Soul Bound Token as Digital Twins in Peer-to-Peer Economic Systems

Denys Virovets[1], Sergiy Obushnyi[1], Andrii Ramskyi[1], and Hennadii Hulak[1]

[1] *Borys Grinchenko Kyiv Metropolitan University, 18/2 Bulvarno-Kudriavska str., Kyiv, 04053, Ukraine*

Abstract

In the real-world economic landscape, economic agents, represented by individuals and organizations, interact through an identification system that grants access to specific goods and services upon meeting predefined access conditions. In essence, employees secure employment from employers if they possess the necessary education and relevant skills, athletes gain entry to competitions following a medical examination and past achievements, applicants become students after successfully passing entrance exams, and entrepreneurs may obtain a bank loan with a positive credit history and repayment guarantees. In practice, such interactions occur through documentary verification or utilizing digital databases. The evolution of peer-to-peer economic systems, offering extensive opportunities for participant interaction through smart contract systems and virtual assets, functioning based on smart contracts, underscores the necessity for digital twins with functions of data preservation and provisioning about an economic agent for their economic interactions. This article explores the concept of the Soul Bound Token (SBT) as a Digital Twin (DT) within economic identification systems in peer-to-peer economic environments and as a tool for interaction within decentralized economic spaces.

Keywords

Soul Bound Token, Digital Twin, Peer-to-Peer, DAO, smart-contracts, DeFi, digital economy, autonomous agents, digital transformations, NFT, blockchain, digital technologies

1. Introduction

The contemporary economic landscape is defined by paradigm shifts accompanying the transition into the Fourth Industrial Revolution, marked by the emergence and development of decentralized economic spaces and collaborative systems based on blockchain technology. One characteristic of interactions in peer-to-peer systems is the absence of physical intermediaries who ensure the security and authenticity verification of participants' data [1, 2]. Digital counterparts, constructed through smart contracts, play the role of such intermediaries by automating the recording of ownership rights to digital assets and facilitating information exchange to grant access to digital services. In the real world, economic and social interactions among participants, such as households, consumers, organizations, etc., occur through information exchange and the formation of agreements aimed at resource allocation and achieving economic or social outcomes. The state acts as the primary intermediary in ensuring economic interaction through its monopoly on personal data registries, property rights, and limitations. Participant verification is conducted by presenting tamper-resistant documents and, if necessary, verified by consulting governmental registries [3, 4].

Data security technologies enable the creation of digital applications for interacting with various services without the need for physical document presentation. For instance, in Ukraine, certain government services have

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EMAIL: seito@ukr.net (D. Virovets); s.obushnyi@kubg.edu.ua (S. Obushnyi); a.ramskyi@kubg.edu.ua (A. Ramskyi); h.hulak@kubg.edu.ua (H. Hulak)
ORCID: 0000-0003-4934-8377 (D. Virovets); 0000-0001-6936-955X (S. Obushnyi); 0000-0001-7368-697X (A. Ramskyi); 0000-0001-9131-9233 (H. Hulak)

transitioned to an automated or semi-automated model [5], including the utilization of the state service "Diia" where users' personal and professional information is stored with electronic signature capabilities. Banking services have also become more accessible using digital applications (Apps) developed and managed by banks as financial intermediaries. Functionally similar digital applications are proposed for use in the interaction of participants in peer-to-peer economic systems, known as Decentralized Identity Applications (DIDs). In these applications, participant information is recorded using smart contracts, enabling automated verification for interaction with other decentralized applications (dApps). This mirrors the functionality observed in the digitalization of certain government and banking services, exemplifying a broader trend towards decentralized and digitally managed interactions in various sectors of the economy.

2. SBT as Personified Digital Twins in Peer-to-Peer Economy

The concept of Digital Twins (DTs) emerged in the 1970s as an idea to create digital replicas of real-world objects. The primary goal of these digital twins is to simulate and model real-world processes in a digital environment. In scientific literature, they are often described as synchronized virtual copies of the underlying object, process, or service, designed for analysis, management, and optimization of operations in the real world [6]. With the evolution of decentralized economic environments based on peer-to-peer technologies, the concept of digital twins is being leveraged to facilitate interaction within partnerships and create virtual assets in the environments of Decentralized Autonomous Organizations (DAOs), video games, metaverse [7], and decentralized finance. The decentralized architecture for utilizing digital twins is presented as a three-tier architecture that connects the physical world with the decentralized economy through a user interface. Economic domains where decentralized digital twins find application include digital health records, insurance, smart grids, the Internet of Things (IoT), partnership platforms with reward and reputation systems [8], and more. The concept of an autonomous digital twin of an enterprise is formalized in the ISO 23247 standard, "Digital twin framework for manufacturing," defining three core properties of digital twins: the virtual representation of a physical object for planning and modeling, continuous synchronization with the real object, and support for autonomy in the virtual object. The architecture of digital twins envisions a three-tier structure for their creation and application in the decentralized economic space, as presented in the table below along with their description.

Table 1
Levels of Interaction of Digital Twins in the Decentralized Space [8]

Levels of Decentralized Twins	Interaction Characteristics	Implementation and Functions
A. Physical/Real World Level	Centralized interaction	Represented by real users, objects, and processes (markets, assets, services, influencing factors, etc.). Interaction with the digital world occurs through a communication level involving the payment of a virtual commission.
B. Communication Level (User Interface)	Sub-level 1 - Simulation/Migration	Represented by services for generating and creating virtual assets on the blockchain, constructing digital models, and copies for their subsequent reproduction in the decentralized space.
	Sub-level 2 – Blockchain	Ready for use after reproducing them on the blockchain and providing access to DApps and other services presented by DAOs, Metaverses, Games, etc.
C. Decentralized Economy Level	Decentralized interaction	Represented by digital twins of processes recorded in smart contracts using interaction models, partnerships, incentives, rewards, and resource distribution. Accounts for changes in the states of digital twins in the form of assets, avatars, decentralized organizations, partnership products, digital art, etc.

With the introduction of Non-Fungible Tokens (NFTs) as a standard for decentralized digital twins, which encapsulate specific unique informational content and ensure its preservation, the issue of identity management in decentralized spaces is effectively resolved. This space is characterized by protocols of decentralized finance, decentralized gaming, decentralized autonomous organizations, and metaverses. Identity management encompasses the registration, revocation, and updating of digital twins, which is the subject of study within its application in the decentralized realms of metaverses, digital learning platforms, and decentralized finance. Decentralization, facilitated using NFT and SBT standards, addresses the problem of copying and counterfeiting complex digital data structures. This opens possibilities for their secure utilization within the decentralized economy.

The development of decentralized infrastructure contributes to investments in the creation of digital twins, subsequently influencing the advancement of the infrastructure itself and decentralized economic instruments. Models of cooperation and economic interactions increasingly demand the identification of participants based on financial capabilities, positive reputation, skills, and previous positive experiences. Thus, when utilizing Soul Bound Tokens (SBT), obtaining credit on decentralized platforms occurs in an automated mode as a result of the interaction between two digital twins, the exchange of information between them, and the automatic execution of agreements through smart contracts.

While blockchain technology addresses some security issues related to digital twins, such as protection against DoS and DDoS attacks, cyberattacks on them in a decentralized environment can exploit vulnerabilities in smart contracts. Protecting against such attacks is a top priority, achieved through technical code audits, including the use of appropriate tools. Confidentiality of participants and data retention are crucial for secure interactions, primarily ensuring data anonymity and non-traceability. Anonymity protects personal information, and non-traceability ensures that no one can trace the connections in the interaction between participants and operators of digital twins. In both real-world and decentralized environments, trust in the digital twins is achieved through automated verification of their authenticity and mutual authentication of participants. In a decentralized environment without a trusted third party or reputation assessment mechanism, ensuring trust becomes a complex technical task based on economic interests and models of resource distribution.

Decentralized blockchain registries provide public confirmation of ownership rights to assets and their security without intermediaries or government institutions [9]. The public registry of states of digital decentralized twins and assets represents an informational decentralized field where any event and fact can be verified, given the presence of relevant references provided by one of the participants and recorded using SBT or NFT standards. According to the carrier architecture, such records may involve consent to these entries and the public dissemination of commercial data. Personal data, also subject to registration and interaction in decentralized environments, is likely to be extensively studied to create corresponding digital twin standards.

Decentralization empowers digital twins to identify a range of characteristics, providing advantages for interaction in respective environments, as presented in Table 2.

One additional problem that needs to be addressed is the challenges of SBT interaction across different blockchain networks. SBTs, with interoperability between networks, enable transactions with seamless movement of assets (registration of ownership rights to them) between different blockchain networks. Such compatibility not only enhances the efficiency of peer-to-peer collaboration but also contributes to scalability, considering the emergence of new, more functional networks. In these conditions, the introduction of cross-network SBTs for interaction in various digital environments is considered advisable.

3. SBT Standards

The necessity to utilize digital twins with their unique characteristics and properties for decentralized economic spaces has led to the development of standards ensuring compatibility and interaction with assets and tools within the respective network. Depending on their technical complexity and functionality, a series of technical solutions have been created and security-tested to ensure their safe usage in the corresponding decentralized network. Standards for Soul Bound Tokens (SBT), designed for personal representation in the decentralized economic space, similar to personal profiles on Google, LinkedIn, Facebook, etc., are used for partnerships and consumption of digital products. These standards are derivatives of NFTs but cannot be alienated, serving as carriers of the personal characteristics of their owner.

Table 2
Advantages of the Decentralized Space for the Use of Digital Twins

Feature	Description
Immutable and Transparent Transactions with Digital Twins	Immutable and transparent transactions, facilitated by distributed ledger technology, allow digital twins to securely conduct operations such as buying, selling, transferring ownership rights, and maintaining state records with a high level of protection against cyber fraud.
Automation	The digital nature of the decentralized economy and blockchain enables the automation of processes, supporting autonomy where third parties cannot interfere with the outcomes of interactions involving Digital Twins.
Identification of Digital Twins	Decentralized identifiers and databases ensure the identification and tracking of Digital Twins by consensus protocols.
Security and Reliability	Blockchain addresses some security issues, but not all. Digital Twins in decentralized spaces are considered more secure and reliable than their centralized counterparts.
High Precision Tracking and Global Accessibility of Digital Twins	The properties of blockchain, such as transparency and immutability, provide global traceability of digital twins and a global infrastructure for their interaction without intermediaries and legislative constraints.
Peer-to-Peer Connectivity	Ensures direct communication between interaction models and users through Digital Twins without intermediaries.
Access Privileges and Trusted Data Coordination for Digital Twins	Blockchain, as the infrastructure of the Metaverse, grants access to DT data that is easily manageable for company coordinators.
Ensuring Transparency and Accountability for Digital Twins Data	Transparency and accountability are key features in the Metaverse, making it easier to address regulatory issues and use Digital Twins effectively.
Decentralized Infrastructure	The Metaverse provides decentralized infrastructure for Digital Twins, supporting all blockchain properties, making the application of Digital Twins in the Metaverse a reliable choice.

It is considered that these characteristics can include personal information such as passport details and data regarding skills, verified knowledge, achievements, ratings, the access to which can be programmed depending on the type and standard of such a token. Additionally, the token architecture for interaction with other agents may involve the use of decentralized economic instruments. Currently, the most widespread developed standards are ERC-721, ERC-1155, ERC-5484, and ERC-5114, designed for the Ethereum smart contract platform, along with their counterparts NEP-359 and Binance Account Bound Token (BABT) for the respective platforms. A more detailed description of them is provided in the table below.

Table 3
SBT Standards and Their Characteristics. Compiled by the authors based on sources

Standard	Characteristics
ERC-721 [10]	Unique, non-fungible, transferable tokens containing information for interaction in virtual games and decentralized partnerships, with the ability to add additional metadata about the represented token. Interface standards ensure compatibility between different token implementations, ensuring interoperability within the Ethereum ecosystem. Suitable for interaction in digital art, gaming markets, etc.
ERC-1155 [11]	Unique, immutable, fungible tokens allow the creation of management models for different token types within a single contract, reducing gas costs and enhancing network efficiency. Permits work with multiple assets simultaneously within a single transaction. Includes combined ownership rights for different token types. Stores metadata for each token involved in a transaction, facilitating its use in cooperative models.
ERC-5114 [12]	Soulbound Badge. Non-fungible token allowing various registration options (email, mobile connection, social networks, and over 250 wallets) and an integrated smart wallet. Used for representing game items and achievements that players wish to retain.
ERC-5484 [13]	Non-fungible, consensus token used for recording data, including external counterparties. Utilized for tracking ratings, including credit ratings, and participation results in partnerships. Enables the development of the SBT ecosystem with trust in the identity of each token.
EIP-5192 [14]	Token with extended transfer and alienation properties. Considered non-fungible but with locking and unlocking control elements, providing flexibility in certain scenarios, such as user and verifier trust levels.
ERC-4973 [15]	Account-bound Tokens. Non-transferable token with components of ownership (e.g., private property, Harberger property, or Soulbound property) suitable for interaction in partnership models and games.
ERC-6454 [16]	Minimally transferable token. Useful in scenarios where the token represents a unique achievement or certificate. Becomes non-transferable after a specific event—block or a predefined number of transactions. Allows defining the maximum number of transactions after which the token becomes non-transferable. Has potential applications in digital art, games, and finance, providing detailed control over individual tokens, and enabling unique restrictions based on their properties or attributes.
ERC-7508 [17]	Minimally transferable token for tracking participation ratings in video games. Enables recording online data at a specific moment of game participation and interactivity with various games.
NEP-359 [18]	An example of SBT implementation on the NEAR platform with capabilities for DAO usage.
BABT [19]	Non-fungible, irrevocable token with user data from Binance and has undergone KYC. Has three key properties: it is not transferable, can only be revoked by issuers, and one user can have only one BAB token at a time and on one chain. Tied to the respective address on the Binance Smart Chain network.

Each standard defines the structure and functionality of Soul Bound Tokens (SBT) within a specific decentralized network, ensuring compatibility and interaction between different blockchain platforms. In doing so, it addresses a range of economic and technical challenges oriented towards practical applications. Modern decentralized networks, such as Metaverses, financial protocols, and DAOs, offer extensive opportunities for the interaction of digital twins, provided security and confidentiality issues are resolved. The variety of token standards creates possibilities for the creation of complex interaction systems among participants, including regulatory mechanisms in specific jurisdictions. For instance, personal KYC [20] verification of a participant may be necessary to comply with national legislation, which is significant for protecting investor interests and combating illegal operations [21]. Such mechanisms can be easily implemented into technical solutions of token standards and executed automatically. Additionally, interaction models themselves can be standardized and represented as corresponding tokens with ownership rights identification and authenticity verification models. These models may include combinations of interaction protocols, payment methods, vulnerability checking methods, data retrieval and storage methods, solutions for managing digital twins [22], reporting protocols, information display methods, protocols for anonymous authentication, and more. An example of such implementation is the EtherTwin concept with its data access control model based on the Ethereum blockchain platform and Swarm combined with encrypted data storage of the network [23].

4. The Economic Significance of SBT

An example of a practical symbiosis between digital twins and smart contracts is illustrated in the Private City [24] project, which implements real-time monitoring of environmental data. These data are governed by a smart contract, enabling forecasting and modeling of various scenarios. Parameters obtained by the smart contract include temperature, humidity, energy, and water consumption, as well as air quality data. The smart contract also considers the state of the observed object, and registers and updates maintenance parameters, providing a reliable access control mechanism. This example showcases the potential of Ethereum smart contracts in combination with digital twins and their ability to interact with real-world data through oracles. Utilizing such an approach, operators can receive real-time information about the state of the observed object with a high level of data security and confidentiality. Below, the decentralized economic system is outlined by a general plan in which participants interact with service platforms through SBT.

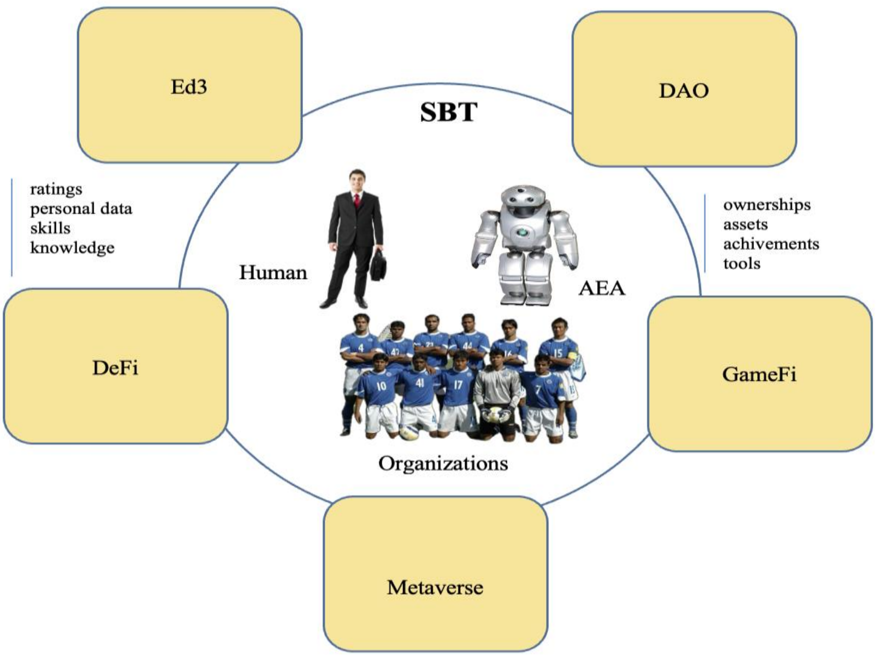

Figure 1: SBT in a Decentralized Economic System

Concepts of using digital twins are also applied in enterprises to ensure multi-agent adaptive allocation, planning, optimization, monitoring, and control of tasks and resources in real time, synchronized with employee plans and competencies [25]. An autonomous digital twin of an enterprise enables the implementation of a fully autonomous Deming cycle [26], including adaptive distribution, planning, optimization, monitoring, and real-time control of tasks and resources, replacing the routine of most business processes and allowing operation with minimal human involvement or entirely without it. The functionality of the enterprise digital twin includes a set of tools and measures for managing and allocating resources, including ontological specification of the enterprise structure, business processes, products, resources, communication plans with employees, medical document verification [27], methods of assessing enterprise productivity and efficiency, and more [25]. For the decentralized economic space, the concept of Decentralized Autonomous Organizations (DAOs) opens opportunities to create models of digital twins of enterprises. The DAO architecture involves the use of smart contracts and virtual assets to automate basic management processes. Such organizations can act both autonomously, without interacting with real-world economic instruments, and as a digital division to operate in the decentralized economic space. To interact with participants and other digital twins, DAOs require their representation and the representation of decentralized economic agents. Such multi-agent systems of digital twins consist of two main classes of agents: task agents, which search for necessary time intervals of resources and book these time intervals, and resource agents, which search for the most suitable orders and tasks to realize their products. Interaction models in multi-agent systems of virtual companies may include basic elements such as materials (resources), the production process, product characteristics, and quality [28]. Thus, we define interaction points between autonomous agents to organize the digital production process and create a product involving digital twins. This process, as noted, requires representation, which can be expressed in the following blocks: identification block, personal information block, agent characteristics block, and functional block. Each such block can be formed by three sources: the operator or agent themselves, the counterparty, and an independent third party. The mechanism for forming such blocks in the decentralized space is provided by SBT.

At the core of SBT, as a collaboration tool, lies the process of tokenization—the automated creation of a representation model based on a smart contract of the corresponding standard. Typically, SBT is anchored to the address of a decentralized platform where digital interaction takes place, with a prohibition on its further transfer. The token owner autonomously manages the information contained within the token, granting or denying access during interactions with others. Since economic interaction requires not only agent identification based on provided information but also the evaluation of their previous experience and results, along with the verification of such information, SBT standards involve the registration and removal of information from the token by both the owner and counterparties or third independent parties. Functioning as a digital twin of a physical or digital entity represented in the decentralized space, SBTs provide data security and functionality for economic interactions. The table below outlines the characteristics of informational blocks necessary for economic interactions.

Table 4

Information Blocks in SBT

Block Class	Data and Information Under Management
Identification Block	Includes address, coordinates in networks and platforms, registration data, search data, metadata, and hash functions.
Personal Information Block	Comprises real-world data used to represent the agent on behalf of an individual. This includes education data, physical ratings, activities, etc.
Agent Characteristics Block	Involves specialized data from the decentralized space obtained through interactions. This includes data on digital ratings, partnership results, interactions with other agents, ownership rights to digital assets, etc., acquired using decentralized tools.
Functional Block	Encompasses special tools for informational interaction in the decentralized space, created or acquired by the agent. This may include mechanisms for forming queries, and proposals, agreeing on interaction terms, and accepting offers on behalf of the agent's operator.

SBT records standardized information in decentralized databases and provides access to it upon request during interactions. Standardization should ensure the classification of data based on various characteristics for further use in communication models, including educational, scientific, professional, etc. Despite research into the possibilities and the definition of standards for digital education [29], there are currently no standards for educational ratings and skills for their use in the decentralized space. By analogy with the origin of many decentralized innovations, we can anticipate that standards for such ratings may be based on video game ratings, where not only the registration of personal information and achievements is possible but also the tracking of ownership rights to digital tools used in interactions with other players.

5. Models of Economic Interaction Using SBT

Economic models utilizing NFTs, as predecessors to SBT, have been studied and discussed in various research studies [30]. SBT records standardized information in decentralized databases and provides access to it upon request during interactions. Standardization should ensure the classification of data based on various characteristics for further use in communication models, including educational, scientific, professional, etc. Despite research into the possibilities and the definition of standards for digital education, there are currently no standards for educational ratings and skills for their use in the decentralized space. By analogy with the origin of many decentralized innovations, we can anticipate that standards for such ratings may be based on video game ratings, where not only the registration of personal information and achievements is possible but also the tracking of ownership rights to digital tools used in interactions with other players. The integration of SBT with Decentralized Finance (DeFi) protocols aims to expand the functionality of SBT beyond asset ownership representation, allowing users, through digital twins, to access lending and other financial services in exchange for personal information and reputation data.

Data from SBT and their integration into partnership systems can be utilized in models assessing efficiency and forecasting future outcomes of digital twin interactions for decision-making. Below is a model for evaluating the efficiency of collaboration using simple data provided by SBT, as well as probabilities obtained empirically or through expert analysis.

$$X = \sum_{i=1}^{n} W_i \cdot P_i \cdot C_i, \qquad (1)$$

where X is the overall cooperation employment assessment, N is the number of criteria considered, W_i is the weight assigned to criterion C_i, representing its relative importance in the assessment. The weights should sum to 1: $\sum_{i=1}^{n} W_i = 1$. P_i is the probability of positive cooperation results associated with criterion C_i. C_i is the assessment value for criterion *i*.

Depending on the specific context of interaction and scenario requirements, the model can be adapted to relevant relationships by adjusting criteria, weights, and probabilities. After performing calculations, based on the evaluation model, a decision is made regarding the acceptance of a proposal for interaction, which is recorded in the decentralized network, creating access to corresponding assets or tools through smart contracts. The model may employ fuzzy logic, machine learning, and artificial intelligence approaches, further contributing to the optimization of interactions, particularly involving digital twins.

Acknowledgments

In summary, the integration of SBT as digital twins in peer-to-peer economic systems defines a new era of transformation in economic interactions. Adherence to established standards ensures data security and functionality, enhancing transparency and transaction efficiency within digital cooperation. SBT's capabilities include tokenizing personal information and data for interaction in systems, cross-chain compatibility, and integration with DeFi, showcasing the potential use of SBT. Considering the rapid development of blockchain technology, SBT will play a key role in redefining the value of decentralized transactions, contributing to the creation of a reliable and efficient economic ecosystem. The further development and use of SBT will align with the movement towards decentralized, transparent, and inclusive economic models, laying the foundation for the future digital paradigm with the principles of peer-to-peer cooperation of digital twins in the blockchain technology context. It is anticipated that DAO partnership models, metaverses, and decentralized finance will establish new SBT standards and architectures for representing participants in decentralized partnerships. These standards, in turn, will provide users with adaptability to interaction tools, including the use of artificial intelligence and various machine learning models.

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