A Framework for Decentralized Payment Instrument Integration with Artificial Intelligence, Big Data, and Digital Identities*

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Abstract

Decentralized payment instruments have emerged as a transformative financial technology, showcasing significant potential across various domains. Leveraging the flexibility of smart contracts and diverse blockchain platforms, these instruments can be tailored with unique functionalities to address the needs of different industries. The integration of decentralized payment instruments with advanced technologies, such as artificial intelligence (AI), decentralized identifiers (DIDs), big data, and social networks, unlocks new opportunities while posing distinct challenges. Owing to their digital nature, these instruments possess substantial potential for seamless incorporation into various technological ecosystems. This paper examines different forms of such integration, outlines the technological tools that facilitate it, and evaluates the associated risks and opportunities. The study underscores the growing importance of decentralized payment instruments in shaping innovative financial and technological landscapes.

Keywords

decentralized finance, DeFi, smart contracts, payment systems, blockchain, tokenomics, artificial intelligence, stablecoins, decentralized autonomous organization, financial technology

1. Introduction

In the modern era, financial technology is undergoing a revolutionary transformation, driven by the rapid adoption of innovative solutions in blockchain technology alongside other digital advancements such as artificial intelligence (AI), big data, the Internet of Things (IoT), and others, which collectively offer cutting-edge financial solutions. One of the most promising technological advancements is decentralized finance (DeFi), which provides an alternative to traditional financial systems through the utilization of smart contracts and decentralized blockchain protocols. Over the past decade, DeFi has evolved from experimental concepts into one of the most significant segments of the blockchain industry, unlocking new opportunities for automation, integration with social networks and AI, and enhancing the transparency and efficiency of financial transactions. Traditional digital financial platforms, such as SWIFT or Visa, often entail high transaction costs, slow payment processing times, reliance on intermediaries, and limitations in meeting the demands of participants in modern technological collaborations. By employing decentralized payment instruments—commonly referred to as "tokens"—created using programmable smart contracts, it has become possible to automate and simulate diverse digital payment models, facilitating their integration with other technological digital products. Smart contracts and decentralized finance protocols enable the development of decentralized payment instruments that not only reduce reliance on traditional economic intermediaries but also promote effective interaction among participants within the digital economic ecosystem.

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This study aims to analyze the technological challenges and opportunities arising from the integration of decentralized payment instruments with other information and communication technologies. Additionally, it seeks to propose approaches for leveraging modern decentralized payment instruments effectively.

2. Literature review

Decentralized finance (DeFi) represents one of the most significant advancements in blockchain technology, gaining popularity for its ability to automate financial processes and eliminate intermediaries. According to Messari and other research platforms, the capitalization of the DeFi market exceeded 50 billion USD as of 2024, underscoring its growing importance in the global financial ecosystem. At the core of DeFi lies the use of smart contracts—automated programs that execute predefined conditions without third-party involvement. These smart contracts underpin the creation of decentralized payment instruments, lending platforms, staking mechanisms, and other financial services. For instance, platforms like Uniswap and Curve demonstrate the efficiency of automated market makers (AMMs) in digital asset trading. Similarly, MakerDAO ensures the stability of the DAI token through decentralized lending mechanisms, token collateralization, liquidation processes, stabilization frameworks, and decentralized governance facilitated by a DAO [1].

A notable technological advancement within decentralized payment instruments is the development of algorithmic stablecoins, which are pegged to fiat currencies or other assets. Schär (2021) [2] explores their significance in payment systems due to reduced volatility, while Krause (2025) [3] examines their functionality and associated risks. Furthermore, numerous studies, including those by Mridul (2024) [4], Shumyliak [5], and Singh [6] highlight the role of smart contracts in creating transparent and efficient payment instruments. However, DeFi systems face several challenges, such as limited scalability, high transaction costs during peak periods (e.g., on Ethereum), and integration difficulties with traditional financial systems. Alamsyah (2024) [7] provides an analysis of the benefits and drawbacks of existing solutions. Blockchain technologies fundamentally transform payment systems by removing the need for centralized transaction processing. Nakamoto (2008) [8] first introduced the concept of a decentralized transaction system based on cryptographic consensus.

Modern blockchain-based payment platforms, such as Ethereum, Binance Smart Chain, and TON, present unique opportunities for the development of decentralized financial services. Adams (2017) [9, 10] focuses on the role of decentralized payments in enhancing trade efficiency, while Harvey (2014) [11] explores the integration of smart contracts with traditional finance through tokenized assets. Additionally, Zamani (2018) [12] emphasizes the effectiveness of sharding technologies in achieving high performance. Despite its potential, the security of smart contracts remains a significant concern. Research by Delmolino et al. (2016) [13] indicates that a considerable proportion of hacking attacks target vulnerabilities in smart contracts, resulting in the loss of user funds. Allen et al. (2022) [14] stress the necessity of adhering to legal standards to mitigate financial crimes in decentralized payment systems. A comprehensive review of the literature demonstrates that decentralized payment instruments when integrated with modern digital products and technologies, possess the potential to revolutionize financial systems. However, challenges such as scalability, security vulnerabilities, and regulatory compliance must be addressed to fully realize this potential.

3. Modern forms of programmable decentralized payment instruments

Programmable decentralized payment instruments, based on smart contracts and peer-to-peer systems, represent a new stage in the evolution of financial systems, offering high levels of automation, transparency, and accessibility. The early 2020s witnessed significant growth in the adoption of platforms for creating DeFi products (e.g., Ethereum, Binance Smart Chain, Solana), which have opened new opportunities for both users and financial institutions [15]. One of the key advantages of these tools is the automatic execution of predefined conditions embedded in code, which is highly resistant to cyber threats. As of late 2024, the most popular forms of programmable financial instruments include staking, liquidity provision through automated market makers (AMMs), credit and debt platforms (e.g., Aave, Compound), and digital derivatives. A further direction for DeFi development is the integration of smart contracts into various economic sectors, ranging from real estate tokenization to automated payments within the Internet of Things (IoT). However, challenges such as the scalability and security of smart contracts remain critical areas of research and innovation.

Table 1 outlines the primary financial services offered by modern decentralized financial platforms (DeFi), highlighting their versatility and innovative nature.

Table 1
Types of DeFi services

DeFi Services	Description	Examples
Lending and Borrowing	Provide decentralized platforms for users to lend and borrow cryptocurrencies with algorithmic rates.	Aave, Compound
Decentralized Exchanges (DEX)	Allow trading of cryptocurrencies without intermediaries, using liquidity pools instead of order books.	Uniswap, SushiSwap
Staking	Enable users to lock tokens in blockchain protocols to support network operations and earn rewards.	Ethereum 2.0 Staking, Lido
Yield Farming	Incentivize liquidity provision to DeFi protocols with high yields on deposits.	Yearn Finance, PancakeSwap
Stablecoins	Cryptocurrencies are pegged to fiat or maintained stable through algorithms.	USDT, DAI, Curve
Derivatives Trading	Facilitate trading of financial derivatives like futures, options, and swaps on decentralized platforms.	Synthetix, dYdX
Insurance	Offer decentralized insurance for risks like smart contract vulnerabilities or hacks.	Nexus Mutual, InsurAce
Asset Tokenization	Enable tokenization of real-world assets for fractional ownership (e.g., real estate, art).	RealT, Centrifuge
Payment Networks	Facilitate fast and low-cost payments using blockchain and stablecoins.	Celo, RippleNet
Prediction Markets	Platforms allow users to bet on the outcomes of future events in a decentralized manner.	Augur, Polymarket
Fund Management	Decentralized tools for managing investment funds, including portfolio rebalancing and yield optimization.	Set Protocol, Enzyme Finance
Financial Analytics	Platforms providing analytical insights and on-chain data for informed decision-making in DeFi.	Dune Analytics, Nansen, Glassnode

Each service is designed to automate and decentralize traditional financial processes, such as lending, asset exchange, risk management, and investment. Decentralized financial protocols and smart contracts ensure transparency, accessibility, and security for financial transactions. Examples of successful implementation include platforms such as Aave, Uniswap, and Synthetix. The integration of these services with advanced technologies, such as AI, oracles, IoT, and Big Data, presents additional opportunities for mitigating technical risks, reducing transaction costs, and fostering the creation of innovative financial products.

Decentralized financial protocols, as components of decentralized infrastructures, often include payment instruments, which play a pivotal role in the operation of their ecosystems [16]. These tokens serve a variety of functions, including governance mechanisms, liquidity incentives, security assurance, and fee payments. The programmable nature of tokens enables decentralized management functionalities within the system, allowing users to vote on protocol changes, such as updates to smart contracts, fee structures, or the introduction of new features. Examples of such tokens include those from the UNI (Uniswap) and AAVE (Aave) projects, which facilitate democratic decision-making within their ecosystems. Tokens also provide liquidity incentives by rewarding participants who contribute to asset liquidity through liquidity pools, thereby enhancing platform activity and ensuring stability. For instance, the CRV token (Curve) is used as a reward for liquidity providers, while SUSHI (SushiSwap) allows token holders to receive a portion of transaction revenue through a programmable long-term holding incentive model. Additionally, tokens can act as collateral within protocols through staking mechanisms (e.g., LDO for Lido or SNX for Synthetix), enhancing the overall security of the network and creating further incentives for users. A significant portion of DeFi tokens also functions as tools for distributing fees generated within the ecosystem. Moreover, token models, when combined with legal frameworks, can represent the value of real or virtual assets, such as tokenized real estate or bond models, thereby providing liquidity and access to highly liquid markets.

4. Decentralized payment instruments in information technologies

The growing popularity of decentralized payment instruments has spurred efforts to integrate them with information technologies, such as social networks and data management systems, creating unique interaction models. Platforms like Rally, Meme.com, Chiliz, and Pump.fun utilize social tokens, often referred to as fan tokens or meme tokens, which serve to stimulate community engagement and facilitate speculation on the popularity of token issuers or emotionally charged events. For example, the Rally platform enables influencers and brands to create their social tokens, which users can utilize to access exclusive content or events. Similarly, Chiliz issues fan tokens for sports clubs, allowing fans to participate in club decisions and receive exclusive rewards. These platforms frequently integrate with services like Twitch, Discord, and TikTok, offering innovative opportunities for monetizing community activity. These trends have also led to the emergence of platforms like Friend.tech and DeSo (Decentralized Social), which enable users to monetize their online presence by purchasing unique tokens or keys associated with social media profiles [17]. Such platforms combine reward systems with DeFi mechanisms to foster active participation within their ecosystems thereby facilitating the development of decentralized social media platforms. By integrating programmable tokens with social networks, these platforms expand opportunities for communities, creating new monetization models and enhancing engagement. The table below provides a concise overview of these platforms.

Table 2
Integration of DeFi Services with Social Networks

Service	System Token	Integrated Social Networks	Short Description
Rally	RLY	Twitch, Discord	A platform for creating social tokens, allowing influencers to monetize their communities.
Meme.com	MEM	Reddit, Twitter	A platform for meme tokenization, enabling users to mint and trade memes as digital assets.
Chiliz	CHZ	Twitter, Instagram	A fan-token platform for sports clubs, allowing fans to vote and gain access to exclusive perks.
Dogecoin	DOGE	Twitter	A meme token with strong community support, used for tipping and micropayments in social networks.
Audius	AUDIO	TikTok	A decentralized music streaming platform that enables musicians to monetize content and integrate with TikTok.
Friend.tech	No token (keys)	Twitter	A platform for trading keys that grant access to exclusive chats and content.
DeSo	DESO	Twitter, Instagram	A decentralized platform for social networks, allowing profile monetization through token purchases.

One example of reputation monetization through DeFi technologies is the $TRUMP token, a meme token issued on the Solana blockchain that capitalizes on the popularity of Donald Trump's brand to attract capital and attention from the cryptocurrency community. The primary functions of the token include generating speculative value, fostering community engagement through meme culture, and associating it with a political brand. While the $TRUMP token offers limited real-world utility and functionality, it serves as a tool for financial speculation, symbolic support for the Trump brand, and raising awareness of novel approaches to tokenization within a political context [18]. However, the centralized ownership structure of the token raises concerns regarding potential market manipulation.

5. Decentralized payment instruments in personal data management systems

Programmable tokens play a significant role in modern approaches to personal data management, offering new opportunities for data protection, access control, and monetization [19]. One of their key advantages lies in enhancing data privacy and security through the use of tokens as unique identifiers. In this context, tokenization replaces sensitive information with anonymous markers, minimizing the risk of data breaches and unauthorized access. For instance, in medical systems, tokens can protect patient information by concealing real data within encrypted databases. Beyond protection, these tokens serve as an effective mechanism for managing access to personal data. Through integration with smart contracts, users can grant or restrict access to their data while retaining full control over who accesses it and under what conditions. Such approaches form the foundation of decentralized identity protocols (DIDs), such as SelfKey and uPort, where tokens act as core elements for authentication and permission management. This enables users to effectively manage their digital identities amid the growing significance of data in the digital economy.

Another critical function of tokens is to incentivize users by enabling the monetization of their data. Platforms like Ocean Protocol and Brave Browser allow users to receive compensation for sharing their data or viewing advertising content. These mechanisms foster active user participation in the digital economy, where data is becoming an increasingly valuable asset. In this way, tokens not only enhance the protection and management of personal data but also facilitate its integration into new models of transparent and secure interactions within digital ecosystems [20].

Table 3
Integration of tokens with Personal Data Management Services

Service	System Token	Integrations with Other Systems	Short Description
Ocean Protocol	OCEAN	DeFi protocols, Data Marketplaces	A decentralized platform for data monetization, enabling users to share and sell their data while retaining control.
Brave Browser	BAT	Advertisers, Payment Systems (Uphold)	A platform for viewing ads where users earn BAT tokens for interacting with content.
SelfKey	KEY	ID managers, KYC Platforms	A decentralized identity protocol that allows users to store, control, and share their data securely.
Dock	DOCK	DID protocols, Data verification services	A system for managing digital certificates and identities with a focus on transparency and security.
Civic	CVC	Business applications, ID managers	A platform for identity verification that simplifies authentication processes through secure digital identities.
Bloom	BLT	Credit services, ID managers	A system for managing credit history and identity with an emphasis on personal data protection.

6. Decentralized payment instruments in the governance of decentralized systems

Tokens play a pivotal role in enabling decentralized governance of projects, particularly within decentralized autonomous organizations (DAOs) and the DeFi protocols used to establish them. In such systems, tokens function as voting mechanisms, empowering community members to participate in decision-making processes without relying on centralized governance structures [21]. For instance, Uniswap's UNI token facilitates voting on protocol changes, such as the introduction of new features or the definition of economic parameters like reward distribution across liquidity pools. Similarly, some DAOs employing DeFi protocols incentivize participation through rewards for voting or contributing liquidity, further encouraging community engagement. The table below outlines examples of DAOs and the characteristics of the tokens utilized within them. These financial and managerial solutions provide a robust decentralized governance mechanism that integrates economic interests, collective decision-making, and technological transparency. This approach establishes new organizational standards within the digital economy.

Table 4
Prominent DAOs and Their Tokens

DAO	Token Name	DAO Characteristics	Token Characteristics
Uniswap DAO	UNI	Decentralized governance for the Uniswap DEX, focused on managing liquidity pools and protocol upgrades.	Governance token enabling voting on protocol updates, fee structures, and liquidity incentives.
MakerDAO	MKR	Decentralized stablecoin platform supporting the issuance of DAI, backed by collateralized assets.	Governance token used for voting on system parameters and ensuring stability of the DAI stablecoin.
Compound DAO	COMP	Decentralized lending and borrowing protocol, enabling algorithmic interest rate determination.	Governance token allows users to vote on protocol changes and distribution of reserves.
Aave DAO	AAVE	Decentralized lending platform enabling overcollateralized loans and earning interest on deposits.	Tokens are used for governance, staking to secure liquidity, and earning rewards.
Curve DAO	CRV	DeFi platform focused on efficient stablecoin swaps with minimal slippage and low fees.	Governance and staking tokens are used to vote on liquidity pool rewards and protocol improvements.
SushiSwap DAO	SUSHI	Decentralized exchange with community-driven governance and yield farming opportunities.	Governance tokens provide voting rights and enable holders to earn a share of platform fees via staking.
Yearn Finance DAO	YFI	Aggregator for DeFi yields, optimizing user returns through automated yield farming strategies.	Highly limited governance token allowing holders to propose and vote on system updates and fee models.
Friends with Benefits DAO	NFT (membership-based)	Exclusive social DAO focused on community-driven collaboration and cultural projects.	NFTs act as membership passes, granting access to DAO resources, events, and decision-making processes.
Aragon DAO	ANT	Platform for creating and managing DAOs, with tools for governance, voting, and treasury management.	Governance token enabling participation in decisions about Aragon's development and ecosystem support.
Gitcoin DAO	GTC	Platform for funding open-source projects and incentivizing developer contributions.	Governance tokens are used to vote on fund allocation and community-driven decisions.

The integration of tokens with GameFi and metaverses represents one of the key components of the modern digital economy, offering significant opportunities for asset monetization and player participation. The programmable nature of tokens is fully realized in this context, enabling their use for a wide range of purposes—from serving as currency or assets to fostering player involvement in DAOs and staking models. GameFi and metaverses are often referred to as full-fledged decentralized economies that attract millions of players, shaping the future of digital interaction [22]. These environments frequently serve as testing grounds for new token models, which are later applied in real-world contexts. For instance, gaming platforms like Axie Infinity and The Sandbox enable players to participate in gameplay while simultaneously earning economic rewards through the Play-to-Earn model by completing tasks or competing in challenges [23]. Additionally, NFTs integrated with tokens offer players unique ownership of assets such as characters, land plots, or exclusive items. These assets can be transferred across platforms, traded, or utilized in decentralized governance, contributing to the development of game economies. The table below highlights major GameFi and metaverse platforms, illustrating the pivotal roles tokens play in governance, economic systems, and functionality.

Table 5
GameFi and Metaverse Platforms with Token Characteristics

GameFi Platform/ Metaverse	Token Name	Platform Characteristics	Token Characteristics
The Sandbox	SAND	A virtual world where players can create, own, and monetize their digital assets and games.	Used as in-game currency, for governance in DAO, and for buying land and assets.
Axie Infinity	AXS/SLP	A play-to-earn platform where players raise, trade, and battle digital creatures (Axies).	AXS for governance and staking; SLP for earning through gameplay and breeding Axies.
Decentraland	MANA	A decentralized virtual world focused on user-generated content, real estate, and experiences.	Used to purchase virtual land and items, and to vote in governance decisions via DAO.
Star Atlas	ATLAS/ POLIS	A space-themed strategy game with exploration, trade, and battles in a vast virtual universe.	ATLAS for in-game transactions; POLIS for governance and decision-making in the ecosystem.
Illuvium	ILV	A fantasy RPG game featuring exploration, collection, and battle with NFT creatures.	Used for staking rewards, governance, and in-game transactions.
Gala Games	GALA	A blockchain gaming ecosystem offering multiple games and decentralized ownership.	Used to purchase in-game items and participate in ecosystem governance.
Gods Unchained	GODS	A blockchain-based trading card game with ownership of digital cards via NFT technology.	Used to craft cards, participate in governance, and earn gameplay rewards.

My Neighbor Alice	ALICE	A multiplayer builder game where players create and manage virtual land.	Used for in-game purchases, land transactions, and governance in the ecosystem.
Enjin	ENJ	A platform for tokenizing in-game items and integrating them into various games.	Backs the value of NFT assets and facilitates cross-platform item portability.
MetaHero	HERO	A platform focused on creating high-definition 3D avatars and digital assets for use in games.	Used for purchasing 3D scanning services and participating in the ecosystem's economy.

7. Application of decentralized payment instruments in AI, IoT, and Big Data–based products

Tokens are becoming a vital tool in various services through their integration with modern technologies such as the Internet of Things (IoT), decentralized artificial intelligence (DeAI) [24], big data, and others. They create innovative models, automate processes, provide transparency, and incentivize participant engagement. In the IoT context, tokens are emerging as systemic payment tools to facilitate data transfer between devices [25]. Projects like Helium (HNT) utilize tokens to build decentralized IoT networks, where participants earn rewards by contributing their devices or infrastructure. Similarly, IOTA (MIOTA) enables micropayments between IoT devices, promoting autonomous interaction. The integration of tokens with AI technologies unlocks new opportunities for decentralized platform development. For example, the SingularityNET (AGIX) project offers an AI services marketplace where tokens are used to pay for access to algorithms or analytics. It also incentivizes AI developers to earn rewards for their contributions while providing users access to necessary tools. Fetch.ai (FET) incorporates tokens to support autonomous AI agents, facilitating transactions and optimizing interactions among ecosystem participants [26].

In the field of Big Data, tokens empower users to monetize their data while maintaining control over its usage. Ocean Protocol (OCEAN) provides a data exchange platform where users earn tokens for sharing or granting access to their data. This establishes a transparent ecosystem where data becomes a valuable asset, tracked via blockchain records, and incentivizes developers to create algorithms for analyzing large datasets. In computing systems such as Theta (THETA), tokens incentivize the provision of resources like computing power or storage. These integrations not only enhance efficiency and decentralization but also create an economic model where all participants benefit [27]. The table below provides a detailed overview of token integration across various technologies, highlighting the diverse functions tokens serve within these ecosystems.

Table 6
Integration of Decentralized Payment Instruments with Modern Technologies

Project	Token Name	Technology Integration	Token Function
Helium	HNT	IoT	Incentivizes users to provide wireless network infrastructure and rewards for device connectivity.
IOTA	MIOTA	IoT	Facilitates fee-free microtransactions between IoT devices for seamless data and value transfer.
Streamr	DATA	IoT	Enables monetization of real-time data streams between devices and users.

SingularityNET	AGIX	AI	Powers a decentralized marketplace for AI services, paying for algorithm access and development.
Fetch.ai	FET	AI	Supports autonomous agents in performing economic transactions and automating workflows.
Ocean Protocol	OCEAN	Big Data	Provides a medium of exchange for buying and selling data on a decentralized marketplace.
Datum	DAT	Big Data	Rewards users for sharing personal data while maintaining control over their data privacy.
Theta	THETA	Edge Computing	Incentivizes users to share their bandwidth and computational resources for decentralized video streaming.
SelfKey	KEY	Decentralized Identity (DID)	Allows users to control access to their personal identity data and facilitates secure authentication.
VeChain	VET	Supply Chain Management	Tracks goods along the supply chain and ensures transparency with tokenized rewards for participants.
OriginTrail	TRAC	Supply Chain Management	Provides traceability of goods and incentivizes data sharing across the supply chain.
Gitcoin	GTC	Open Source Development (Big Data)	Facilitates funding for open-source projects and rewards contributors in a decentralized ecosystem.

In summary, tokens developed using decentralized protocols and smart contracts possess significant potential to fulfill a wide range of functions, spanning both public and commercial applications. In the public sphere, tokens enhance transparency, efficiency, and inclusiveness in resource management. For example, they can be utilized to monitor the spending of charitable organizations or government projects, providing the public with real-time insights into the allocation and use of funds. Furthermore, tokens can be effectively deployed in social incentive programs, such as promoting participation in environmental initiatives or volunteering efforts.

8. Security and testing technologies for decentralized payment instruments

The integration of decentralized payment instruments with modern technologies opens new opportunities for financial innovation but simultaneously introduces several risks, particularly vulnerabilities in smart contracts and associated systems. Ensuring the security and resilience of decentralized systems necessitates the use of specialized tools and approaches aimed at identifying, preventing, and mitigating potential threats [28]. The security of smart contracts and decentralized protocols, which serve as the foundation of decentralized payment instruments, is critically important for ensuring system reliability. Specialized tools such as MythX, Slither, and Echidna, used for static and dynamic analysis of smart contracts, enable the identification of potential vulnerabilities, including reentrancy attacks, numerical overflows, and improper access control. For more sophisticated systems with complex networks of smart contracts, analytical platforms like Certik and OpenZeppelin Defender provide automated auditing combined with expert evaluation to ensure comprehensive protection. Certik utilizes formal verification methods to conduct mathematically proven security analyses of smart contract code, while OpenZeppelin Defender offers ready-made secure code templates and integrated testing frameworks. Additionally, Certik employs artificial intelligence (AI) technologies to detect anomalies in smart contract operations, analyze transactions, and predict risks. These services integrate with cloud platforms to provide convenient access to analytics and audit results. Machine learning further enhances the analysis through continuous data collection from real-world usage scenarios. To integrate external data and connect with broader ecosystems, these services utilize decentralized oracles, such as Chainlink, which facilitate the transmission of data to smart contracts for functionality verification. The LLM-SmartAudit [29] technology also appears promising, leveraging the advanced capabilities of large language models (LLMs) as an innovative approach to vulnerability analysis and detection. Its primary advantage lies in its ability to handle complex logical vulnerabilities often overlooked by traditional tools. The use of a multi-component system with agents interacting within a multi-level audit represents an innovative step, enhancing process efficiency. Another innovative approach involves an n-gram language model for detecting semantic contexts, which employs three different tokenization standards and demonstrates impressive accuracy in experimental results [30].

Smart contract testing is a critical stage in the development of decentralized payment instruments. Modern frameworks and tools are employed to verify their functionality, security, and compliance with business logic. One of the most widely used tools is Hardhat, which provides a local environment for testing and debugging contracts. Hardhat enables the creation of stress test scenarios, simulation of contract behavior under varying conditions, and quick detection of logical errors. The tool integrates seamlessly with the Ethers.js platform to simplify interaction with the blockchain, ensuring efficient testing before deploying contracts on a live network. Another tool, Ganache, facilitates the testing process by providing an environment for simulating the operation of smart contracts in real blockchain conditions, allowing developers to identify potential vulnerabilities during the development stage. The Echidna tool offers automated test generation to verify the security of contracts when interacting with other components of the ecosystem [31]. Additionally, some developers propose the use of sidechains as platforms for auditing smart contracts [32]. The table below outlines security, technology risk management, and testing services, along with their characteristics for working with decentralized payment instruments.

Table 7
Audit and testing services for smart contracts of decentralized payment instruments

Service	Main Functionality	Features	Use Cases
Certik	Smart contract auditing and code verification	Formal code verification Real-time monitoring Vulnerability detection	Analyzing DeFi protocol smart contracts to avoid risks
OpenZeppelin Defender	Smart contract management, update automation	DevOps tools for contracts Secure contract upgrades Blockchain integration	Automating updates for DAOs or tokens
MythX	In-depth analysis of smart contracts	Static and dynamic code analysis Integration with development frameworks (Truffle, Hardhat)	Identifying logical errors and potential attacks in smart contracts

Slither	Tool for smart contract analysis and optimization	Quick vulnerability detection Code quality analysis Performance reports	Optimizing contract performance before deployment
Echidna	Framework for security testing of smart contracts	Test generation for verification Detecting anomalies in contract behavior	Ensuring smart contracts align with business logic
Chainalysis	Transaction and risk monitoring	Suspicious transaction detection Monitoring financial flows Regulatory compliance support	Analyzing crypto flows to detect fraud
Elliptic	Blockchain risk management	Wallet behavior analysis Fraud probability assessment Integration with external databases	Identifying risky wallets in DeFi networks
ImmuneFi	Bug bounty platform	Organizing bounty programs Collaboration with ethical hackers Identifying critical vulnerabilities	Preventing attacks by involving third-party experts
Hardhat	Framework for developing and testing smart contracts	Local testing environment Debugging Creating scenarios for stress tests	Testing smart contracts before deploying on the main network
Ganache	Local blockchain network for testing	Isolated environment Fast transaction debugging Analyzing contract behavior	Simulating smart contract behavior under real-world conditions
Chainlink	Decentralized oracle for external data	Reliable data exchange between blockchain and external sources Protection against data manipulation	Providing data for DeFi protocols, such as asset prices or weather data
DSCAPS	Decentralized smart contract auditing platform based on sidechain	Leverages two-way peg sidechain technology Encourages collaborative audits Submarine commitments Incentive and punishment mechanisms	Auditing smart contracts pre-deployment with distributed miners and users to detect vulnerabilities and ensure contract security efficiently

9. Tools for technological integration of decentralized payment instruments with modern technologies

The functionality of tokens and their integration with modern digital technologies are founded on decentralized protocols and smart contracts, which automate transactions and facilitate interactions between participants. In the context of the Internet of Things (IoT), tokens are utilized to automate micropayments between devices for data or resource exchanges, ensuring efficient, secure, and autonomous interactions through smart contract structures or token protocols. A crucial component of a smart contract is its device identification mechanism, which authenticates transaction participants. Each device is assigned a unique cryptographic identifier to establish trust. Additionally, the smart contract defines parameters for resource exchange, including data volume, service type, and transaction costs. For instance, in the Helium project, devices that provide network access are rewarded with HNT tokens based on their contributions to the infrastructure.

Another essential aspect of token integration with technologies is the mechanism for resource accounting and automatic payment execution. Smart contracts must register resource usage and automatically debit tokens from users' accounts to compensate service providers. This ensures complete autonomy for devices in conducting transactions. Data security and confidentiality are achieved through encryption and decentralized protocol methods, such as Zero-Knowledge Proofs [33]. The integration of tokens with modern technologies relies on advanced tools, methods, and functionalities to ensure their versatility, efficiency, and adaptability across diverse ecosystems. Smart contracts are among the primary tools, automating transaction execution and enabling tokens to meet predefined conditions, thereby maintaining process continuity. Token integration methodologies include standardization and the use of APIs and SDKs (Software Development Kits), which simplify token implementation in applications and technologies [34]. Ethereum-based payment token standards, such as ERC-20, ERC-777, ERC-721, and ERC-1155 (for combined payment instruments), facilitate seamless interactions between tokens, platforms, and services.

Token functions, such as enabling access to big data, incentivizing participant activity, and providing computational power, further integrate tokens with modern technologies. APIs (Application Programming Interfaces) act as bridges between blockchain protocols and external applications, simplifying access to token functionalities and retrieving information about tokens' technical and economic characteristics. For instance, APIs like those from Etherscan provide real-time data on token metrics, including capitalization and transaction volumes, while Infura streamlines access to smart contracts for seamless integration. These tools enable tokens to interact with analytical platforms, IoT devices, AI systems, and Big Data solutions without requiring complex development processes.

Given the diversity of token functionalities, tokens can be classified based on their risks, functionalities, and complexities, enabling an effective assessment of their role within digital ecosystems. Risk analysis involves identifying key threats that could impact the token's stability and its trustworthiness among users. Specifically, volatility risks are linked to the speculative nature of certain tokens that lack a stable connection to real assets. Centralization risks arise when token management is concentrated within a narrow group of organizations, diminishing trust in the project. Additionally, security risks represent one of the most significant threats, as vulnerable smart contracts can become targets for hacker attacks, causing harm to both users and the broader ecosystem. The functionality of tokens determines their primary role within the system, allowing them to be categorized into several groups, which are outlined in the table below.

Table 8
Token Classification by Risks, Functionality, and Complexity

Token Type	Risks	Functionality	Complexity	Examples
Payment Tokens	High volatility, regulatory risks	Medium: Exchange of value, payments	Low: Basic transactional functionality	Bitcoin (BTC), Ethereum (ETH)
Utility Tokens	Market adoption, lack of demand	Medium: Access to platform services	Medium: Requires integration into platforms	Filecoin (FIL), Basic Attention Token (BAT)
Security Tokens	Regulatory compliance, legal risks	High: Represents ownership or investment	High: Subject to complex legal frameworks	tZERO, Polymath (POLY)
Stablecoins	Pegging risks, algorithmic failure	Medium: Stable value for transactions	Medium: Needs stable mechanisms for value	Tether (USDT), DAI
Governance Tokens	Low liquidity, governance attacks	High: Voting and governance in DAOs	Medium: Requires DAO or platform integration	Uniswap (UNI), Aave (AAVE)
NFTs (Non-Fungible Tokens)	Market speculation, low utility	Medium: Digital ownership and collectibles	Low: Simple creation but market-driven	Bored Ape Yacht Club (BAYC), CryptoPunks
Wrapped Tokens	Technical risks, reliance on collateral chains	High: Bridging assets across blockchains	High: Depends on interoperability protocols	Wrapped Bitcoin (WBTC), Wrapped Ether (WETH)

The scheme below illustrates the current complexity of integrating tokens with technologies. It highlights key components necessary for integrating tokens with financial systems and modern technologies, as analyzed above, showcasing the versatility and adaptability of tokens for integration within innovative technologies in a decentralized economy.

This scheme illustrates the logic behind integrating tokens as decentralized payment instruments with modern technological products to form a comprehensive ecosystem. At the core of this process is a tokenization platform that facilitates the creation, management, and destruction of tokens (mint/burn tokens), enabling their integration with traditional funds, DAOs, and other participants. The primary issuance of tokens (Primary Token Issuance) lays the groundwork for their utilization in secondary markets, including exchanges and OTC platforms, establishing an infrastructure for financial interactions. All operations are supported by identity verification processes (KYC), ensuring compliance with regulatory requirements and security for all participants.

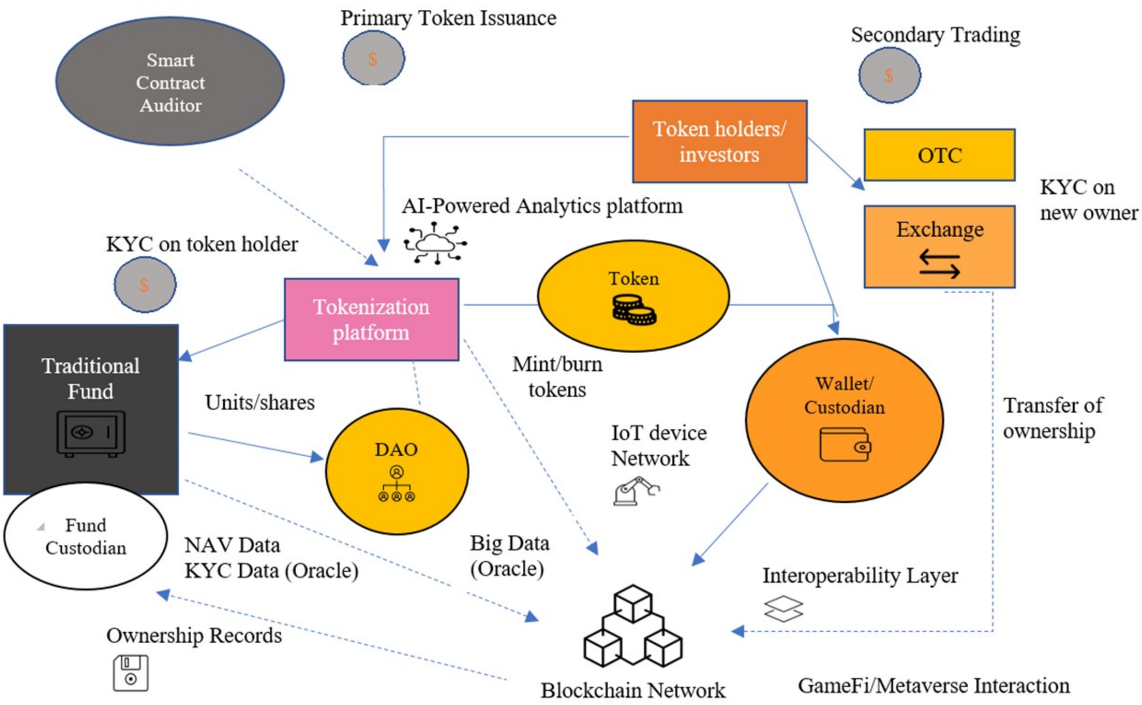

Figure 1: Integration of decentralized payment instruments with traditional and modern technologies

The further advancement of token integration relies on modern technologies such as artificial intelligence (AI-Powered Analytics Platforms), which optimize asset management; IoT networks, which enable efficient data collection and exchange; and Big Data, which enhances decision-making accuracy through advanced analytics. Additionally, the incorporation of tokens into the metaverse (GameFi/Metaverse Interaction) facilitates interactions between virtual assets and real economic processes through technological interoperability layers, which in some cases correspond to Layer 2 solutions in cryptocurrency architectures [35]. Blockchain technologies provide the foundation for decentralization and transparency across all financial transactions, fostering the development of infrastructure where tokens serve as a universal tool for modeling new forms of ownership, asset exchange, and the growth of the digital economy.

The integration of decentralized payment instruments with modern technologies requires specialized tools that provide essential functionality and meet technical requirements. The table categorizes these tools into key technical areas, clearly outlining their role in the development of innovative applications. The foundation of most DeFi solutions lies in platforms for smart contracts, which serve as core infrastructure. Ethereum, Polygon, and Ton Blockchain deliver high levels of decentralization, scalability, and support for tokenized assets. Additionally, oracles such as Chainlink and Band Protocol play a critical role in transferring external data, bridging the gap between the real world and the blockchain. For instance, platforms like IoTeX and IOTA offer mechanisms to automate transactions between IoT devices, enabling the development of micropayments and integrated smart contracts. Analytical tools such as The Graph and Covalent facilitate the collection, processing, and analysis of large datasets, enhancing liquidity management and risk mitigation in DeFi. The integration of artificial intelligence, represented by platforms like OpenAI API and SingularityNET, introduces automation in trading, lending, and forecasting market conditions, thereby expanding the horizons of financial innovation. The table below provides an overview of several tools for integrating DeFi with modern technologies.

Table 9
Tools for Integrating DeFi with Modern Technologies

Category	Examples	Features
Smart Contract Platforms	Ethereum, Polygon, Ton Blockchain, Binance Smart Chain	Provide the basic infrastructure for developing smart contracts, high decentralization, support for tokens, and DeFi applications.
Oracles	Chainlink, Band Protocol, API3	Enable integration of data from external sources (IoT, Big Data) into blockchain for use in DeFi.
Analytics and Big Data Tools	The Graph, Dune Analytics, Covalent, Flipside Crypto	Collect, index, and analyze large volumes of data for use in DeFi applications (liquidity, markets, trends).
IoT Integration Tools	IoTeX, Helium Network, IOTA	Connect IoT devices to blockchain, support microtransactions between devices, and enable smart contracts for automation.
Artificial Intelligence (AI)	OpenAI API, Hugging Face, Ocean Protocol, SingularityNET	Used for forecasting, optimization, credit scoring, and risk management in DeFi.
Development Frameworks	Hardhat, Truffle, Moralis	Tools for developing, testing, and deploying smart contracts and integrating DeFi into various applications (Web3, IoT, metaverse).
Metaverse and NFT Tools	Decentraland SDK, Sandbox Game Maker, Enjin, Aavegotchi	Tools for creating virtual economies and working with digital assets (NFTs, tokens, DAOs) in metaverses.
Token Management Tools	Uniswap SDK, Balancer, Gnosis Safe	Support for creating and managing tokens, liquidity pools, automated market makers (AMMs), and DeFi DAOs.
Data Storage Protocols	Filecoin, Arweave	Provide decentralized data storage for DeFi solutions, NFTs, metaverses, and Big Data.
Decentralized Exchange Platforms	Uniswap, Sushiswap, PancakeSwap	Protocols for decentralized token exchange, enabling automated token trading integration into various services (metaverse, IoT, Web3).

Another promising area is the integration with metaverses and NFTs. Tools such as Decentraland SDK and Enjin support the creation of virtual economies utilizing tokenized assets, which are increasingly integrated into DeFi. Metaverses are becoming platforms for decentralized exchanges, digital asset management, and economic models based on DAOs. The development of token management tools (e.g., Uniswap SDK, Balancer) and decentralized data storage protocols (e.g., Filecoin, Arweave) ensures a stable and scalable foundation for the adoption of innovations. This synthesis of DeFi and cutting-edge technologies forms the basis for creating new business models and transforming the financial ecosystem.

Conclusions

The integration of decentralized payment instruments with modern digital technologies, such as artificial intelligence, social networks, the Internet of Things (IoT), big data, and the metaverse, is reshaping traditional financial systems by introducing new models of automation, transparency, and accessibility. The use of artificial intelligence for risk prediction and liquidity optimization, IoT for dynamic interaction between physical devices and the blockchain, and decentralized identifiers (DID) for data protection and secure authentication significantly enhances the efficiency of financial processes. These advancements lay the foundation for a digital asset economy, unlocking opportunities for innovation in ownership, trade, and asset management. The potential for further development of such integration includes the creation of scalable solutions, deeper interaction between technologies and the real sector, and enhanced regulatory interoperability. These advancements will enable the establishment of decentralized ecosystems with global reach, offering extensive opportunities for businesses and society as a whole.

Declaration on Generative AI

While preparing this work, the authors used the AI programs Grammarly Pro to correct text grammar and Strike Plagiarism to search for possible plagiarism. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

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