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Review Of Blockchain-based Tokenization Solutions For Assets In Supply Chains

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Abstract

Recently, blockchain-based tokens have earned an important role in fields such as the art market or online gaming. First approaches exist, which adopt the potentials of blockchain tokens in supply chain management to increase transparency, visibility, automation, and disintermediation of supply chains. In context, the tokenization of assets in supply chains refers to the practice of creating virtual representations of physical assets on the blockchain. Solutions in supply chain management based on the tokenization of assets vary in terms of application objectives, token types, asset characteristics, as well as the complexities of supply chain events to be mapped on the blockchain. Currently, however, no review exists that summarizes the characteristics of blockchain-based tokens and their scope of applications. This paper provides a clear terminological distinction of existing blockchain token types and therefore distinguishes between fungible tokens, non-fungible tokens, smart non-fungible tokens, and dynamic smart non-fungible tokens. Subsequently, the token types are classified regarding their traceability, modifiability, and authorization to evaluate suitability for mapping assets in supply chains. Given the potential of blockchain in supply chain management, the results of the review serve as a foundation for a practical guide supporting the selection process of suitable token types for industrial applications.

Keywords

Supply Chain Management; Blockchain; Tokenization; Traceability; Review

1. Introduction

Blockchain-based tokens have significantly grown in popularity and public attention. Especially so-called Non-Fungible Tokens (NFTs) have created a growing digital market for artworks, collectibles, and other digital assets. In recent years the development shows a shift from digital markets almost exclusively trading digital art to increasingly different categories such as items in games or metaverses [1]. Furthermore, there are emerging applications aiming to tackle real-world problems using NFTs. Creating and selling NFTs could post a viable option to raise financing and awareness for art museums or wildlife conservation efforts [2,3]. Other applications include the management of privacy when sharing genetic data with health care providers to mitigate the risk of sensitive information abuse [4]. The concept of NFTs is also progressively being adapted in an industrial context. In particular, blockchain with its NFTs bears the potential to increase transparency, automation, visibility, and disintermediation in Industry 4.0 driven supply chains [5].

The idiosyncrasy of blockchain tokens results from the technical and organizational properties of blockchain technology. In 2008, the pseudonym Satoshi Nakamoto published the Bitcoin white paper and thus introduced blockchain technology with the aim of creating a secure electronic currency independent of trusted third parties [6]. The US National Institute of Standards and Technology defines blockchain technology as “distributed digital ledgers of cryptographically signed transactions that are grouped into blocks. Each block is cryptographically linked to the previous one (making it tamper evident) after validation and undergoing a consensus decision” [7]. The emergence of Ethereum, introduced in Vitalik Buterin’s white paper in 2013 [8], extended the scope of blockchain from financial applications to other fields. The Ethereum white paper marks the start of blockchain-based ‘smart contracts’ as an enabler for further decentralized applications. Ethereum integrates the characteristics of blockchain with a fully-fledged Turing-complete programming language. Following the mathematical concept of Turing-completeness, which inter alia provides means to compute loops and/or complex recursions [9], Ethereum represents the first general-purpose blockchain platform that is able to compute and run all kinds of complex logical constructs, which serves as the technological foundation for the so-called ‘tokenization of assets’ [10].

2. Related works

The process of creating virtual representations of physical assets on the blockchain is usually referred to as the ‘tokenization of assets’ [11]. Initially, supply chain assets were tokenized to prove the ownership and provenance of the underlying physical asset [12]. Evolving blockchain technology and platforms allowed the extensions of blockchain-based tokenization to supply chain transparency applications [13]. Here, the definition and adaption of token standards played an important role in facilitating the integration of tokens for such applications. Currently, the Ethereum blockchain still implements the most pertinent token standards [14]. The establishment of the Ethereum standards ERC-20 and ERC-721 led to the common distinction between different types of blockchain tokens, namely Fungible Tokens (FTs) and the already mentioned NFTs. Different units of token that conform to ERC-20 can be interchanged with each other and therefore are, as the term suggests, fungible. The ERC-721 standard on the other hand implements tokens with unique identifications making tokens non-fungible [14]. On the Ethereum blockchain, the multi-token standard ERC-1155 extends the functionalities of the ERC-721 standard with the possibility of deploying several tokens using one smart contract [15].

These token standards, however, only represent minimum specifications of required functions to implement certain applications. The functionalities of a token itself are thereby determined by the underlying smart contract. Extensions of these standards are necessary to address the challenges of more complex structures such as supply chain applications. Arcenegui et al. [16] describe tokens that require an extension regarding their core functionalities as ‘Smart NFTs’.

Westerkamp et al. [17] present an extension to the ERC-721 token standard specifically aiming at solving the challenges of manufacturing supply chains. To map complex manufacturing processes that include the assembling of parts the authors introduce so-called ‘Token Recipes’. This enables the tracing of assembled goods and their components throughout supply chains [17]. Elaborating on this idea Watanabe et al. [18] introduce a token structure that embeds a link to previous states in the token transactions [18]. This enables more efficient retrieval of information in blockchain networks, which facilitates the tracing capability of tokens and therefore preferably suits applications aiming at increasing supply chain transparency. Kuhn et al. [19] present an approach utilizing the Ethereum multi-token standard ERC-1155 to build tokens mapping complex assembly structures. The ERC-1155 standard includes the possibility to deploy multiple fungible and non-fungible tokens using a single smart contract [15]. The approach of Kuhn et al. extends this smart contract to a so-called ‘Assembly Token Manager’ [19]. This manager governs the token balances and transformation events while also providing traceability information through an event log. To increase the viability of token-based applications in dynamic environments, Dietrich et al. [20] present a token concept allowing the definition and assignment of clear authorities when deploying the smart contract. These authorities can consent to dynamic changes on a deployed token smart contract such as adding new parts or partners to the supply chain. Additionally, this approach embeds the token history and composition into the token structure making external event logs superfluous. This streamlines the ability to holistically map complex and dynamic supply chains.

As the breakdown of the different approaches exemplifies, literature shows a range of different token solutions tackling the adaptation of blockchain tokens for supply chain applications. With the adaptation of blockchain tokens for increasingly complex application scenarios, an incrementally more complex token landscape has emerged that extends far beyond the originally defined token standards. There is, however, a degree of overlap between the different token solutions as well as a lack of uniform terminology. Therefore, this review of tokenization solutions aims on the one hand to provide a clear terminological distinction of existing blockchain token types and on the other hand to serve as a foundation for a practical guide supporting the selection process of suitable token types for industrial applications.

3. Review of tokenization solutions

The following chapter comprises a review of blockchain-based tokenization solutions for assets in supply chains. The first section defines the dimensions of classifiable differences by investigating the process of tokenization in comparison with already established identification systems. The second section examines the extent to which the complexity of the underlying asset affects the mapping by means of tokenization and derives important token characteristics. Lastly, a token classification is presented considering different token designs of existing approaches.

3.1 Tokenizing of assets

For the tokenization of supply chain assets, it is necessary to create a virtual reflection of assets on the blockchain [10]. This requires the introduction of an asset-backed token on the blockchain as well as a clear linkage of the virtual token to the physical or abstract real-world asset. In the case of physical assets, the linkage can be realized by using identification technologies such as RFID or QR Codes [21,22]. Such identification systems are subject to extensive legal and technical standardization. The IEC 62507-1:2010 standard provides a reference model for the reflection of assets from the physical world into the virtual world, which includes the combination of metadata, a unique identifier, and a physical or abstract asset [23].

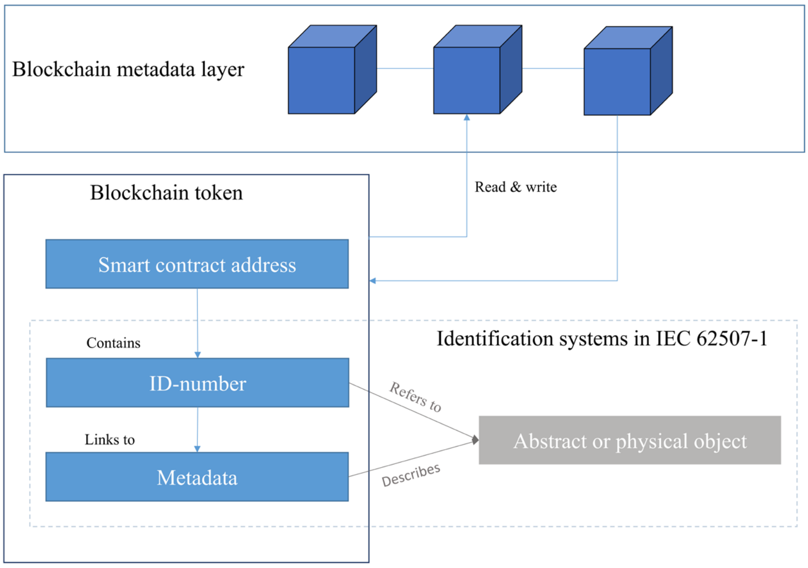

Figure 1: Referencing model for tokenization of assets

Here, the unique identifier refers to the physical or abstract object and links to its metadata. Accordingly, an object's metadata describes the physical or abstract object. The complexity of tokenization, however, goes beyond the IEC 62507-1:2010 reference model, in particular since NFTs eventually represent unique assets in publicly available networks. Figure 1 shows an extended reference model specifically designed according to the properties of NFTs. The composition of an NFT is determined by a token smart contract, which can be identified with its unique address on the blockchain. The smart contract contains the unique token identifier, typically represented by hexadecimal numbers as a unique result of underlying hashing functions [17,20]. This identifier links to the token's metadata. As Figure 1 indicates, the connection between the unique identifier and the metadata overlaps with the reference model of the IEC 62507-1:2010 standard. Furthermore, the extended model takes the relationship between the blockchain metadata layer into account. Typically, smart contracts embedded into a blockchains block structure own the ability to exchange information with the metadata layer itself. The extended reference model only describes the relationships between the aspects of tokenization. However, it does not specify to what extent data and functions must be included in the token architecture in order to meet the requirements of the respective application scenario to be mapped on the blockchain.

3.2 Adapting tokens to asset complexity

To enable the mapping of supply chain assets by means of tokenization, blockchain tokens must meet the requirements of the assets as well as the supply chain network. This involves the mapping of information and material flows as well as relationships within the supply chain network [24]. To facilitate such mapping, information systems rely on a standardized division into so-called supply chain events, which determine "what, when, where and why" something happens [25]. Previous research has already shown that the underlying supply chain complexity in terms of different supply chain events to be mapped impacts the requirements and selection of different token types [5]. In this context, Bozarth et al. [26] distinguish between the detail complexity, which describes the "distinct number of components or parts that make up a system", and the dynamic complexity, which deals with "the unpredictability of a system's response to a given set of inputs, driven in part by the interconnectedness of the many parts that make up the system". Derived from the intended application of blockchain tokens and the requirements arising from an increased supply chain complexity, this paper identifies three characteristics impacting the complexity of assets to be mapped on the blockchain.

Traceability: Traceability can be described as the ability to gather information on the whole downstream path of a product [27]. Companies have to deal with the growing interests of customers, governments, and non-governmental organizations in having greater transparency of brands, manufacturers, and producers throughout the supply chain [28,29]. As a result, social and environmental sustainability issues have become increasingly important for manufacturers in order to maintain the flawless reputation of their brands [30]. The ability to mitigate the risks of counterfeit products and the enforcement of sustainability standards in multi-tier supply chains rely on the effective traceability of assets [31]. Furthermore, emerging legal requirements increase the pressure on companies to ensure traceability throughout their supply chains. For example, initiatives such as the "EU rules on due diligence in supply chains" aim at making companies accountable for their entire supply chain [32].

Modifiability: Modifiability refers to the ability of an asset to experience transformation and aggregation events throughout its lifecycle according to the EPICS standard by GS1 [25]. This includes assets to eventually experience changes in terms of their modular composition. The modularity of assets describes the division of a structure into different subsections that can be combined using interfaces and may be replaced or reused in other products [33]. While this practice can reduce the overall complexity of an asset's structure it increases the number of processing events that can occur in a given supply chain. The modularization of products represents an important tool in achieving mass customization capabilities [34,35]. The aim to deliver customized products at the cost of mass production is closely tied to the emergence of the ideas of Industry 4.0 [36]. Furthermore, modular product architectures along with the ability to disassemble and reuse the modules are central characteristics of products in a circular economy [37].

Authorization: The collaboration in supply chain networks requires the establishment of authorization mechanisms governing the role and activities of participating supply chain members [38]. The sweeping collaboration between partners in supply chains has the potential to create benefits for every partner and ultimately a competitive advantage for the whole supply chain [39]. The need for collaboration is driven by the occurrence of uncertainties, disruptions, and dynamic changes in modern supply chains [40,41].

3.3 Token type classification

When summarizing the existing approaches adopting supply chain tokens and investigating their properties in terms of traceability, modularity, and authorization, four main categories of token types emerge.

These token types, Fungible Token, Non-Fungible Token, Smart Non-Fungible Token, and Dynamic Smart Token are classified in Table 1 according to their functional and data properties in terms of traceability, modularity, and authorization.

Table 1: Token type classification

			Token types			
			Fungible Token	**Non-Fungible Token**	**Smart Non-Fungible Token**	**Dynamic Smart Non-Fungible Token**
Token characteristics	**Token traceability**	**Functionality**	Not possible	Possible	Possible	Possible
		Data	Not available	Retrievable from blockchain metadata layer: • Transaction history	Retrievable from blockchain metadata layer: • Transaction history • State history	Retrievable from token: • Transaction history • State history
	Token modifiability	**Functionality**	Not possible	Not possible	Possible events: • Transformation • Aggregation	Possible events: • Transformation • Aggregation • Disaggregation
		Data	Not available	Not available	Event history retrievable from blockchain metadata layer	Event history logically coupled to the token
	Token authorization	**Functionality**	Not possible	Possible verification: • Token authenticity	Possible verification: • Token authenticity • Account and role authenticity	Possible verification: • Token authenticity • Account and role authenticity • Administrative permissions
		Data	Not available	Accessible via blockchain metadata layer: • Smart contract address	Accessible via blockchain metadata layer and embedded token functions: • Smart contract address • Account and role data	Accessible via blockchain metadata layer and embedded token functions: • Smart contract address • Account and role data • Permissions in authorization concept

Fungible Tokens: Fungible Tokens are closely resembled by the specifications of the ERC-20 token standard [42]. They facilitate in particular the mapping of volume exchanges of a given good. However, they do not offer technical properties to enable the tracing of individual tokens as well as the implementation of a smart contract logic to govern token modifications and interactions. One conceivable scenario for the use of fungible tokens in a supply chain context is the token-based exchange of freight pallets, where only the total volume and available quantity are relevant for traceability purposes.

Non-Fungible Tokens: NFTs are closely resembled by the specifications of the ERC-721 token standard [43]. NFTs possess unique identifiers and therefore allow linking tokens to a physical or abstract asset according to the extended reference model shown in Figure 1. This enables token traceability by extracting the transaction history from the blockchain metadata layer. Pure NFTs do not offer the possibility to add extensive creation requirements to the token smart contract allowing mapping of the modularity of assets. Furthermore, it is only possible to verify a token's authenticity without connecting it to governance models. In a supply chain context, a conceivable scenario for applying NFTs is the management of tools that allows a flexible distribution and tracking of tools across a supply chain network.

Smart Non-Fungible Tokens: As Arcenegui et al. [16] describe, Smart NFTs extend the core functionalities of the NFT standards with supply chain specific functions and creation requirements. While the core properties regarding the traceability remain the same as with NFTs, Smart NFTs allow users to include token transformation and aggregation functions. These functions can additionally be assigned to first authoritative permissions. Thus, Smart NFTs allow the mapping of assets that experience predictable changes regarding their modular composition throughout the supply chain, such as comprehensively certified medical devices.

Dynamic Smart Non-Fungible Tokens: Dynamic Smart NFTs extend the idea of Smart NFTs by adding dynamic elements to the functions and creation requirements as well as embedding an authority concept into the token smart contract. Furthermore, Dynamic Smart NFTs enable the inclusion of a token's history and composition inside their token structure [20]. This functionality forms the basis for enabling not only an aggregation of tokens but also a subsequent disaggregation. A conceivable scenario for Dynamic Smart NFTs is the mapping of assets that can experience dynamic changes regarding their modular composition as well as underlying supply chain authority structure throughout the entire lifecycle of an asset, such as in the automotive industry.

4. Result

The review of different tokenization solutions of assets in supply chains results in a procedure for adopting blockchain tokens, which incorporates the modeling of tokens as well the classification of token types. Figure 2 shows the structured flow scheme of the procedure.

The first layer describes the necessity to initially define a clear scope of the supply chain and the respective assets to be mapped. This step must always be oriented towards the objective of the corresponding use case. Based on this, the second layer describes the adaption of token requirements according to the asset complexity. This includes an asset's requirements in terms of traceability, modifiability, and authorization as well as the respective functionalities and data. According to the derived requirements, a suitable token type can be selected in the last layer. Here, the flow scheme distinguishes between FTs, NFTs, Smart NFTs, and Dynamic Smart NFTs.

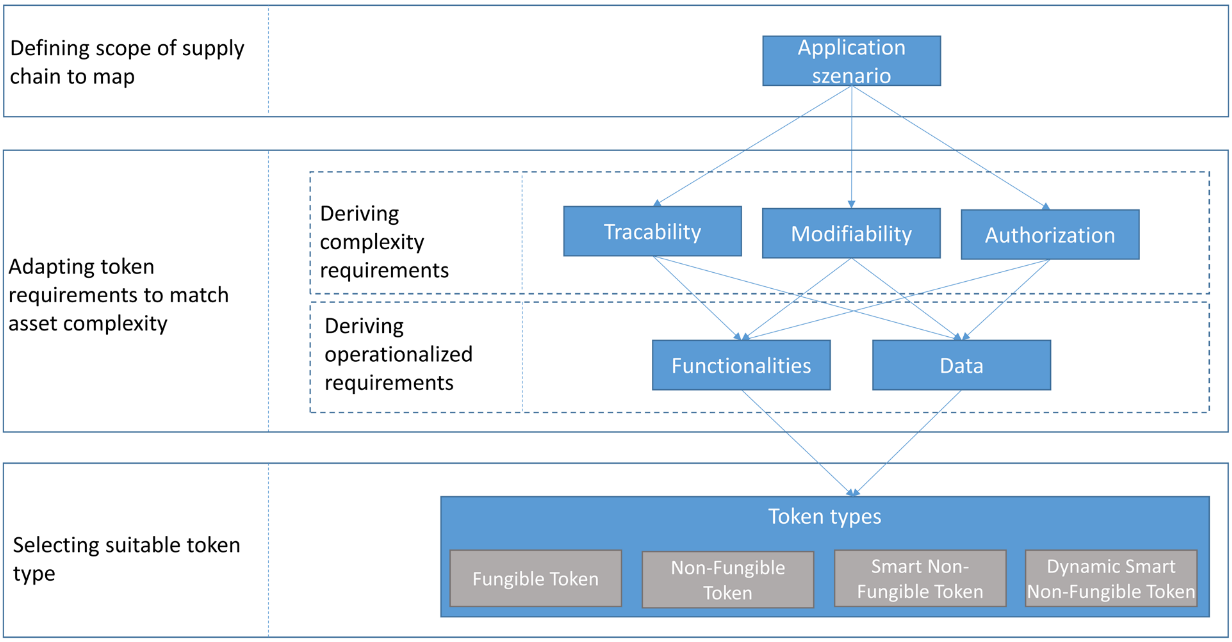

Figure 2: Procedure for adopting blockchain-based tokenization for assets in supply chains

5. Discussion and conclusion

The tokenization of assets is an innovative solution for mapping physical or abstract objects on the blockchain. This trend is also increasingly becoming important for industrial use cases bearing the potential to increase transparency, automation, visibility, and disintermediation in supply chains. The transfer of the tokenization of assets to increasingly complex use cases has led to the continuous development of different token solutions, in order to meet the increasing requirements regarding traceability, modifiability, and authorization. This paper provides a clear terminological distinction of existing blockchain token types and therefore distinguishes between FTs, NFTs, Smart NFTs, and Dynamic Smart NFTs. FTs and NFTs are very much based on the characteristics of the well-established token standards ERC-20 and ERC-721. Smart NFTs extend the token functions with supply chain specific requirements, which enables a static mapping of modifiable assets. Dynamic smart NFTs, as the name indicates, embed the token functions into dynamic authority and token concepts allowing the mapping of flexible supply chains with changeable assets. The findings are summarized in a procedure, which supports the selection process of suitable token types for industrial applications. So far, the token types classified in this paper have only been evaluated theoretically or based on a very limited amount of industrial case studies. This bears the potential that new token solutions with more extensive functionalities are necessary in order to meet industrial requirements holistically, which would require an extension of the available tokenization types. Therefore, further research is necessary to identify further requirements of assets to be mapped on the blockchain in a wide range of industrial domains. Currently, further research is being conducted in developing a framework serving as a practical implementation guide for industrial token-based applications.

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