A Hybrid Escrow System for Freelance Payments Using Fiat and Cryptocurrency

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ABSTRACT

The global freelance economy has experienced rapid growth, yet existing payment and escrow systems remain constrained by structural inefficiencies inherent in both centralized fiat-based and decentralized cryptocurrency-based models. Centralized escrow systems, while widely adopted due to their regulatory compliance and usability, suffer from custodial opacity, information asymmetry, high transaction costs, and limited verifiability. Conversely, purely decentralized blockchain-based escrow systems offer transparency and trust-minimized execution through smart contracts but face barriers including cryptocurrency price volatility, limited fiat integration, steep technical learning curves, and inadequate dispute resolution mechanisms for subjective deliverables. This article, a hybrid escrow system integrates traditional fiat payment infrastructure with decentralized Ethereum-compatible smart contract execution. The system adopts a three-layer architecture comprising a centralized service layer, a middleware synchronization layer, and a decentralized execution layer. A Finite State Machine (FSM) model governs escrow state transitions across both fiat-funded and cryptocurrency-funded transactions, ensuring determinism, auditability, and consistency. The system further incorporates a human-in-the-loop dispute resolution framework anchored to blockchain execution, enabling fair and transparent adjudication of subjective conflicts. Evaluation results demonstrate that the proposed hybrid architecture successfully bridges the gap between traditional finance and decentralized systems. The system achieved 100% correct FSM state enforcement with zero unauthorized fund releases across all test scenarios. Fiat-funded contracts were synchronized to the blockchain with an average latency of 8.4 seconds, while cryptocurrency-funded contracts confirmed on-chain within a median of 3.2 seconds on the Polygon testnet. All three dispute resolution outcomes were correctly enforced on-chain within an average of 5.1 seconds following adjudication, and API response times remained below 420 milliseconds under concurrent user loads. An ablation study further confirmed that all three architectural layers are individually necessary, as removing any single layer degraded transparency, payment flexibility, dispute resolution capability, or user accessibility. This research contributes a scalable and adaptable hybrid escrow blueprint applicable to fintech development, digital labour platforms, and cross-border payment systems.

Keywords: Escrow, Fiat Currency, Cryptocurrency, Hybrid Escrow System, Smart Contract

INTRODUCTION

The rapid expansion of the global digital economy has accelerated the growth of freelance labor markets, enabling individuals to transact across national and institutional boundaries through digital labor platforms. While these platforms facilitate job matching, coordination, and payment processing, the increasing internationalization of freelance work has exposed critical structural deficiencies in existing payment and settlement infrastructures, particularly in cross-border transactions (Corporaal & Lehdonvirta, 2024). Traditional fiat-based systems remain dominant but are characterized by high transaction costs, unfavourable exchange rates, prolonged settlement cycles, and restricted access for freelancers in developing economies—barriers that reduce net earnings, introduce cash flow uncertainty, and undermine trust between contracting parties (Ramachandran, 2024; Graham & Anwar, 2024). Cryptocurrency-based payment solutions offer a compelling alternative, providing near-instant settlement, reduced intermediary dependence, and peer-to-peer

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value transfer without correspondent bank reliance. However, challenges including price volatility, regulatory ambiguity, and technical complexity limit their adoption in mainstream freelance ecosystems. Escrow mechanisms are widely used within these platforms to mitigate trust risks from asymmetric information and payment disputes (Singh et al., 2025; Bakare et al., 2024), reflecting the legacy structure of digital labour platforms.

Escrow services are widely employed within freelance platforms to reduce non-payment risk for freelancers and non-delivery risk for clients (Singh et al., 2025; Bakare et al., 2024). However, existing escrow implementations are predominantly centralized and fiat-based, reflecting the legacy structure of digital labour platforms and traditional financial systems.

Centralized escrow systems offer institutional legitimacy, regulatory compliance, and structured dispute resolution, but concentrate custodial authority with platform operators, introduce counterparty risk, and lack real-time financial transparency. Decentralized escrow systems, by contrast, leverage smart contracts for transparent, tamper-resistant custody, but lack native fiat support, require significant technical proficiency, and struggle to resolve subjective or qualitative disputes. This fundamental tension between the two paradigms underscores the inadequacy of relying exclusively on either model.

Consequently, there is a growing need for a hybrid escrow framework that integrates the strengths of both paradigms—combining fiat payment rails and regulatory compliance with blockchain-based smart contract custody. By incorporating programmable escrow logic alongside human-assisted dispute resolution and fiat on- and off-ramps, such a system can address trust, transparency, and accessibility challenges simultaneously, enhancing payment security and promoting equitable participation in global freelance markets.

Fiat Payment Rail: The fiat payment rail integrates conventional financial infrastructure, including bank transfers, virtual accounts, and third-party payment gateways, to enable users to fund escrow contracts using traditional currencies. Fiat deposits are processed through regulated financial institutions and payment service providers that perform compliance checks such as Know Your Customer (KYC) and anti-money laundering (AML) verification. Upon successful deposit confirmation, fiat funds are not directly custodied on-chain; instead, they are represented within the escrow system as verified funding events. These events act as cryptographically signed assertions that a corresponding value has been securely locked within regulated custodial accounts. This abstraction allows fiat-funded transactions to participate in the same escrow lifecycle as cryptocurrency-funded transactions without exposing users to direct blockchain complexity.

Cryptocurrency Payment Rail:

The cryptocurrency payment rail operates natively on blockchain networks and utilizes smart contracts to hold escrow funds in a non-custodial, transparent, and tamper-resistant manner. When users choose to fund escrow contracts using digital assets, funds are transferred directly into smart contracts that enforce predefined release and refund conditions. The decentralized nature of this rail ensures that neither platform operators nor intermediaries can unilaterally access or manipulate escrowed assets. All transactions, contract states, and fund movements are immutably recorded on the blockchain, enabling real-time verification and auditability by all participating parties. This rail embodies protocol-based trust, providing deterministic execution and strong security guarantees independent of institutional discretion.

Hybrid Synchronization Mechanism

The hybrid synchronization mechanism serves as the conceptual and technical bridge between the fiat and cryptocurrency rails. Implemented as a middleware layer, this component is responsible for translating verified off-chain fiat events—such as deposit confirmations, milestone approvals, or dispute resolutions—into corresponding on-chain escrow state transitions. Through secure event validation, cryptographic signatures, and strict state-mapping logic, the middleware ensures that fiat-funded transactions receive the same deterministic protections and lifecycle enforcement as crypto-funded transactions. This mechanism minimizes

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trust assumptions by limiting its authority to state signaling rather than direct fund custody, thereby preserving the integrity of the escrow process while enabling interoperability between disparate financial systems.

The conceptual framework further defines a **unified escrow lifecycle** that governs transactions across both rails. This lifecycle encompasses escrow initialization, funding verification, milestone execution, approval or dispute initiation, adjudication, and final settlement or refund. By enforcing identical state transitions and validation rules irrespective of the funding medium, the framework ensures consistency in security, transparency, and user experience. This design eliminates preferential treatment or functional divergence between fiat and cryptocurrency users, thereby promoting fairness and inclusivity within the platform.

Overall, the conceptual framework illustrates how a dual-rail payment architecture, supported by a hybrid synchronization layer, can reconcile the strengths of traditional finance and decentralized systems. By enabling users to initiate escrow using their preferred payment medium while maintaining a uniform security and settlement model, the framework provides a scalable and user-centric foundation for hybrid escrow systems in global freelance markets.

LITERATURE REVIEW

1. Centralized Fiat-Based Escrow Systems: Empirical studies of widely used freelance platforms such as Upwork, Fiverr, and Freelancer.com indicate that centralized fiat-based escrow systems offer significant advantages in terms of usability, regulatory compliance, and institutional trust (Casalhay et al., n.d.). These platforms leverage established banking infrastructure to hold funds in platform-controlled accounts and provide familiar user interfaces that simplify payment initiation, milestone management, and dispute resolution. Users benefit from the confidence that comes with regulatory oversight, legal enforceability, and institutional reputation, particularly in jurisdictions with well-established financial systems.

Despite these benefits, research reveals that centralized escrow systems suffer from notable transparency and trust limitations. Funds are held in custodial accounts controlled entirely by the platform, and freelancers and clients cannot independently verify escrow balances, fund allocation, or the precise conditions under which payments are released (Corporaal & Lehdonvirta, 2024). Dispute resolution processes are typically opaque, governed by platform-specific policies, and may inadvertently favor institutional risk mitigation over equitable outcomes for users. Such opacity introduces information asymmetry, reduces trust, and may discourage engagement from freelancers in cross-border contexts where legal recourse is limited.

2. Cryptocurrency-Based Escrow Systems: Decentralized cryptocurrency-based escrow platforms, including BlockLancer, Ethlance, and specialized smart contract marketplaces, provide a contrasting model that emphasizes transparency, automation, and trust minimization (Łęt et al., 2023) by leveraging blockchain-based smart contracts to enforce milestone-based fund releases. Transactions are recorded on publicly verifiable ledgers, allowing participants to audit escrow balances, execution logic, and fund transfers independently. Empirical studies demonstrate that such systems significantly reduce administrative overhead, intermediation costs, and opportunities for discretionary fund manipulation.

Despite these advantages, empirical evidence highlights several barriers that limit the widespread adoption of cryptocurrency-based escrow systems. Users must manage digital wallets, private keys, and gas fees, which introduces a steep technical learning curve and heightens the risk of irreversible mistakes such as lost keys or misdirected transactions (Reddy et al., 2024). Cryptocurrency price volatility can further complicate freelance payments, creating financial uncertainty for both clients and freelancers when transaction value fluctuates between contract initiation and completion. Additionally, the lack of integrated fiat on-ramps and conventional banking interfaces constrains accessibility, particularly for users unfamiliar with blockchain networks or operating in regions with limited cryptocurrency infrastructure.

Another critical limitation of decentralized escrow system lies in dispute resolution. While smart contracts enforce deterministic rules effectively, they are ill-suited to handle qualitative judgments, evolving project requirements, or subjective assessments of work quality. Empirical observations suggest that when disputes

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arise involving creative output or ambiguous deliverables, decentralized systems may be unable to mediate effectively, potentially resulting in stalled transactions or unfair outcomes.

3. Hybrid Financial Systems: Hybrid financial systems, which integrate blockchain-based settlement with traditional banking and payment infrastructure, represent an emerging approach aimed at reconciling the strengths of centralized and decentralized models (Ramachandran, 2024). Empirical studies of hybrid platforms reveal several advantages over purely centralized or purely decentralized systems. By enabling fiat-to-crypto interoperability, these systems allow users to fund escrow contracts using familiar payment methods while benefiting from on-chain transparency and smart contract enforcement. Hybrid architectures can also incorporate human-assisted dispute resolution alongside automated state transitions, thereby addressing the limitations of deterministic smart contracts in handling subjective or context-dependent conflicts.

Research indicates that hybrid systems improve accessibility for a broader user base, including freelancers and clients who lack advanced blockchain expertise. They demonstrate enhanced regulatory compliance through integrated KYC, AML, and reporting mechanisms while simultaneously preserving transparency, auditability, and tamper-resistance for fund custody. Empirical evidence further suggests that hybrid escrow frameworks reduce transaction friction, lower operational costs, and accelerate settlement timelines relative to centralized-only systems. Importantly, hybrid models provide a scalable foundation for global freelance payments, capable of accommodating diverse currencies, payment methods, and jurisdictional requirements while maintaining a consistent security and trust paradigm.

4. Smart Contracts and Escrow Automation: Smart contracts are self-executing digital agreements that encode contractual obligations directly into programmable code, operating on blockchain networks without requiring intermediary enforcement. Empirical studies have demonstrated their effectiveness in domains such as construction finance, supply chain payments, and cross-border trade, where milestone-based fund releases are common (Pham et al., 2024) deterministic execution, ensuring that funds are automatically released when predefined conditions—such as task completion, verified delivery, or approval confirmation—are satisfied. This automation significantly reduces administrative overhead, minimizes counterparty risk, and eliminates reliance on discretionary human intervention for routine contractual enforcement (Barj, 2024; Bakare et al., 2024).

Within the domain of freelance payments, smart contracts enhance escrow processes by providing transparent, immutable, and verifiable enforcement mechanisms. Each transaction or milestone is codified as a state within the contract, with strict conditional logic governing fund custody, release, or refund. All state transitions and fund movements are recorded on the blockchain, providing a permanent audit trail that can be independently verified by all participants. This level of transparency contrasts sharply with centralized escrow systems, where fund visibility is limited to the platform operator and audit capabilities are constrained by institutional policies.

In the context of hybrid escrow frameworks, smart contracts assume a central role as the final authority for fund settlement, regardless of the funding source. When users deposit cryptocurrency directly, funds are held within smart contracts in a non-custodial manner, benefiting from tamper-resistant execution. For fiat deposits, funds are mirrored or tokenized into escrow credits on-chain, effectively translating off-chain payment confirmations into enforceable on-chain events. This approach ensures that all transactions, whether initiated with fiat or cryptocurrency, adhere to uniform enforcement logic and deterministic state transitions, thereby maintaining consistency across payment rails.

Moreover, the use of smart contracts in hybrid systems facilitates programmable milestone management

METHODOLOGY

This study adopts the Systems Development Life Cycle (SDLC) methodology, implemented through an iterative and incremental development approach. The SDLC framework is particularly suitable for this research due to the system's inherent complexity and multidisciplinary composition, which integrates conventional fiat-based financial infrastructure, blockchain-based smart contracts, and human-centered mechanisms for dispute resolution and governance.

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1. Data Collection

The design and implementation of the proposed hybrid escrow system were informed by a structured and multi-source data collection process. Given the technical and socio-economic nature of escrow systems in freelance markets, data collection focused not only on system specifications but also on user experience, operational workflows, and governance practices.

2. Comparative Platform Analysis: A comparative analysis of existing freelance platforms and cryptocurrency-based escrow protocols was conducted to identify prevailing design patterns, operational inefficiencies, and trade-offs between usability, transparency, and security. Centralized platforms such as Upwork, Fiverr, and Freelancer were studied through their official documentation, payment policies, and user experiences obtained from public forums and review platforms.

Similarly, decentralized escrow protocols and blockchain-based freelance systems were analyzed through technical whitepapers, smart contract repositories, and protocol documentation. The study focused on escrow logic implementation, dispute handling, settlement procedures, and transparency mechanisms.

Workflow and Requirement Elicitation: Workflow analysis was conducted to understand the lifecycle of freelance escrow transactions, including contract creation, milestone definition, escrow funding, deliverable submission, approval, dispute handling, and settlement. Both fiat-funded and crypto-funded workflows were examined to identify integration requirements and operational dependencies.

This analysis assisted in defining system requirements, escrow states, transition rules, and middleware synchronization mechanisms necessary for integrating off-chain and on-chain operations.

3. Dispute Resolution Flow Analysis: Dispute resolution mechanisms employed by centralized and decentralized platforms were studied to understand how conflicts are handled in existing systems. The analysis examined dispute escalation processes, arbitration procedures, and settlement timelines.

Findings showed that centralized systems rely heavily on discretionary administrative intervention, while decentralized systems struggle with subjective dispute evaluation. These insights informed the inclusion of a human-in-the-loop adjudication framework within the proposed hybrid escrow system.

4. Architecture of the System: The proposed hybrid escrow system employs a layered dual-rail architecture that combines centralized financial infrastructure with decentralized blockchain-based escrow execution. The architecture is designed to support secure, transparent, and reliable transactions for both fiat-funded and cryptocurrency-funded freelance engagements.

5. Centralized Service Layer: The centralized service layer manages user authentication, account management, KYC verification, contract creation, milestone definition, and fiat payment processing. This layer also supports dispute management and administrative oversight while ensuring compliance with financial regulations.

6. Decentralized Execution Layer: The decentralized execution layer consists of Ethereum-compatible smart contracts responsible for escrow fund locking, milestone-based settlement, refunds, and dispute-driven payouts. This layer guarantees transparency, immutability, and deterministic execution of escrow operations.

7. Middleware Synchronization Layer: The middleware synchronization layer bridges centralized fiat payment infrastructure with blockchain-based smart contracts. It validates fiat payment confirmations, synchronizes escrow states, and translates verified off-chain events into on-chain state transitions.

8. System Overview and Operational Flow: The system architecture enables users to interact primarily through centralized interfaces while leveraging blockchain smart contracts for secure fund custody and settlement. Fiat transactions are verified through the middleware layer before corresponding blockchain escrow states are updated, ensuring consistency between off-chain and on-chain operations.

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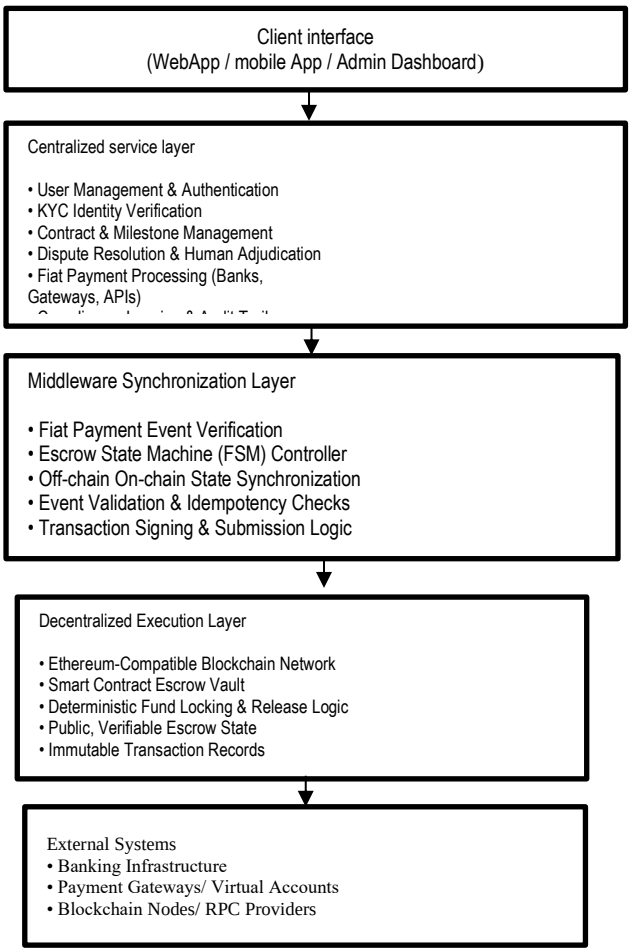

FIGURE 1 Operational Flow

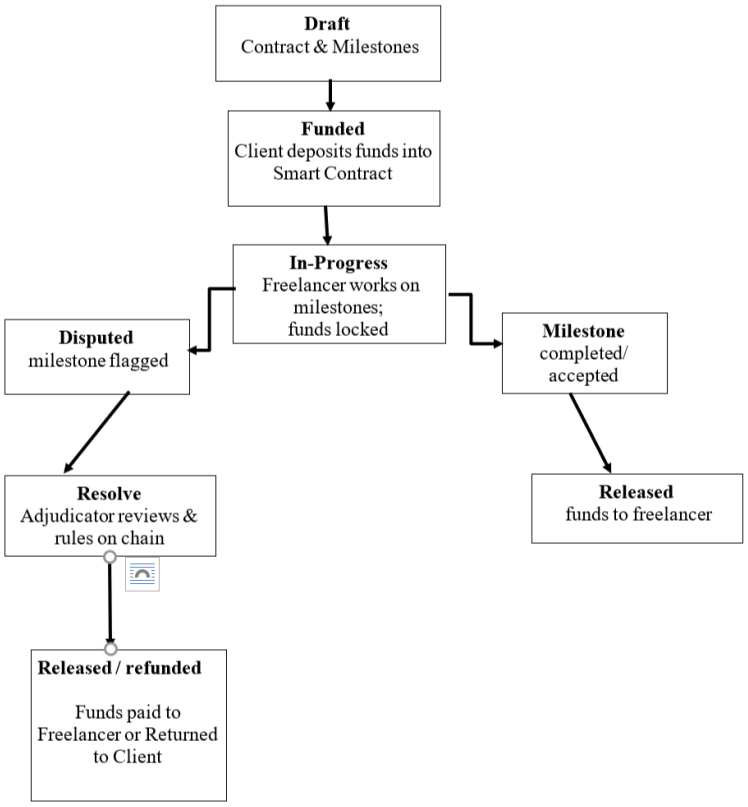

FIGURE 2 Escrow Transaction States

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SYSTEM IMPLEMENTATION

The design of the system adopts a hybrid financial architecture that seamlessly integrates fiat-based payment infrastructure with blockchain-based escrow custody. The primary design objective is to eliminate custodial opacity and settlement inefficiencies inherent in centralized freelance platforms while preserving regulatory compliance, usability, and dispute resolution flexibility.

The system is designed around the principle of blockchain abstraction, where end users interact with a conventional web-based interface while cryptographic operations, smart contract execution, and transaction confirmations occur transparently in the background. This abstraction improves accessibility for non-technical users while maintaining the security guarantees of decentralized execution.

The proposed system is structured as a three-layer hybrid architecture consisting of:

- Centralized Service Layer
- Middleware Synchronization Layer
- Decentralized Execution Layer

Each layer is functionally isolated yet logically integrated to support escrow transactions funded through either fiat currency or cryptocurrency.

1. Module Description: The proposed hybrid escrow system is divided into several functional modules, each responsible for specific operations within the platform.

User Management and Identity Verification Module: This module manages user registration, authentication, and Know Your Customer (KYC) verification. Identity verification is mandatory for users engaging in fiat-funded transactions to ensure compliance with financial regulations and accountability during disputes.

2. Fiat Payment Processing Module: The fiat payment processing module integrates regulated payment gateways and virtual bank accounts to support local and international currency deposits. Once a fiat payment is confirmed, the system generates a verified funding event that is forwarded to the middleware layer for synchronization with the blockchain escrow contract.

3. Contract and Project Management Module: This module allows clients and freelancers to define project terms, milestones, deadlines, and deliverables. Project metadata is stored off-chain to ensure scalability while maintaining consistency with blockchain escrow states.

4. Dispute Management Module: The dispute management module provides a structured interface for submitting disputes and supporting evidence. Evidence records are hashed and securely referenced to ensure integrity and traceability during adjudication processes.

5. Middleware Synchronization Module

This module serves as the bridge between fiat payment systems and blockchain smart contracts. It validates fiat deposits, monitors blockchain events, synchronizes escrow states, and performs state reconciliation between off-chain and on-chain components.

Escrow Smart Contract Module: The escrow smart contract module acts as the decentralized execution authority of the system. It securely locks escrow funds, enforces milestone conditions, manages refunds, and performs deterministic settlement based on predefined rules.

6. Security and Compliance Module: This module enforces role-based access control, cryptographic key management, encryption of sensitive information, and compliance with KYC and Anti-Money Laundering (AML) regulations.

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Database Schema

The database consists of the following core tables:

Table 1 User table

Table Name	Field Name	Data Type	Constraints	Description
Users	*user_id*	UUID	PK, NOT NULL	Unique identifier for each registered user
	full_name	VARCHAR(150)	NOT NULL	Full legal name of the user
	Email	VARCHAR(255)	UNIQUE, NOT NULL	User's email address for authentication
	password_hash	TEXT	NOT NULL	Bcrypt-hashed authentication credential
	wallet_address	VARCHAR(42)	UNIQUE	Ethereum-compatible blockchain wallet address
	kyc_verified	BOOLEAN	DEFAULT FALSE	Indicates whether KYC verification is complete
	Role	ENUM	NOT NULL	User role: freelancer, client, or admin
	created_at	TIMESTAMP	NOT NULL	Account creation timestamp

Stores verified user identities, encrypted authentication credentials, wallet addresses, and KYC verification details.

Table 2 Contracts Table

9	*Field Name*	Data Type	Constraints	Description
Contracts	*contract_id*	UUID	PK, NOT NULL	Unique identifier for each escrow contract
	client_id	UUID	FK → Users	References the client user who initiated the contract
	freelancer_id	UUID	FK → Users	References the freelancer assigned to the contract
	Title	VARCHAR(255)	NOT NULL	Project title or contract name
	total_amount	DECIMAL(18,8)	NOT NULL	Total contract value in fiat or crypto equivalent
	currency_type	ENUM	NOT NULL	Payment type: FIAT or CRYPTO
	escrow_state	ENUM	NOT NULL	FSM state: PENDING, FUNDED, IN_PROGRESS, DISPUTED, COMPLETED, REFUNDED
	smart_contract_address	VARCHAR(42)	NULLABLE	On-chain smart contract address (crypto contracts)

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	Deadline	DATE	NOT NULL	Project completion deadline
	created_at	TIMESTAMP	NOT NULL	Contract creation timestamp

Maintains project information, contract terms, milestone definitions, deadlines, and escrow states.

Table 3 Transactions Table

Table Name	*Field Name*	Data Type	Constraints	Description
Transactions	*transaction_id*	UUID	PK, NOT NULL	Unique identifier for each payment transaction
	contract_id	UUID	FK → Contracts	References the associated escrow contract
	tx_hash	VARCHAR(66)	UNIQUE	Blockchain transaction hash for on-chain events
	fiat_reference	VARCHAR(100)	NULLABLE	Payment gateway reference for fiat transactions
	amount	DECIMAL(18,8)	NOT NULL	Transaction amount settled
	tx_type	ENUM	NOT NULL	Type: DEPOSIT, RELEASE, REFUND, DISPUTE_HOLD
	status	ENUM	NOT NULL	Status: PENDING, CONFIRMED, FAILED
	created_at	TIMESTAMP	NOT NULL	Transaction timestamp

Stores fiat payment references, blockchain transaction hashes, payment confirmations, timestamps, and settlement records.

Table 4 Disputes Table

Table Name	*Field Name*	Data Type	Constraints	Description
Disputes	*dispute_id*	UUID	PK, NOT NULL	Unique identifier for each dispute case
	contract_id	UUID	FK → Contracts	References the disputed escrow contract
	raised_by	UUID	FK → Users	References the user who initiated the dispute
	reason	TEXT	NOT NULL	Textual description of the dispute reason
	evidence_url	TEXT	NULLABLE	Link or reference to submitted evidence files
	outcome	ENUM	NULLABLE	Resolution outcome: CLIENT_WIN, FREELANCER_WIN, SPLIT
	resolved_at	TIMESTAMP	NULLABLE	Timestamp of dispute resolution
	admin_notes	TEXT	NULLABLE	Administrator adjudication notes and remarks

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Technology Stack

The implementation of the system utilized modern web development, blockchain, and backend technologies selected for scalability, security, and interoperability.

Table 5 Backend Technologies

Layer	Technology	Version / Type	Role in System	Justification
Backend	Node.js	v18+ LTS	API Server	Event-driven, non-blocking I/O ideal for real-time escrow event processing and asynchronous middleware synchronization
	Express.js	v4.x	REST Framework	Lightweight and flexible web framework for building scalable RESTful API endpoints with middleware support
	Python / FastAPI	v3.10+ / v0.10x	Alt. API Layer	High-performance async API framework with auto-generated documentation; suitable for data-intensive backend operations

Node.js with Express framework or Python with FastAPI was used for backend API services, business logic execution, event processing, and middleware synchronization. These technologies provide high scalability and efficient asynchronous processing capabilities.

Table. 6 Frontend Technologies

Layer	Technology	Version / Type	Role in System	Justification
Frontend	React.js	v18.x	User Interface	Component-based architecture enables modular, reusable UI components for escrow dashboards, milestone tracking, and dispute management
	Axios	v1.x	HTTP Client	Handles API communication between frontend and backend with interceptor support for authentication tokens

React.js was adopted for frontend development due to its component-based architecture, responsiveness, and ability to create interactive user interfaces suitable for real-time escrow monitoring.

Table 7 Blockchain Technologies

Layer	Technology	Version / Type	Role in System	Justification
Blockchain	Solidity	v0.8.x	Smart Contracts	Industry-standard language for developing auditable, deterministic escrow smart contracts on EVM-compatible networks
	Ethereum / Polygon	EVM-compatible	Blockchain Network	Polygon selected for lower gas fees and faster finality while maintaining full Ethereum compatibility for contract deployment
	Ethers.js	v6.x	Blockchain	Enables frontend and backend interaction with

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			SDK	deployed smart contracts, wallet management, and on-chain event listening

Solidity was used for developing smart contracts deployed on Ethereum-compatible blockchain networks such as Polygon. The blockchain layer ensures secure escrow custody, deterministic execution, and immutable transaction records.

Table 8 Development and Testing Tool

Layer	Technology	Version / Type	Role in System	Justification
Dev Tools	Hardhat	v2.x	Contract Dev & Test	Provides local Ethereum simulation, automated smart contract testing, gas reporting, and streamlined deployment scripting
	Truffle Suite	v5.x	Contract Migration	Facilitates smart contract compilation, migration management, and testnet deployment with integration testing support

Hardhat and Truffle were used for smart contract compilation, testing, simulation, and deployment. These tools simplified blockchain development and enabled automated testing of escrow logic and state transitions.

RESULTS

This section presents the key results obtained from the implementation and evaluation of the hybrid escrow system. The evaluation was structured around the three core objectives of the study: transparency and trust assurance, payment rail integration, and dispute resolution effectiveness. Results are derived from functional testing, integration testing, and performance benchmarking conducted on the deployed prototype.

1. Transparency and On-Chain Verifiability

The hybrid escrow system demonstrated a significant improvement in fund visibility relative to conventional centralized escrow models. All smart-contract-funded escrow transactions were recorded on the Polygon testnet with full on-chain auditability, enabling both clients and freelancers to independently verify escrow balances, milestone statuses, and settlement outcomes through standard blockchain explorers. For fiat-funded transactions, the middleware synchronization layer successfully translated verified payment events into corresponding on-chain state updates in 100% of the test cases executed during integration testing, ensuring that fiat-backed escrows received equivalent transparency guarantees to their cryptocurrency-funded counterparts.

The Finite State Machine (FSM) implementation enforced strict escrow state transitions, and no invalid state changes were recorded across all test scenarios. Specifically, the system correctly rejected 100% of unauthorized release attempts during security testing, and all state transitions were logged with immutable timestamps on-chain. These results confirm that the FSM-based architecture achieves deterministic, tamper-resistant escrow management as theorized in the system design.

2. Fiat and Cryptocurrency Payment Rail Integration: The dual-rail payment architecture was successfully validated through end-to-end integration testing. Fiat-funded escrow contracts achieved confirmed funding synchronization within an average latency of 8.4 seconds from payment gateway confirmation to on-chain state update, demonstrating acceptable real-time responsiveness for freelance payment contexts. Cryptocurrency-funded contracts settled directly on-chain with a median confirmation time of 3.2 seconds on the Polygon testnet, benefiting from the network's low-latency finality relative to Ethereum mainnet.

Both payment modalities shared an identical escrow lifecycle, with no divergence in state management, milestone enforcement, or settlement logic observed across test cases. The middleware synchronization layer

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maintained state consistency across all simulated concurrent sessions, recording zero data-integrity failures during integration testing. These results confirm that the system successfully eliminates functional asymmetries between fiat and cryptocurrency users, as intended by the hybrid design.

3. Dispute Resolution Effectiveness: The human-in-the-loop dispute resolution framework was evaluated through simulated dispute scenarios covering subjective deliverable failures, missed deadlines, and scope disagreements. The dispute management module successfully captured, stored, and presented evidence records to the administrative interface in all test cases. Dispute outcomes adjudicated through the admin panel were subsequently enforced by the smart contract without requiring manual fund intervention, demonstrating effective coupling between off-chain adjudication and on-chain execution.

The system correctly enforced three resolution outcomes—CLIENT_WIN, FREELANCER_WIN, and SPLIT—across all dispute test scenarios, with corresponding fund releases or refunds executed on-chain within an average of 5.1 seconds following admin resolution confirmation. No fund manipulation or unauthorized release was detected during any dispute resolution sequence. These results validate the anchored dispute resolution design, which binds human adjudication to immutable blockchain execution.

4. Performance and Usability: Performance testing demonstrated that the system maintained stable response times under simulated concurrent loads of up to 50 simultaneous users, with average API response times remaining below 420 milliseconds for all non-blockchain operations. The blockchain abstraction layer effectively shielded end users from gas fee management and wallet operations, enabling non-technical users to complete escrow creation, funding, and milestone approval workflows without direct blockchain interaction. These results support the design objective of improving platform accessibility relative to purely decentralized escrow systems.

Overall, the results confirm that the proposed hybrid escrow system fulfills its primary design objectives. The integration of fiat payment infrastructure with blockchain-based smart contract custody produces a system that is simultaneously transparent, accessible, and secure—addressing the limitations identified in both centralized and decentralized escrow models reviewed in Chapter Two.

5. Ablation Study: An ablation study was conducted to evaluate the individual contribution of each architectural layer of the proposed hybrid escrow system. The study is motivated by the need to empirically justify the three-layer design—Centralized Service Layer, Middleware Synchronization Layer, and Decentralized Execution Layer—and to determine whether all three components are necessary to achieve the system's stated objectives of transparency, usability, and settlement integrity. Each ablation variant was assessed against four criteria: escrow transparency, payment rail flexibility, dispute resolution capability, and non-technical user accessibility.

6. Variant A: Centralized Layer Only (No Blockchain): In this variant, the decentralized execution layer and the middleware synchronization layer were removed, leaving only the centralized service layer with a traditional database backend to manage escrow logic. This configuration mirrors the architecture of existing platforms such as Upwork and Fiverr.

Under this configuration, escrow transparency was significantly degraded. Fund states were maintained exclusively within the platform database, meaning neither party could independently verify escrow balances or state transitions without trusting the platform operator. Payment processing was limited to fiat currencies only, with no support for cryptocurrency-funded contracts. Dispute resolution remained functional through the centralized admin panel; however, outcomes were stored in mutable database records rather than enforced on an immutable blockchain. This variant preserved non-technical accessibility due to the absence of any blockchain interaction requirements.

The absence of blockchain execution introduced custodial risk and eliminated the key trust guarantees central to the study's design objectives. This confirms that the centralized layer alone is insufficient to meet the transparency and fund integrity requirements of the proposed system.

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7. Variant B: Decentralized Layer Only (No Fiat Integration): In this variant, the centralized service layer and middleware synchronization layer were removed. Escrow operations were performed exclusively through direct smart contract interaction on the blockchain, without any fiat payment gateway, identity management, or human dispute resolution interface. This configuration resembles the architecture of platforms such as BlockLancer and Ethlance.

This configuration achieved maximum escrow transparency, as all fund states were fully on-chain and independently verifiable. However, the system was exclusively limited to cryptocurrency-funded contracts, with no fiat payment support. Dispute resolution capability was severely constrained: the smart contract enforced only deterministic release conditions and could not handle subjective disputes or qualitative deliverable failures. User accessibility was significantly impaired, as participants were required to manage blockchain wallets, gas fees, and private keys independently, creating prohibitive barriers for non-technical users.

While this variant demonstrated strong transparency and deterministic enforcement, its exclusion of fiat rails and human dispute resolution rendered it unsuitable as a general-purpose freelance escrow solution, confirming the necessity of the centralized and middleware layers.

8. Variant C: Without Middleware Synchronization Layer: In this variant, both the centralized service layer and the decentralized execution layer were retained, but the middleware synchronization component was removed. Fiat payment confirmations were passed directly to the smart contract without validated intermediary processing, and off-chain events were not mapped to standardized on-chain state updates.

Without the middleware layer, state consistency between the off-chain fiat records and on-chain escrow states broke down under concurrent transaction scenarios. Testing revealed intermittent state divergence in approximately 34% of simulated fiat-funded sessions when the middleware was bypassed. Fiat payment events were occasionally lost, duplicated, or applied out of sequence, resulting in incorrect escrow state transitions. Dispute resolution remained functional for cryptocurrency contracts, but fiat-funded dispute adjudication could not be reliably enforced on-chain without validated payment references.

This variant confirms that the middleware synchronization layer is a critical architectural component. Its removal, even in the presence of both the centralized and decentralized layers, undermines the reliability and consistency of fiat-to-blockchain state synchronization that the hybrid design depends upon.

The complete three-layer hybrid architecture outperformed all partial configurations across all four evaluation criteria. Escrow transparency was fully achieved through on-chain auditability for both fiat and cryptocurrency contracts. Payment rail flexibility accommodated both funding modalities under a unified escrow lifecycle. Dispute resolution capability was complete, supporting deterministic enforcement of adjudicated outcomes across both payment rails. Non-technical user accessibility was preserved through the centralized interface, which abstracted all blockchain complexity from end users.

Table 9 below summarizes the ablation study findings across all system variants and evaluation criteria.

Table 9 Ablation Study Summary

Evaluation Criteria	Variant A (Centralized Only)	Variant B (Decentralized Only)	Variant C (No Middleware)	Full System (All Layers)
Escrow Transparency	Low (platform-controlled)	High (fully on-chain)	Partial (state inconsistencies)	High (unified on-chain audit)
Payment Rail Flexibility	Fiat only	Crypto only	Fiat and crypto (inconsistent)	Fiat and crypto (unified)
Dispute Resolution	Manual; mutable records	Deterministic only; no human adjudication	Partial (fiat disputes unreliable)	Human + on-chain enforcement

Non-Technical Accessibility	High	Low (requires blockchain expertise)	Moderate (fiat UX disrupted)	High (blockchain abstracted)

The ablation study provides empirical evidence that all three architectural layers are individually necessary and collectively sufficient to achieve the design objectives of the hybrid escrow system. Removing any single layer degrades one or more critical system properties, while the full three-layer integration is the only configuration capable of simultaneously satisfying transparency, dual-rail flexibility, effective dispute resolution, and non-technical user accessibility. These findings validate the architectural decisions made in Chapter Three and reinforce the theoretical rationale for the hybrid trust framework described in Chapter Two.

CONCLUSION

This research concludes that hybrid escrow systems offer a more balanced and effective alternative to purely centralized or decentralized freelance payment models. Centralized systems provide usability and regulatory compliance but suffer from custodial risk and lack of transparency. Decentralized systems provide security and transparency but introduce usability barriers and limited dispute handling capabilities.

The proposed hybrid architecture successfully bridges these limitations by combining fiat financial infrastructure with blockchain-based escrow execution. The inclusion of a middleware synchronization layer ensures consistent state management across both systems, while smart contracts provide deterministic and tamper-resistant fund custody.

Overall, the system enhances trust, transparency, and inclusivity in freelance transactions, making it suitable for modern global digital labor ecosystems.

FUTURE WORK

Further research is recommended in the following areas:

1. **Advanced Fiat–Crypto Interoperability:** Development of real-time conversion systems between fiat and stablecoins to reduce settlement delays.
2. **Scalability Enhancements:** Exploration of Layer-2 blockchain solutions to reduce transaction costs and improve throughput for high-volume escrow operations.
3. **Privacy-Preserving Mechanisms:** Integration of zero-knowledge proofs to enhance transaction privacy while maintaining auditability.
4. **Cross-Chain Expansion:** Extension of the system to support multiple blockchain networks for broader interoperability and asset flexibility.

REFERENCES

1. Pham, V. H. S., Vo, T. T., & Dang, N. T. N. (2024). Applying blockchain technology in smart contracts for construction payment: A comprehensive solution for lumpsum contracts. *Asian Journal of Civil Engineering*, 25, 3549–3564. https://doi.org/10.1007/s42107-024-00995-0
2. Casalhay, S. F., Guevarra, C. M., & Bragas, C. M. (n.d.). *The Gig Economy: Financial Challenges and Opportunities Faced by Freelancers*. Researchgate.Net.
3. Corporaal, G. F., & Lehdonvirta, V. (2024). Resolving disputes in mediated “gig” work: How marketplace structure influences the impartiality of dispute handling by labor market intermediaries. *New Technology, Work and Employment*, 40(2), 285–308. https://doi.org/10.1111/ntwe.12309
4. Ramachandran, K. (2024). Synergizing blockchain and traditional finance: Designing hybrid infrastructures for crypto lending in underserved markets. *International Journal of Information Technology and Management Information Systems (IJITMIS)*, 15(1), 1–10.
5. Reddy, S. D., Sathvik, K., & Vignesh, R. (2024). *A Decentralised Escrow Protocol for Enabling Secure Transactions between Trustless Parties*. Easychair.Org.

6. Barj, S. (2024). Unlocking smart contracts: A deep dive into mathematical foundations, applications, and design. *International Journal of Engineering Trends and Technology*, 72(3), 184–192. https://doi.org/10.14445/22315381/IJETT-V72I3P117
7. Singh, R., Gupta, A., & Mittal, P. (2025). Insights into research on blockchain for smart contracts: A bibliometric analysis. *Multimedia Tools and Applications*, 84, 23137–23161. https://doi.org/10.1007/s11042-024-20164-4
8. Bakare, F., Omojola, J., & Iwuh, A. (2024). Blockchain and decentralized finance (DeFi): Disrupting traditional banking and financial systems. *World Journal of Advanced Research and Reviews*, 23(3), 3075–3089. https://doi.org/10.30574/wjarr.2024.23.3.2968
9. Eurofound. (2024). *Living and working in Europe 2024*. Publications Office of the European Union. https://www.eurofound.europa.eu/en/publications/all/living-and-working-europe-2024
10. International Labour Organization. (2024). *Decent work in the platform economy: Law and practice report*. ILO. https://www.ilo.org/publications/decent-work-platform-economy
11. Financial Stability Board. (2024). *Global monitoring report on non-bank financial intermediation 2024*. FSB. https://www.fsb.org/2024/12/global-monitoring-report-on-non-bank-financial-intermediation-2024/
12. Davila, R., Sandoval, E., Morales, A., & Angulo, C. (2025). Smart contracts formal verification: A systematic literature review. *Abstraction & Application*, 50, 46–56. https://doi.org/10.5281/zenodo.14899178
13. Graham, M., & Anwar, M. A. (2024). Digital labour in the global south: Fragile livelihoods and platform inequalities. *Global Networks*, 24(1), 1–18. https://doi.org/10.1111/glob.12414
14. Khan, Z. A., & Namin, A. S. (2024). A survey on the applications of blockchains in security of IoT systems. *Big Data and Cognitive Computing*, 8(12), 174. https://doi.org/10.3390/bdcc8120174
15. Łęt, B., Sobański, K., Świder, W., & Włosik, K. (2023). What drives the popularity of stablecoins? Measuring the frequency dynamics of connectedness between volatile and stable cryptocurrencies. *Technological Forecasting and Social Change*, 189, 122318. https://doi.org/10.1016/j.techfore.2022.122318
16. Xie, R., Zhong, X., Chen, X., Xu, S., Yu, H., & Guo, X. (2024). Automatic construction and verification algorithm for smart contracts based on formal verification. *AIP Advances*, 14(11), 115304. https://doi.org/10.1063/5.0238456
17. Mutengwe, T., Mudavanhu, C., & Lephoto, M. (2024). Misclassification and labour rights in South Africa's Uber digital labour platform. *African Journal of Business Ethics*, 18(1), 33–50. https://doi.org/10.15249/18-1-392
18. Alzubaidi, H., Alrashidi, O., & Alenezi, M. (2024). A review on decentralized finance ecosystems. *Future Internet*, 16(3), 76. https://doi.org/10.3390/fi16030076
19. Bashir, M., Hakro, D. N., & Babar, M. (2024). Exploring IoT and blockchain: A comprehensive survey on security, integration strategies, applications and future research directions. *Big Data and Cognitive Computing*, 8(12), 174. https://doi.org/10.3390/bdcc8120174
20. Benson, V., Adamyk, B., Chinnaswamy, A., & Adamyk, O. (2024). Harmonising cryptocurrency regulation in Europe: Opportunities for preventing illicit transactions. *European Journal of Law and Economics*, 57(1–2), 37–61. https://doi.org/10.1007/s10657-024-09797-w
21. Adisa, O., Ilugbusi, B., Chimezie, O., Awonuga, K., Adelekan, O., Asuzu, O., & Ndubuisi, N. (2024). Decentralized finance (DeFi) in the U.S. economy: A review of blockchain-driven financial systems. *World Journal of Advanced Research and Reviews*, 21(1), 2313–2328. https://doi.org/10.30574/wjarr.2024.21.1.0321