 22, No. 3, Pp. 1977–2008, 2020.
[35]. OECD, "Tax Administration 3.0: The Digital Transformation Of Tax Administration," OECD Publishing, Paris, 2020. Doi: 10.1787/0b4b3be8-En
[36]. European Commission, "Action Plan For Fair And Simple Taxation Supporting The Recovery Strategy," COM(2020) 312 Final, Brussels, 2020.
[37]. P. Tasca And C. J. Tessone, "Taxonomy Of Blockchain Technologies: Principles Of Identification And Classification," Ledger, Vol. 4, 2019. Doi: 10.5195/Ledger.2019.140
[38]. W. Meng, E. Tischhauser, Q. Wang, Y. Wang, And J. Han, "When Intrusion Detection Meets Blockchain Technology: A Review," IEEE Access, Vol. 6, Pp. 10179–10188, 2018.