ISSN-L 2664-9969; E-ISSN 2706-5448

UDC 336.71:330.322:004.9
JEL Classification: G10, G21, G23, C58
DOI: 10.15587/2706-5448.2026.357878

Oleksandr Manoylenko,
Svitlana Kuznetsova

IMPROVEMENT OF THE TYPOLOGY OF TOKENIZED FINANCIAL INSTRUMENTS

The object of research is the process of issuance and circulation of tokenized real-world assets (RWA), as the basis for the formation of digital financial instruments. The problem is the gaps in the typology of digital financial instruments, as a basis for expanding their issuance and circulation. Methods of content analysis of scientific literature and descriptive statistics of panel data, as well as methods of comparison and synthesis, typology and clustering serve as the methodological basis of this research, implemented on the basis of statistical data from the Statista and Market cap databases. The dynamics and changes in the structure of the tokenized real assets market are analyzed, clusters of related theoretical studies are identified. The rapid growth of the tokenized digital financial instruments market, which is moving from the "acceptance" stage to the "formation" stage, is substantiated. Two classes are distinguished in their structure: payment and investment. Payments are undergoing a stage of exponential growth and have already overtaken traditional payment systems in terms of total turnover. Investment is only being introduced in the financial market. The generalization of theoretical research allowed to identify the following contours of tokenization of real assets: legal, technological, informational. This became the basis for the allocation of the stages of emission and circulation of tokenized real assets and the formation of their topology. The practical significance of the results lies in determining the typology of tokenized RWA, which allows for their standardization, the formation of a regulatory framework and the personalization of financial instruments and payment services. The proposed typology connects real assets of different classes, takes into account the legal features of the functioning of financial markets, technological standards and identifies key participants in digital ecosystems. This approach allows to adapt/synchronize key elements of the formed digital financial architecture and regulatory and normative support.

Keywords: *finance, digital financial ecosystem, tokenized financial instruments, financial technologies, digital transformation, tokenization.*

Received: 17.02.2026
Received in revised form: 05.04.2026
Accepted: 16.04.2026
Published: 30.04.2026

How to cite
Manoylenko, O., Kuznetsova, S. (2026). Improvement of the typology of tokenized financial instruments. Technology Audit and Production Reserves, 2 (4 (88)), 88–97. https://doi.org/10.15587/2706-5448.2026.357878

1. Introduction

The formation of a hybrid financial architecture involves the transformation of traditional markets by introducing tokenization of real assets. The advantages of tokenization are the possibility of increasing the liquidity of real assets, 24/7 access to it (through the use of smart contracts that are automatically executed) and their division into shares. However, the lack of a unified and standardized typology does not allow for transparent mass issuance and wide circulation of tokenized instruments. The asymmetry between the possible market capitalization of tokenized RWA and the transaction efficiency of stablecoins (as payment instruments) indicates a transition from store-of-value to utility networks. With this approach, the ERC-3643/T-REX standards solve the issue of on-chain compliance, and the x402/ISO 20022 protocols solve the problems of integration into the traditional financial architecture. RWA tokenization reduces the costs of issuance and circulation, but hybrid financial models create legal uncertainty. One of the directions of the solution of which is typology for standardization and unification, as the basis of regulatory regulation and, accordingly, ensuring the scaling and development of digital financial ecosystems.

In the work [1, 2] it is noted that tokenization is the process of transforming financial assets into compatible and trust-minimized digital forms. This increases the reliability of transactions, facilitates and accelerates the exchange. The author identifies three elements, such as the legal relationship between the token and the underlying asset; the characteristics of the tokens and their infrastructure, as well as the ownership model. In interaction, these elements affect economic opportunities, legal certainty and technical guarantees.

Legally protected rights as the main legal form of the asset are embodied by direct tokens. This provides a clear possibility of transferring assets and high legal certainty. Indirect tokens represent rights to underlying assets. Their emission occurs through intermediary structures, they are also secured by assets. Complexity and potential uncertainty are created by the dependence of legal protection on the reliability of intermediary agreements. In contrast, incomplete tokenization can be compared to a "digital twin" with limited or no legal value [1].

Direct tokenization becomes the basis for technological neutrality and autonomy. It uses traditional contractual forms, such as loans for participation, minimizing the regulatory burden [3]. In turn, indirect tokenization can complicate the processes of ownership and transfer, as it requires compliance with securities market rules [1]. Hybrid models combine direct and indirect elements and form complex legal structures [1].

Tokenized financial instruments are also classified according to their functional and economic role. In [4] presents that cryptoassets encompass various categories such as cryptocurrencies, utility tokens, security tokens, tokenized assets and securities, and stablecoins. Cryptocurrencies are decentralized digital units of value that provide secure and transparent transactions. Utility tokens provide access to certain services or products on a blockchain network. Security tokens provide rights and powers similar to traditional securities, representing ownership of real

assets or participation in investment opportunities. Tokenized assets and securities are digital representations of tangible or intangible assets, allowing for fractional ownership and increased liquidity.

In [5], the conceptual difference between a currency token and a tradable utility token is only in the size of the crypto environment in which the token is used. Utility tokens combine a payment mechanism for customers with a utility component, and when traded on the secondary market, with an investment component.

Payment tokens are used for transactional payments with a variable regulatory regime and function as digital currencies [4].

Security tokens are key tools in decentralized finance. They take into account regulatory implications, but face interoperability and jurisdictional issues [6]. Hybrid and utility tokens have different functions for investment profiles due to innovative funding mechanisms [7].

Innovative hybrid tokens combine investment ownership with access functionality. This raises regulatory and economic challenges. Their dual nature requires new taxonomies, legal frameworks, and accounting methods that challenge traditional classifications. [2, 5, 8, 9]. Hybrid tokens serve multiple roles, such as investment, access, tradability, and incentive mechanisms [5, 10]. Programmable smart contracts integrate investment contracts with operational functionalities [6, 11].

In [12] demonstrates the utility and benefits of tokenized bonds. Blockchain-based tokenization has revolutionized the real-world assets (RWA) space, focusing on fixed-income securities such as bonds. In financial markets, tokenization – the process of converting ownership rights to physical assets into digital tokens on the blockchain – has become a revolutionary innovation that promises improved accessibility, liquidity, and transparency. Tokenization mechanisms, distributed ledger technology, and smart contracts simplify processes, reduce settlement times, and reduce the need for intermediaries.

Thus, global stock exchanges are witnessing an exponential growth in the volume of green bonds as the main source of financing for the energy transformation. In this regard, tokenization of green bonds can simplify access for potential investors [13]. Also, tokenization can potentially increase real estate investments by reducing the cost and simplification of legal procedures and diversifying ownership models [14].

These conclusions are confirmed in [15], which identifies the main directions of integration of decentralized finance and tokenization and the corresponding trends in the transformation of the financial landscape through their synergy.

Having grouped the scientific approaches highlighted in the literature, the following conclusions can be drawn. Firstly, tokenized financial instruments, their functional purpose is determined by the features of legal regulation and technological properties of blockchain platforms [1, 2, 4]. Secondly, tokenization, as a process based on blockchain technology and the features of smart contract formation that determine its properties, allows for the determination of ownership rights, which ensures high liquidity, but this causes problems in scaling processes due to the incompatibility of different technological protocols [4, 12]. Thirdly, the need to adapt hybrid tokens for cross-border transactions in terms of differentiation of regulatory legislation, which causes the need for harmonization of national legislative norms [5, 10]. Fourthly, tokenization introduces the principles of inclusion, increases liquidity and reduces transaction costs, at the same time, fragmentation and market volatility of asset values increase, which requires additional research and their implementation in the practice of market activity [7].

Thus, these works mainly highlight the technological features and regulatory issues of the tokenization processes of real assets, while practically ignoring the issues of forming a comprehensive typology of tokenized financial instruments, which would allow for the synergistic integration of digital financial technologies into the traditional finance sector. In addition, the features of the emission and circulation of tokenized real assets of various types and types were not considered. In addition, the definition of the financial sphere in practice is developing too quickly, which leads to a significant delay in the adoption of a legislative and regulatory framework that regulates digital financial instruments. As a result, the literature review creates a basis for understanding the main theoretical premises and approaches to forming a typology of tokenized financial instruments. Existing scientific developments allow to identify the contours of classification features by technological and legal forms and their connection with the economic essence. The additional introduction of the information circuit determines the connection of the Defi sector with traditional finance, which accelerates the implementation of technological developments and the harmonization of regulatory legislation of different jurisdictions. Also, there are gaps in the typology of digital financial instruments as a basis for expanding their emission and circulation. Thus, taking into account the literature review, the issue of forming a typology of tokenized financial instruments and identifying their patterns is relevant for research.

The object of research is the process of emission and circulation of tokenized real-world assets (RWA), as the basis for the formation of digital financial instruments.

The aim of research is to improve the typology of digital financial instruments as a basis for expanding their emission and circulation.

To achieve the set aim, the following objectives were solved:

1. To analyze the dynamics and structural changes in the market of tokenized real assets.

2. To develop a topological scheme of emission and circulation of tokenized real assets.

3. To propose a multi-level generalized typology of tokenized financial instruments.

2. Materials and Methods

The research of the typology of tokenized financial instruments (RWA, stablecoins, utility/security tokens) and their architecture in digital financial ecosystems was conducted using the methods of content analysis of the scientific literature Scopus/Web of Science for 2019–2026 and descriptive statistics of panel data using MS Excel 365 (Microsoft) and VOSviewer 1.6.20 software. Methods of comparison and synthesis, typology and clustering were also used.

The sources of information were secondary data from Statista, peer-reviewed articles. Bibliometric analysis was performed in VOSviewer (min 5 keyword matches), statistical processing – calculation of Tx/Cap ratio, with full replication in Excel for verification.

3. Results and Discussion

3.1. Dynamics and structure of the tokenized real assets market

The rapid growth of cryptoasset users (in 2018–2020, the growth was about 190%, then, stabilization in 2021–2022, continued growth starting in 2023) indicates that the tokenized assets market has moved from the "acceptance" stage to "emergence" as an alternative means of making operational payments and investing (Fig. 1).

This allows to identify two main prerequisites for the transformation of the financial architecture:

– recognition of cryptoassets (in the form of stablecoins) as payment instruments;

– implementation of cryptoassets and derivatives on this basis in the sphere of traditional finance.

The increasing personalization of financial instruments and financial services (as components of financial inclusion), the introduction of a regulatory framework for the circulation of tokenized real assets allow the formation of a hybrid financial architecture that is suitable for the new digital one. Considering that stablecoins are becoming the dominant class of cryptoassets, ensuring the circulation not only of the crypto market, but also being introduced as ordinary payment instruments, the structure of its provision is of crucial importance. The composition of USDT reserves is shown in Fig. 2.

ISSN-L 2664-9969; E-ISSN 2706-5448

Total assets of Tether Operations Limited used to provide off-chain USDT stablecoin support from Q4 2023 to Q1 2025 (in billions of USD).

Analysis of the structure of reserves of the most liquid stablecoin in the financial market shows that most of its issuance is secured by US Treasury bonds (in effect, it becomes legal tender). Also, a significant part is made up of fiat money liquidity instruments, which allows to quickly convert stablecoins into fiat funds and make payments in the real economy. And only a small part is made up of crypto market assets, or high-risk assets that can provide additional income to the issuer. In fact, stablecoins become a "bridge" between crypto and traditional financial markets.

If to analyze the number of transactions in crypto networks, it is possible to note that the dominance of a particular cryptocurrency is very volatile (Fig. 3). The largest number of transactions occurs in TRON, USDC, STELAR and AVALANCHI, their networks are characterized by very fast transaction execution, as well as the presence of technological and economic infrastructure for their use.

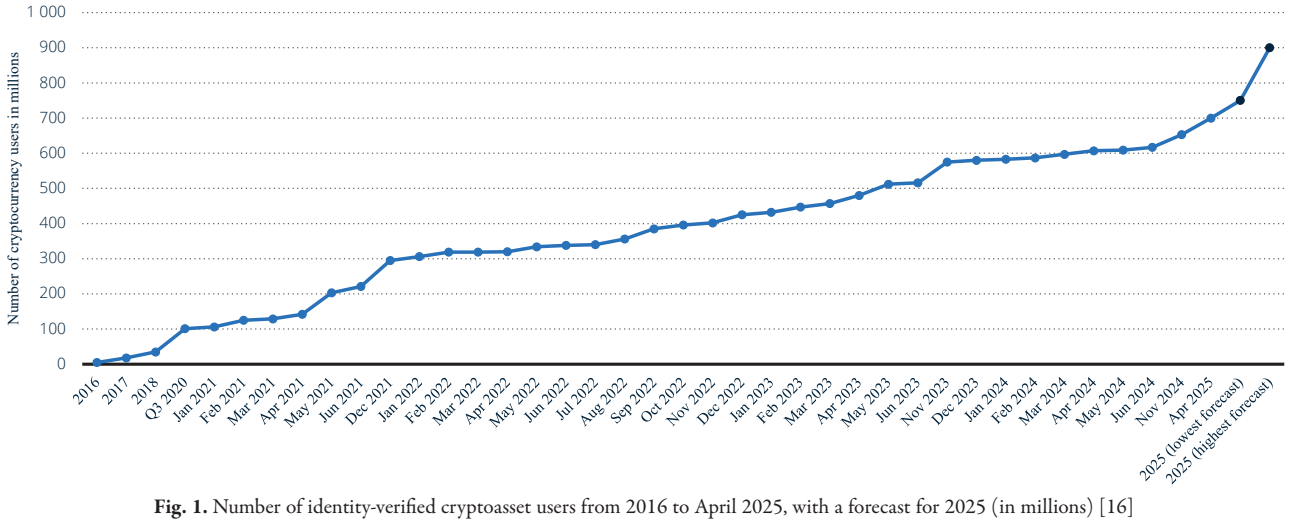

Fig. 1. Number of identity-verified cryptoasset users from 2016 to April 2025, with a forecast for 2025 (in millions) [16]

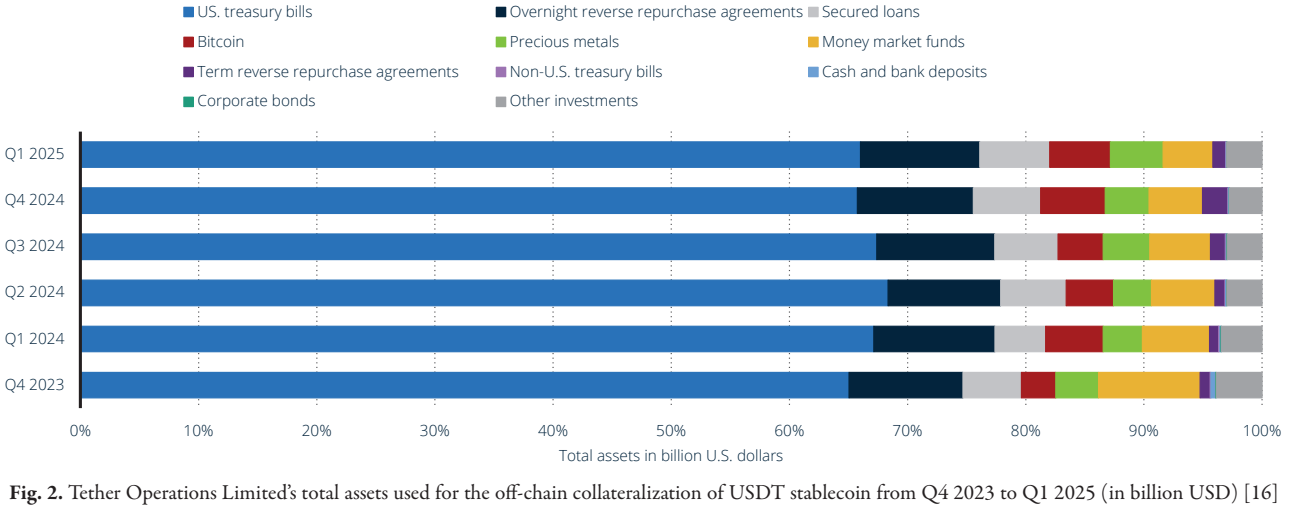

Fig. 2. Tether Operations Limited's total assets used for the off-chain collateralization of USDT stablecoin from Q4 2023 to Q1 2025 (in billion USD) [16]

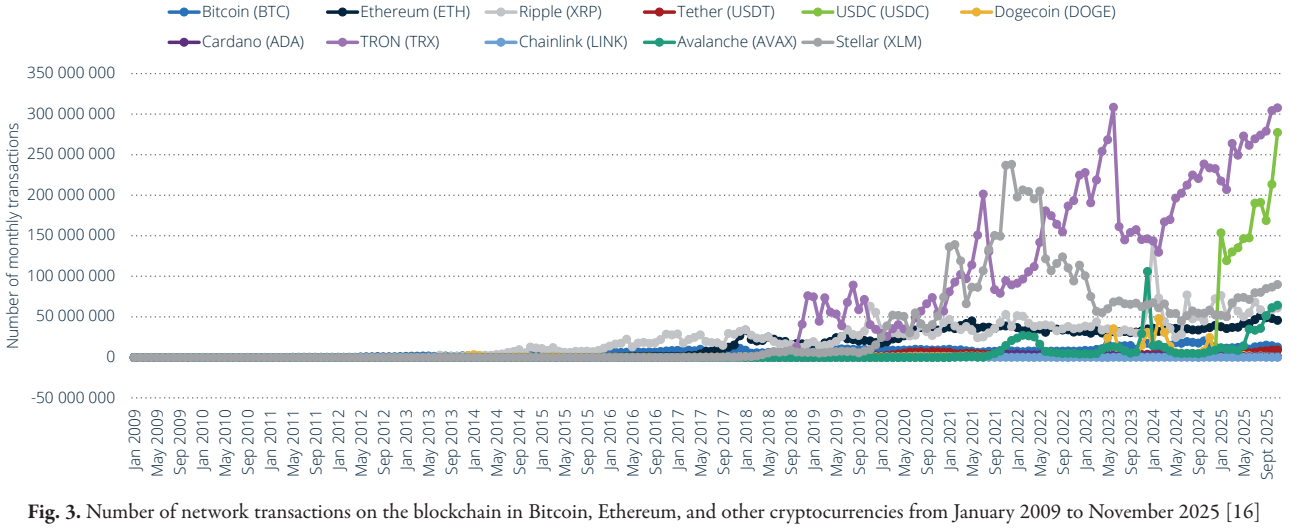

Fig. 3. Number of network transactions on the blockchain in Bitcoin, Ethereum, and other cryptocurrencies from January 2009 to November 2025 [16]

Analysis of the above Figs. 1–3 leads to the conclusion about the exponential growth of crypto markets and digital financial services. Moreover, the largest volume of transactions is provided by payment financial instruments, but in terms of market capitalization, the main crypto assets have the greatest weight, which is demonstrated by the data presented in Table 1 [16, 17].

Table 1

Ratio of monthly transactions to market capitalization of the top 4 cryptocurrencies for November 2025*

Crypto	Average monthly cryptocurrency value for November, USD	Cap dominance (%)	Transaction volume $T_{x\ volume}$ (million)	Transaction-to-market cap ratio $T_{x/cap\ ratio}$
BTC	95930	59	12.86	0.65
ETH	3178	12	45.67	11.20
TRX	~0.29	3	307.92	305.00
USDC	~1.00	~1	277.46	>700

Correlation with BTC dominance of 59% cap and ETH of approximately 12% control 71% of the top 125 market, but ETH is transactionally almost 3.5 times more efficient than BTC, which illustrates Metcalfe's Law [18], i. e. the value of the network is approximately n^2, where n is active users. TRX of almost 3% cap generates almost 24 times more BTC transactions. This signals decentralization in the direction of utility tokens (Table 1).

The identification of a two-layer structure of the cryptoasset market: dominance by capitalization and number of transactions confirms the conclusion that the underlying assets form the capitalization of the financial market, and payment instruments ensure continuous circulation and transfer of value. That is, Store-of-value (low frequency, high cap) forms investment financial instruments (tokenized RWA), stablecoins (via DeFi networks – ETH/TRX/USDC, as an example) – payment financial instruments that expand circulation and serve as the basis for scaling the digital financial architecture. The growth of transactions by 10^6 times since 2009 indicates the transformation and scaling of digital financial ecosystems, and the implementation of its tools in the form of digital financial instruments (tokenized RWA and stablecoins) into the traditional financial system.

3.2. Topology of emission and circulation of tokenized real assets

In a theoretical context, a review of scientific sources creates the basis for studying the typology of tokenized financial instruments. The article proposes the use of the method of constructing a bibliometric network. This method is aimed at clustering the relationships between key definitions of a certain subject area to determine the components of a certain concept and its correlation with other areas of research. The list of keywords for building a network is formed by importing from the abstract Scopus database (other databases were not considered in the article). For the visual representation of the relationships between keywords, the VOSviewer software environment developed by specialists from Leiden University [19] was used. The Scopus database contains 185 articles that mention the concept of tokenization of financial assets (financial instruments). The search was conducted using the phrase "tokenized financial instrument*" OR "tokenized asset*" OR "tokenized securit*" OR "asset tokenization" OR "security token*" OR "tokenized securit*" OR "security tokens". The search was limited only to economic scientific sources. A visual representation of the clustering of concepts for this sample is presented in Fig. 4, which proposes an abstract-logical method to identify a number of clusters directly related to the concept of "tokenized financial instruments" and a number of related subject areas.

The visual clustering performed in VOSviewer allowed to identify five main clusters of subject areas of research related to the tokenization of financial instruments. During the research, the following clusters were identified:

– crypto markets and digital fundraising;
– blockchain infrastructure and smart contracts of the financial market;
– DeFi and decentralized financial markets;
– tokenization of assets in business systems: investments, commerce and information systems;
– trust and cyber resilience of tokenized markets (cryptography/authentication/data security).

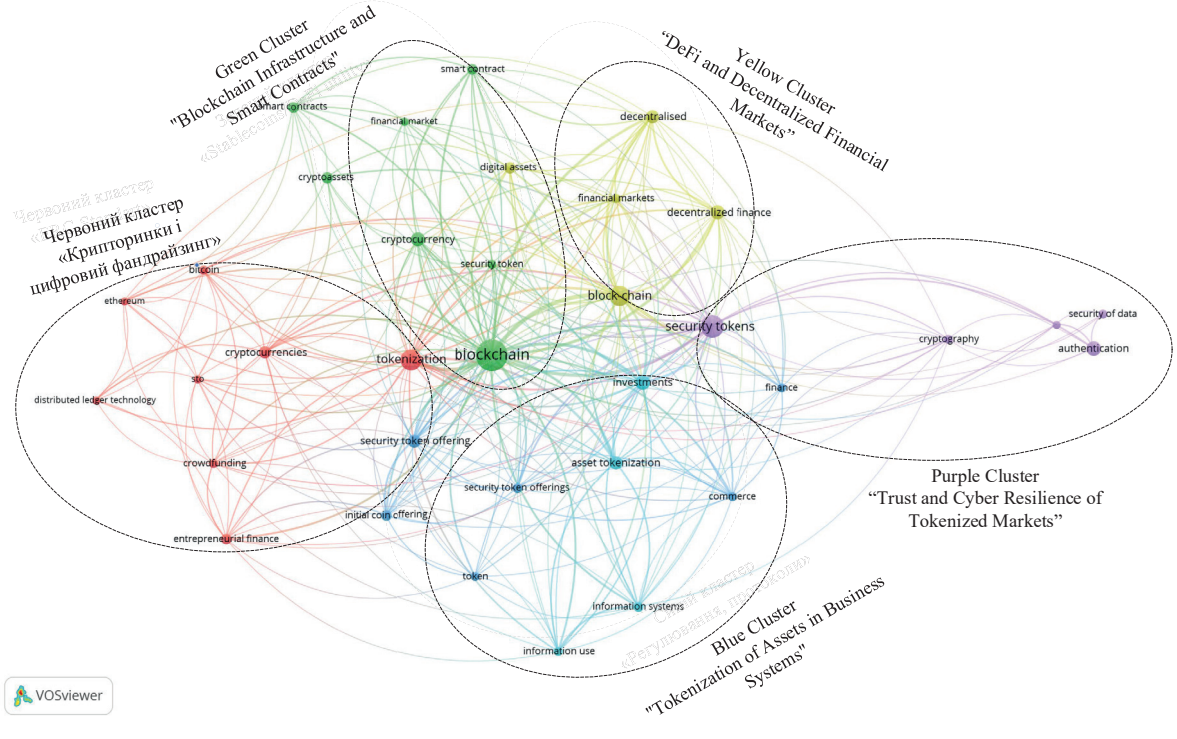

Fig. 4. Bibliometric network of the concept of "tokenized financial instruments" (constructed using VOSViewer)

ISSN-L 2664-9969; E-ISSN 2706-5448

Moreover, the central object of scientific research is the integration of blockchain infrastructure with security tokens. Accordingly, a topological scheme of tokenized financial instruments can be distinguished, which includes several contours that focus on the following areas: juridical or legal status; infrastructure (including technological standards) and information. In addition, it is necessary to identify key participants in the digital finance market, including those related to implementation and security; asset classes that are tokenized.

At the same time, scientific reviews confirm that tokenization is indeed considered as the creation of digital representations of assets on programmable platforms. Its "scaling" rests on interoperability, the quality of settlement assets and operational/legal risks that are "familiar, but evolving" in the new technological envelope. Moreover, the sustainable growth of tokenized markets depends on symbiotic technological innovations based on interdisciplinary research and adaptation of regulatory influences to new technological challenges.

The presented theoretical research allows to distinguish several contours of the topology of tokenization of real assets [1–15, 20, 21]:

1. *Juridical or legal.* Includes regulatory legal regimes of the functioning of digital financial markets (national jurisdictions); determination of the rights of the token owner to the asset (shareholder, creditor, receipt of dividends or capital gains, management of the underlying asset). This involves the creation of a special legal entity – the owner of the tokenization object to avoid the risk of bankruptcy or liquidation of the "parent company".

2. *The technological contour* includes various standards, protocols, applications. The standards include: standards for directly creating a token (as a key indivisible asset), standards for identifying the asset and a participant in the digital financial ecosystem. Among the protocols, it is necessary to highlight: turnover, emissions and valuation (determination of value/price) of the tokenized asset (blockchain platforms, cross-chain bridges, oracle protocols); data storage, security and asset accounting.

3. *The information contour* that connects digital financial markets of tokenized real assets with the traditional finance sector.

The most significant circuit or technological core of tokenization of real assets, which should be highlighted separately, is the blockchain infrastructure and smart contracts, which become the basis for the formation of the technological infrastructure for the functioning (emission and circulation) of digital financial instruments. Blockchain in this context acts as a distributed ledger with an immutable transaction history, and smart contracts ensure the automatic execution of the business logic of transactions.

Participants in the digital financial ecosystem:

– issuers;
– tokenization platforms and ensuring the functioning of the tokenized asset market infrastructure (market makers);
– identification (validation);
– compliance monitoring and audit;
– investors (institutional and individual);
– regulatory and supervisory authorities.

Tokenized asset classes. The most generalized groups of assets can be distinguished: debt instruments; real estate, raw materials and goods, equity, shares, shares or derivative financial instruments of investment funds, "green finance". A separate group can be distinguished by unique assets (objects of art, intellectual property objects, sports rights, etc.).

When forming a digital financial infrastructure for the emission and circulation of tokenized financial assets, their class is the basis, which determines the application of technical standards and legal aspects of tokenization. In accordance with this, the necessary participants of the digital financial ecosystem are involved.

The relationship between the asset class and the tokenization standard is determined by the physical nature of the asset and the interchangeability of its components, as presented in Table 2.

Table 2

The relationship between the nature of the asset and the tokenization standards (the relationship between the nature of the asset and the technical outline)

Physical nature of the asset/Substitutability	Fungible	Non-fungible
Tangibility	Category 1. Commodities, energy resources, standardized industrial goods, construction materials/ ERC-20, ERC-1400	Category 2. Real estate, works of art, luxury goods, equipment, infrastructure/ ERC-721, ERC-1155
Non-Tangibility	Category 3. Financial instruments (stocks, bonds), carbon credits, revenue streams, digital currencies/ ERC-20, ERC-1400	Category 4. Intellectual property, licenses, digital rights, legal documents/ ERC-721, ERC-1155

Several key standards are used for tokenizing real assets and their circulation. ERC-20 is a basic standard for fungible tokens that does not contain internal rules. ERC-1400 is a standard for securities tokens that includes a limited number of rules. ERC-721 is a standard for non-fungible (NFT) tokens that are used for unique assets (works of art, individual real estate, etc.).

In addition, there is a class of hybrid token standards:

ERC-1155 is a multi-token standard that supports fungible and non-fungible tokens in a single smart contract.

ERC-3643 (T-REX) is the only officially adopted ERC standard for regulated tokenized assets, which has a modular architecture and allows the token to change state between fungible and non-fungible depending on the use case.

The presented relationship determines the technical aspect of tokenization of real assets, i. e. their emission.

On the other hand, it is necessary to analyze the payment infrastructure that allows for transactions on the transfer of ownership rights (PvP and DvP), which uses various payment networks and protocols. Among the main payment protocols, it is necessary to highlight: x402 is an open, decentralized payment protocol developed for Web3 payments, HTTP 402; L402 is based on the HTTP 402 code, but uses an existing network, the ILP protocol, connecting various payment networks (banks, blockchains, mobile wallets).

Separately, it is necessary to highlight the ISO 20022 standard, which was created for the exchange of financial data between banks and traditional payment systems, it ensures the transfer of structured payment information along with the money itself. FinTech companies – developers of blockchain networks (for example, Ripple or Stellar) strive for their full compatibility with ISO 20022 with the aim of forming a hybrid financial architecture.

In addition, it is necessary to highlight the standard or protocol AP2 for automated payment interaction of digital intelligent agents (payments between AI agents). A generalized characteristic of the main digital payment instruments is presented in Table 3.

Transactions for the transfer of property rights (PvP and DvP) act as the financial and economic core of the system that connects all participants in the digital financial market. The connection with traditional financial markets is provided by oracles and custodians, which form the information circuit.

The legal-law circuit serves to ensure the security of transactions, the preservation of investor funds and a guarantee of transactions. The topology of RWA tokenization is presented in Fig. 5.

Table 3

Characteristics of the main digital payment instruments [1–12, 20, 21]

Tokenized asset class	Issuer	Legal and accounting nature	Access	Networks	Typical role in RWA tokenization
Deposit tokens	Commercial bank	Deposit liability	Permissioned	Permissioned DLT or EVM networks	Institutional cash legs for DvP/PvP:
Stablecoins	Financial institution, fund, DeFi organization	reserve-backed, crypto-collateralized, algorithmic/hybrid	More often public, sometimes permissioned version	Public L1/L2, cross-chain bridges	Universal onchain cash legs: settlements, liquidity
Wholesale CBDC	Central Bank	Central Bank digital money	Permissioned	Permissioned DLT or hybrid DLT+RTGS;	Cash legs for interbank DvP
Retail CBDC	Central Bank	Central Bank digital money	Permissioned	National CBDC platform	Cash legs for mass settlements and capital markets
Tokenized Money Market Funds MMF	Management company/fund	Securities/part of fund	Permissioned	Public networks (EVM) or permissioned DLT	"Quasi-money" for parking liquidity and collateral

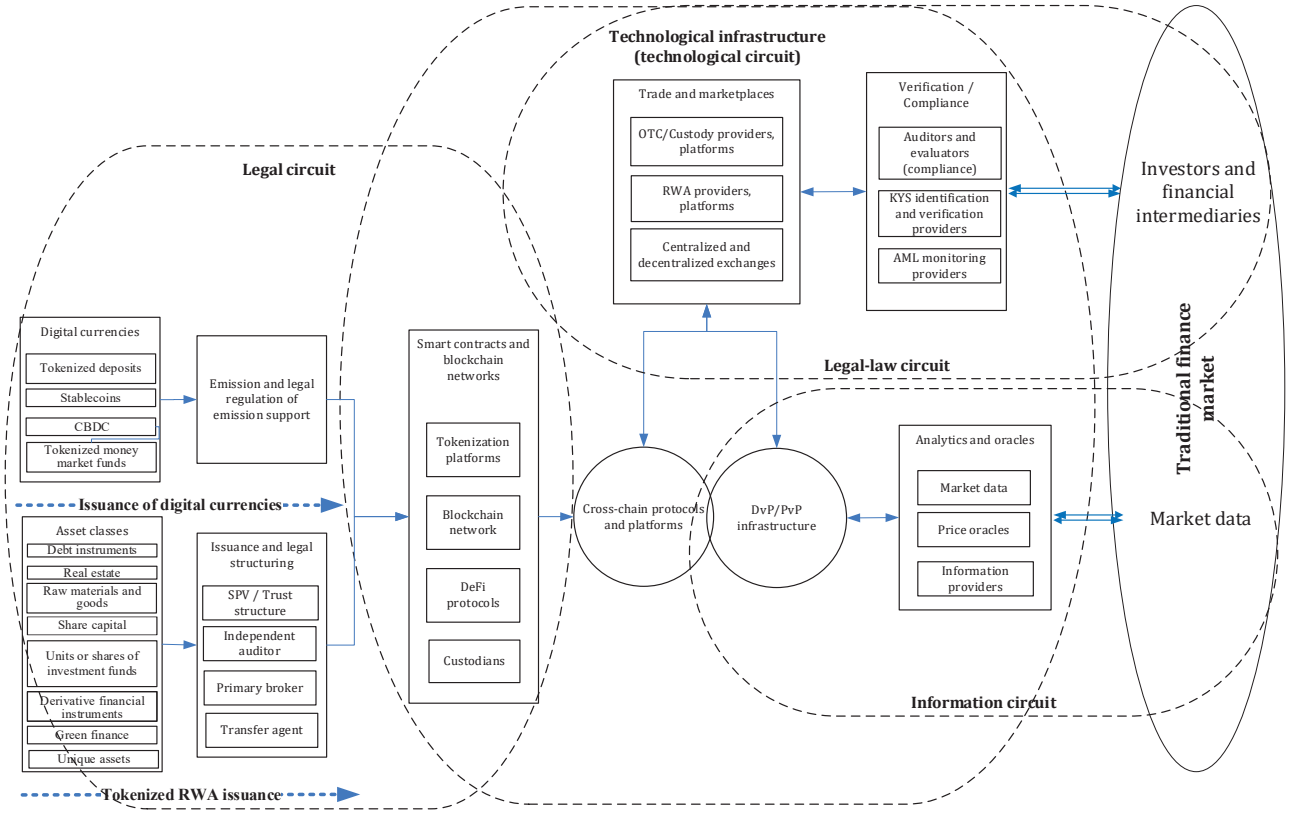

Fig. 5. Scheme of the topology of the emission and circulation of tokenized real assets

First of all, it should be noted that the largest scale of the financial market for tokenized assets is occupied by such a financial instrument as a stablecoin (a token backed mainly by US Treasury securities).

If to consider the market for tokenized RWA (non-payment financial instruments), it showed growth from 114M USD in 2023 to 5.9B USD in 2025 [20]. It can be noted that the greatest growth is observed in the sector of tokenization of standardized, regulated assets (mainly treasury bonds), on the contrary, only pilot projects are observed for the issuance of such assets as real estate, raw materials, and works of art. This can be explained by the fact that there is practically no secondary market for such tokenized RWA due to low liquidity and regulatory problems. Among the tokenized commodity assets that show rapid growth, one can single out gold and silver tokens and pilot projects for trading tokenized oil (i. e. standardized commodities that show significant turnover in the traditional financial market).

Among the most successful examples of tokenization, it is worth noting the experience of BlackRock BUIDL (occupies 40% of the market and demonstrates exponential growth) [22]. The fund is based on the regulatory legislation of the Securities Act, uses key blockchain protocols (from the top 10 of the market) and invests exclusively in US Treasury bonds, and the fund's shares can be used as collateral for credit and investment instruments. Ondo Finance is the first platform for tokenized Treasuries, investing mainly in BlackRock BUIDL [22]. In addition, in 2025 the platform received a registered broker-dealer license for trading tokenized securities in the USA.

In terms of tokenization of money market funds, it is necessary to highlight the experience of JPMorgan – the Kinexys platform (turnover 1.5T USD), which provides financial services with Digital Payments (tokenized deposits 24/7) and Digital Assets (tokenized collateral) [22]. Another example of implementing RWA tokenization is the

ISSN-L 2664-9969; E-ISSN 2706-5448

Coinbase Base JPMD deposit token, which is subject to FDIC insurance. Among its key partners, it is worth highlighting: B2C2, Coinbase, Mastercard, J.R Morgan. It is also worth noting Franklin Templeton FOBXX – the first SEC-registered mutual fund that uses a public blockchain as a system of record. It uses more than 10 blockchain platforms: Ethereum, Polygon, Base, Arbitrum, Avalanche, Aptos, Solana, BNB Chain and Canton Network. EIB, HSBC Orion and Project Guardian – have become issuers of institutional European digital bonds. Among the problematic examples of RWA tokenization, organizations operating exclusively in the DeFi market should be highlighted. Yes, Celsius Network, which used hundreds of millions of customer deposits to manipulate the price and froze payments.

Terra/LUNA – reached a market capitalization of 60B USD through the issuance of the algorithmic stablecoin UST. However, due to the additional issuance of tokens from 400M to ~32B, froze payments, and the token suffered hyperinflation [22].

Among the defaults on credit protocols, Maple Finance should be highlighted – the company was liquidated. In 2022, defaults accounted for 66% of the protocol's total active loans (with a 50% drop in capitalization) [22].

3.3. Multi-level architecture of the typology of tokenized financial instruments

The above studies necessitate the construction of a typology scheme for digital financial instruments and the definition of the topology of its construction. A generalized scheme of the typology of financial instruments based on the separation of the main components of the hybrid financial architecture is presented in Fig. 6.

The technical basis for the functioning of payment systems and networks for the circulation of financial assets (tokenized real assets) are blockchain protocols of the first, second levels and multi-chain protocols. Their placement on exchanges is based on automated registers, order and combined solutions. Payment protocols perform the functions of: payment networks (streaming payments), group transfers, subscription models, inter-network transfers.

At the same time, crypto-assets are divided by the degree of collateralization into: secured by real assets (government or municipal bonds, raw materials, goods, etc.), other crypto-assets or those with algorithmic support, as well as unsecured.

In turn, tokenized real assets can be divided into derivative synthetic financial instruments: stocks, goods and raw materials, currency, index, real estate (which are based on real assets). A separate block is non-personalized protocols and derivative tokenized financial instruments based on decentralized indices and ETFs, as well as non-fungible tokens – NFTs (areas of application: culture and art, multimedia, etc.).

The value of cryptocurrencies and tokenized assets is determined based on: centralized data sources, aggregated data from differentiated sources, time-weighted average prices (external data). Data within a separate blockchain protocol (network), which serves as the basis for cross-chain or cross-platform arbitrage.

Transactions with tokenized assets and cryptocurrencies can be carried out by forming appropriate pools: they can be mono-active, multi-product, stabilization or with a weighted structure of assets of various types. At the same time, passive income can be obtained by placing in liquidity pools (to ensure exchange operations), algorithmic pools, as well as during the liquidation of positions.

The main financial instruments that are formed from tokenized real assets based on the application of technological protocols, the use of intelligent agents and the formation of smart contracts include: risk management, financial services, derivative financial instruments and arbitrage operations.

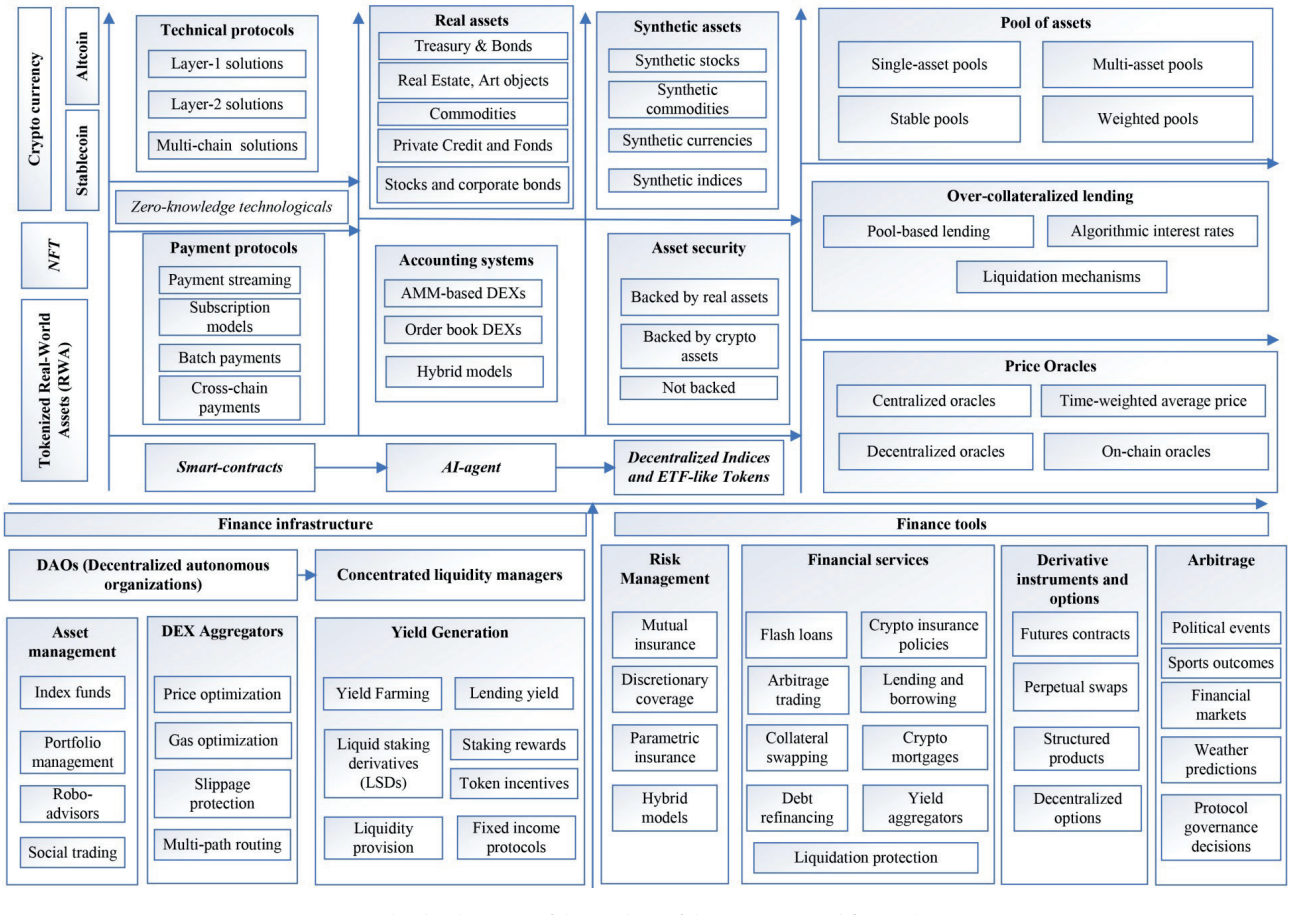

Fig. 6. Generalized architecture of the typology of the main tokenized financial instruments

DeFi institutions can be conditionally divided into DAOs that manage assets and DEX aggregators (including centralized and decentralized crypto exchanges). Separately, there are yield generators, in which liquidity is placed in the form of cryptocurrency or tokenized financial instruments, which allows to receive a conditionally fixed income with minimal risks.

Digital financial infrastructure, thus, allows to distinguish a typology of digital financial instruments, which includes: risk management, financial services, derivatives and options (derivative financial instruments) and financial instruments for arbitrage on sports, political and other events.

Fig. 7 shows a generalized scheme of payment and investment DeFi services in their relationship with the financial services market, which is based on traditional financial architecture.

Investment digital financial instruments were disclosed in detail in the previous figure, but it can be noted that in general they can be further divided into: active, passive and invested in the development of digital infrastructure. That is, from the point of view of obtaining income from investments in crypto assets, it can have different forms: with a fixed return (in the development of digital financial infrastructure), as well as be implemented through active and passive investment.

As for payment financial instruments, they can be divided in general into: transit (connecting digital assets and fiat currencies), liquidity aggregators, storage of digital assets; transaction security (DvP/PvP solutions).

The transfer of crypto assets to fiat assets can be carried out through the banking system, special accounts through exchange platforms (closely related to liquidity pools), as well as through direct p2p transfers.

Crypto assets can be stored with a link to a specific real financial asset or currency, serve to optimize taxation (depending on the jurisdiction) and exist in an impersonal form. Storage can be carried out on cold (physical media) and hot (digital) wallets, on exchange and investment accounts, as well as in tokenized assets.

By linking to bank and virtual cards (fintech companies in a number of jurisdictions have received banking licenses), instant mediated cross-border financial transfers can be made. In addition, the use of blockchain networks such as Solana, Etherium, XPR and others in the activities of such payment services as Visa, MasterCard allows for transactions with tokenized assets (in the investment sector) and the receipt of real goods and services in the consumer market, and for transfer operations on both national and international markets.

The typology of tokenized instruments in the research is presented in the form of a multi-level architecture and solves the dilemma of legal uncertainty [1]. In contrast to existing studies, a dualistic market structure is traced, where BTC dominates cap about 59% and accumulates value, but does not generate the main volume of transactions. TRX and USDC outperform tx-efficiency by 305x and 700x, respectively, and generate liquidity. This is explained [18] by the fact that the value of the network is formed not only through the scale of capitalization, but through the intensity of use.

3.4. Limitations and directions of research development

The practical significance of the results lies in determining the topology of emission and circulation of tokenized RWA, which allows reducing costs, accelerating turnover and transaction time, ensuring 24/7 liquidity and personalizing financial instruments and payment services (without unnecessary costs). The proposed architecture of the multi-level typology connects real assets of different classes, takes into account the legal features of the functioning of financial markets, technological standards and identifies key participants in digital financial ecosystems. This approach allows for the subsequent adaptation/synchronization of key elements of the formed architecture of typologically homogeneous financial instruments with standardized protocols and platforms based on blockchain technologies with their regulatory and normative support, in contrast to [5] when forming a hybrid financial architecture.

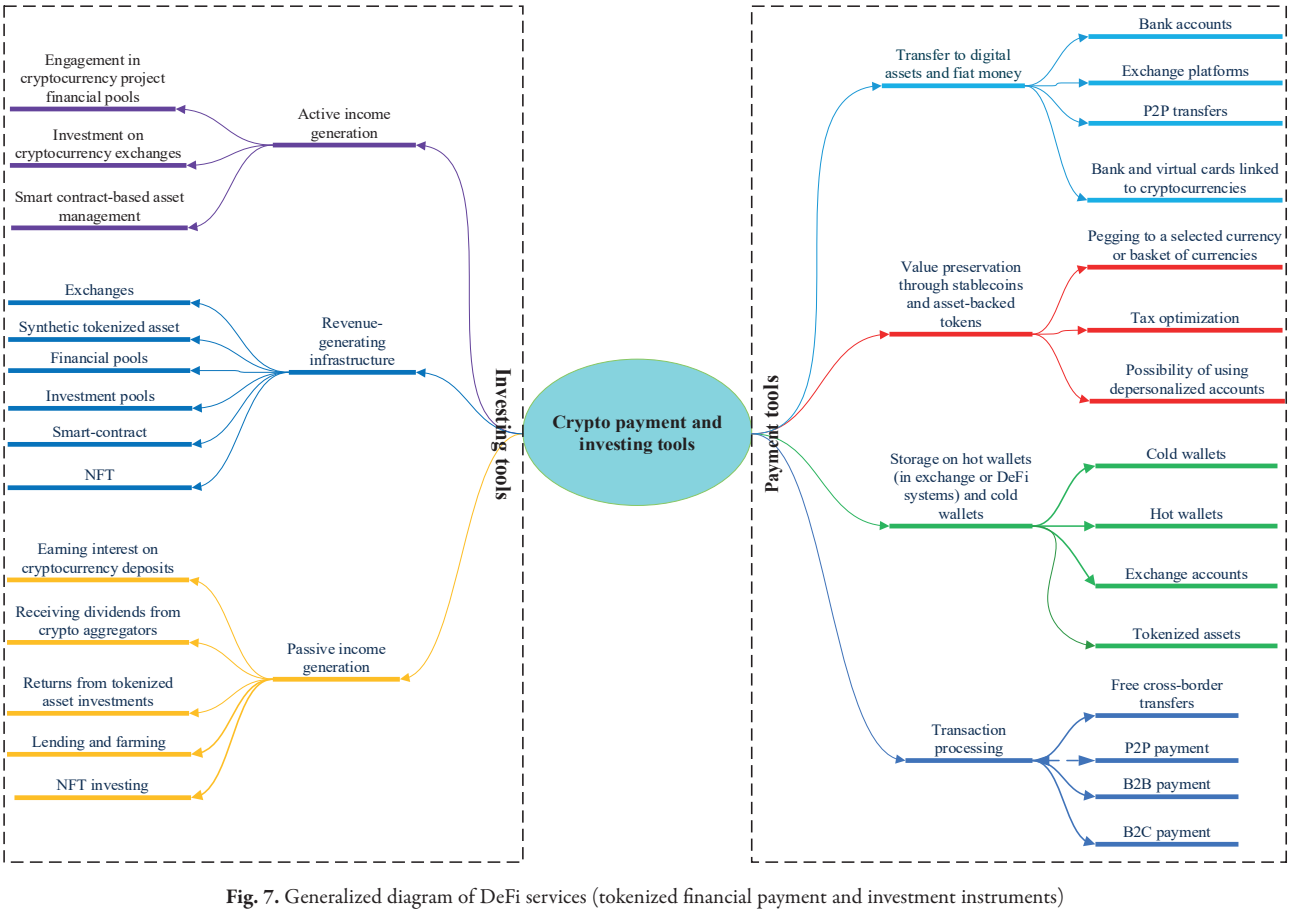

Fig. 7. Generalized diagram of DeFi services (tokenized financial payment and investment instruments)

ISSN-L 2664-9969; E-ISSN 2706-5448

The limitation of the research is the formation of the architecture of the multi-level typology only on public data, but corporate (permissioned) solutions require a separate study (due to the limitation of public information about the functioning of these networks). It should also be emphasized that this research has additional limitations: its qualitative nature does not provide a comprehensive quantitative assessment, and the rapid pace of innovation in the DeFi sphere may change some elements of the digital financial infrastructure. However, the results obtained open promising directions for future research, including quantitative assessment of the effectiveness and scalability (replication) of RWA tokenization, analysis of the sustainability of decentralized systems and the behavior of investors and consumers of financial inclusion services within the CeDeFi sector.

Possible directions for research development include the development of econometric models and metrics for assessing RWA portfolios taking into account regulatory risks.

4. Conclusions

1. According to the research results of the dynamics of the tokenized RWA issuance and circulation market, it was determined that the payment instrument sector under the PvP and DvP protocols is experiencing exponential growth in transactions and circulation. The dynamics of the tokenized asset market is characterized by an exponential growth in transactions of 106 times since 2009. The RWA issuance topology covers 8 levels such as L1 DLT and MTF markets with ERC-3643/T-REX as a compliance hub, which reduces regulatory costs by 85% compared to ICO. CeDeFi standardization for banks/DAOs, increasing 24/7 liquidity. The number of users of tokenized payment instruments, the collateral of which is liquid RWA (US Treasury bonds, precious metals and short-term deposits, etc.), is also growing sharply. In general, tokenized payment instruments exceed the turnover of traditional payment systems in terms of total circulation. But the potential of tokenized financial investment instruments remains unrealized, only the market of tokenized precious metals shows dynamic growth. Thus, tokenization becomes a systemic process that causes the transformation of the global financial architecture. This necessitates the typology of tokenized financial instruments as the basis for their standardization and unification of the legal environment of operation.

2. A topology of the emission and circulation of tokenized real assets has been developed, which includes a legal, technological and information circuit that connects the DeFi and traditional finance markets. The features of the emission and circulation processes of tokenized RWA are determined by the nature of the real asset, which determines the tokenization standard and forms a technological circuit – a digital financial infrastructure. The elements of which include: protocols, networks, platforms and smart contracts. The connection of DeFi and traditional finance markets determines the legal contour, which allows to identify key market participants and justifies the features of regulatory procedures. The information contour allows to link tokenized RWA with traditional finance markets in terms of value. The presented scheme of the topology of the emission and circulation of tokenized RWA from the allocation of payment (PvP (stablecoins), DvP) and investment (DAO/DEX pools) protocols and platforms allows to justify the features of the development of the DeFi and CeDeFi markets at the theoretical level. The gradual development of the technological, legal and information contour justifies the stages of emission and the market volume of different in nature tokenized RWA assets, which moves from the most standardized and interchangeable to non-standardized and non-interchangeable. This approach allows for the formation of directions for the gradual resolution of legal uncertainty, technological complexities and cost determination of tokenized RWAs of different nature, which reduces spreads and forms a close relationship between the DeFi and TradFi markets. This allows for the implementation and scaling of DeFi technologies in the financial market, which reduces the issuance and circulation time and ensures greater personalization of financial services (financial inclusion) by introducing new types of digital financial instruments.

3. The architecture of a multi-level typology of tokenized financial instruments has been proposed, which generalizes the classification features of the nature of real assets, the processes of their tokenization and turnover in connection with key elements of the infrastructure and, accordingly, the technological, legal and information circuit. The basic level is determined by the nature of real assets, which determines technological and payment protocols and allows for the tokenization of derivatives. The features of accounting and securitization systems (guarantee systems) allow for the formation of asset pools and the development of derivative financial instruments and services. The connection of smart contracts, AI agents and derivative financial instruments identifies financial market participants that, on a decentralized basis, carry out liquidity management in close connection with the TradFi market by using price indicators of various types. This allows to highlight key financial instruments related to: risk management, financial services, derivatives and arbitrage operations. Such a multi-level architecture typology becomes the basis for the formation of an integrative hybrid digital financial architecture (CeDeFi), which is based on the allocation of key DeFi services. The use of such an approach allows for the standardization of tokenized financial instruments based on the allocated components and the unification of the regulatory framework for certain national economies. The implementation with subsequent replication of pilot projects of RWA tokenization in the DeFi sector becomes the basis for the transformation of the market of traditional financial services. In addition, such an approach becomes the basis for structural changes in the DeFi market – the transition from the value dominance of underlying crypto assets to the scaling of the market of tokenized financial instruments. This increases financial inclusion, personalization of service provision, accelerates transactions and allows for a more clear separation of the risks of tokenization of real assets and the implementation of transactions. Due to the significant segmentation of the DeFi sector of the financial market, further research is related to the development of tools for the formation of digital financial hubs and cross-chain bridges to ensure close integration of tokenized RWAs between individual CeDeFi segments and certain national jurisdictions.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The research was performed without financial support.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies in creating the submitted work.

Authors' contributions

Oleksandr Manoylenko: Methodology, Validation, Investigation, Resources, Data curation, Writing – original draft, Writing – review and editing, Visualization, Supervision, Project administration,

Funding acquisition; ***Svitlana Kuznetsova***: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review and editing, Supervision, Project administration, Funding acquisition.

References

1. Lavayssière, X. (2025). Legal Structures of Tokenised Assets. *European Journal of Risk Regulation,* 1–13. https://doi.org/10.1017/err.2024.88
2. Lavayssière, X. (2024). Research Note on the Heterogeneity of the Tokenization of Financial Assets. *2024 6th Conference on Blockchain Research & Applications for Innovative Networks and Services (BRAINS).* Berlin: IEEE, 1–2. https://doi.org/10.1109/brains63024.2024.10732456
3. Arrieta-Sevilla, L. J. (2025). La inversión inmobiliaria directa a través de tokens. *Revista de Derecho Civil, 12 (2),* 77–115. Available at: https://hdl.handle.net/10171/116945
4. Benedetti, H., Smith, S. S.; Baker, H. K., Filbeck, G., Black, K. (Eds.) (2024). Cryptoassets and Fintech. *The Emerald Handbook of Fintech.* Emerald Publishing, 267–281. https://doi.org/10.1108/978-1-83753-608-520241034
5. Boreiko, D., Ferrarini, G., Giudici, P. (2019). Blockchain Startups and Prospectus Regulation. *European Business Organization Law Review, 20 (4),* 665–694. https://doi.org/10.1007/s40804-019-00168-6
6. Momtaz, P. P.; Baker, H. K., Benedetti, H., Nikbakht, E., Stein Smith, S. (Eds.) (2023). Security Tokens. *The Emerald Handbook on Cryptoassets: Investment Opportunities and Challenges.* Emerald Publishing, 61–78. https://doi.org/10.1108/978-1-80455-320-620221005
7. Nowak, K. A., Wiśniewski, M., Litwiński, M. (2024). Is It Worth Investing in Tokens? Investment Performance of Digital Tokens in Financial and Axiological Contexts. *Journal of the Knowledge Economy, 16 (1),* 663–690. https://doi.org/10.1007/s13132-024-01962-5
8. Yatsyk, T., Shvets, V. (2020). Cryptoassets as an emerging class of digital assets in the financial accounting. *Economic Annals-XXI, 183 (5–6),* 106–115. https://doi.org/10.21003/ea.v183-10
9. Parrondo, L. (2020). DLT-based Tokens Classification towards Accounting Regulation. *Proceedings of the 2nd International Conference on Finance, Economics, Management and IT Business.* SciTePress, 15–26. https://doi.org/10.5220/0008937600150026
10. Herschaft, J. A., Gitlitz, M. A. (2019). Heads or tails? Making sense of crypto-tokens issued by emerging blockchain companies. *The Banking Law Journal, 136 (6).* Available at: https://www.blankrome.com/publications/heads-or-tails-making-sense-crypto-tokens-issued-emerging-blockchain-companies
11. Subramanian, H. (2019). Security tokens: architecture, smart contract applications and illustrations using SAFE. *Managerial Finance, 46 (6),* 735–748. https://doi.org/10.1108/mf-09-2018-0467
12. Mirdala, R. (2025). Tokenization of Real-World Assets: Legal Frameworks, Market Dynamics, and Policy Pathways for a Decentralized Financial Future. *Journal of Applied Economic Sciences (JAES), 20 (16),* 285. https://doi.org/10.57017/jaes.v20.2(88).09
13. Pramudya, H., Alamsyah, A., Tricahyono, D. (2024). Blockchain-Based Tokenization for Green Bonds: A Model for Transparency and Compliance in Sustainable Finance. *2024 IEEE Asia-Pacific Conference on Geoscience, Electronics and Remote Sensing Technology (AGERS).* Manado: IEEE, 64–69. https://doi.org/10.1109/agers65212.2024.10932908
14. El Jaouhari, A., Samadhiya, A., Kumar, A., Chokshi, H., Šešplaukis, A., Raslanas, S. (2025). Tokenization and the future of property investment: A new paradigm for real estate. *International Journal of Strategic Property Management, 29 (4),* 297–315. https://doi.org/10.3846/ijspm.2025.24814
15. Bhatia Sarin, A.; Vardari, L., Qabrati, I. (Eds.) (2024). Understanding of Decentralized Finance and Tokenization in FinTech. *Decentralized Finance and Tokenization in FinTech.* IGI Global Scientific Publishing, 285–309. https://doi.org/10.4018/979-8-3693-3346-4.ch016
16. *Statista.* Available at: https://www.statista.com/
17. Historical cryptocurrency market capitalizations. *CoinMarketCap.* Available at: https://coinmarketcap.com/
18. Wheatley, S., Sornette, D., Huber, T., Reppen, M., Gantner, R. N. (2019). Are Bitcoin bubbles predictable? Combining a generalized Metcalfe's Law and the Log-Periodic Power Law Singularity model. *Royal Society Open Science, 6 (6),* 180538. https://doi.org/10.1098/rsos.180538
19. Visualizing scientific landscapes. *VOSviewer.* Available at: https://www.vosviewer.com/
20. Analytics on Tokenized Real-World Assets. *RWA.xyz.* Available at: https://app.rwa.xyz/
21. Suresh, R., Kumar, S., Liu, D., Kronfellner, B., Kaul, A. (2022). Relevance of On-Chain Asset Tokenization in "Crypto Winter". *Boston Consulting Group.* Available at: https://www.bcg.com/publications/2022/relevance-of-on-chain-asset-tokenization
22. *ForkLog.* Available at: https://forklog.com/

Oleksandr Manoylenko, *Doctor of Economic Science, Professor, Head of Department of Accounting and Finance, National Technical University "Kharkiv Polytechnic Institute", Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0001-5979-4077*

✉ ***Svitlana Kuznetsova,*** *PhD, Associate Professor, Department of Accounting and Finance, National Technical University "Kharkiv Polytechnic Institute", Kharkiv, Ukraine, e-mail: Svitlana.Kuznetsova@khpi.edu.ua, ORCID: https://orcid.org/0000-0002-1567-4791*

✉ *Corresponding author*