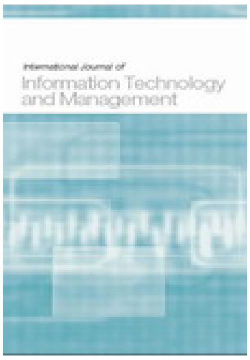

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Tokenisation approaches on blockchain: state-of-the-art and classification framework

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Tokenisation approaches on blockchain: state-of-the-art and classification framework

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Abstract: Tokens released and sold on blockchains have drawn a lot of attention. Some say it is just a fad, others argue they will radically change many industries. While the truth is probably in the middle, we believe that in order to fully grasp the potential of tokens and to advance our knowledge about the phenomenon, it is necessary to understand multiple aspects of it, such as: what are tokens, what kind of tokens are there, how are they designed, and what new advances need to be done? In this paper, we aim to provide a first step in that direction. Specifically, we propose a classification framework that will allow us to analyse the existing tokenisation approaches and whose application can point us to relevant research directions. The practical implications of this work are threefold. Firstly, it will enable interested readers to understand the fundamentals of the tokenisation process and of tokens. Next, it will help with the comparison of existing tokenisation approaches and with the decision regarding the most appropriate process for a given use case. Finally, the framework could make the design of future tokenisation approaches easier.

Keywords: blockchain; tokenisation; fungible tokens; non-fungible tokens; NFTs; classification framework.

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Biographical notes: Sarah Bouraga is currently an Associate Professor in Information Management at the University of Namur, where she is a member of MINDIT Research Center and of the Namur Digital Research Institute (NaDI). She has always been interested in requirements engineering, data analytics, and artificial intelligence. For the last few years, she has also grown an interest in blockchain, as illustrated by her recent publications, her presentations at international conferences, and by the international workshop (blockchain for information systems) she has been co-organising since 2020.

1 Introduction

In March 2021, Kings of Leon became the first band to release an album as a non-fungible token (NFT).[1] A couple weeks before that, the Nyan Cat, a popular *meme*, sold for about $590,000.[2] These are only a few examples of a larger phenomenon, where all kinds of assets are being *tokenised* today on a blockchain. Multiple questions naturally arise, and among others: What are tokens? What is tokenisation? How does it work? In this paper, we dive into this tokenisation frenzy and try to bring some clarity to the phenomenon.

Over the past decade, blockchains have garnered global attention, driven by the increasing popularity of Bitcoin and Ethereum. Blockchain is a decentralised transparent public ledger storing transactions (Swan, 2015; Xu et al., 2019), which was designed originally for monetary transactions. However, the introduction of programmable blockchains, such as Ethereum, enabled the design and implementation of smart contracts and decentralised applications (DApps).

This evolution has paved the way for multiple opportunities. One of them is the release of tokens representing real-world assets on the blockchain. As mentioned earlier, questions naturally arise from this situation. Consequently, the aims and corresponding contributions of this paper are the following:

G.1 Provide a landscape of tokenisation approaches.

G.2 Provide recommendations for the appropriate tokenisation approaches.

G.3 Identify future research directions.

In order to reach these goals, we will analyse various tokenisation approaches introduced in the literature. Based on this analysis, we will propose a classification framework whose application will give us some insights regarding:

1. the relevance of this framework
2. potential future research directions.

Specifically, we will devise the classification framework and apply it to the tokenisation approaches we identified. The results will allow us to draw useful conclusions about the existing processes, about the way one can use these existing approaches, and about new research directions.

This study holds numerous practical implications for both researchers and practitioners. Primarily, it will allow interested readers to grasp the fundamentals of the tokenisation process and its output, i.e., the tokens. Next, it will help with the comparison of existing tokenisation approaches and with the decision regarding the most appropriate process for a specific use case. Ultimately, the framework could streamline the development of future tokenisation strategies.

The contributions and implications are aligned with Gregor's (Gregor) theory for analysing, the first type of theory in information systems (ISs). This theory for analysing is appropriate when little is known about the phenomena and thus aims to provide an analysis and description of these phenomena, making tools such as classification schema, frameworks or taxonomies particularly useful.

2 Related work

2.1 Blockchain

Blockchain technology is usually defined as a decentralised public ledger, where transactions are stored into blocks and where blocks are cryptographically linked with one another; hence forming a chain of blocks (Xu et al., 2019).

Blockchain is the underlying technology of Bitcoin, a decentralised cryptocurrency proposed in 2008 (Nakamoto, 2008). At first, the technology focused solely on the transfer of cryptocurrency between peers. With time, it turned into a platform allowing the design of DApps and the design of tokens (Section 2.2). Multiple benefits of blockchain have been recognised, such as: decentralisation, transparency, immutability, security and privacy (Nguyen et al., 2019).

2.2 Tokens and tokenisation

On a blockchain, tokens can represent almost any valuable asset. They are sometimes referred to as crypto-asset. Crypto-assets or tokens are a type of digital assets that take advantage of the properties and components of blockchain technology in order to trade in a decentralised manner (Pillai et al., 2019). In this paper, we will use the term token. These tokens are released on three different layers of the blockchain, embodying three different types of values (Yano et al., 2020), and representing different asset classes (Pillai et al., 2019).

Firstly, *security tokens* (or *asset-token*) represent shares in a company or, more generally, represent ownership of an asset. Examples of such tokens include: virtual pets or trading cards (Dorfleitner and Braun, 2019; Pillai et al., 2019; Tasca, 2019; Yano et al., 2020).

The second type of token is the *utility token*. Utility tokens provide the token holder with rights or digital access to a blockchain-based application or to a blockchain-based service. They are the DApp tokens and an example of such tokens is Steemit (Dorfleitner and Braun, 2019; Pillai et al., 2019; Tasca, 2019; Yano et al., 2020).

A further distinction can be made between *fungible and NFTs*, i.e., tokens representing interchangeable commodities or unique assets respectively. Tokens in general can be created using smart contracts, and standards are available for the creating of fungible tokens and NFTs: the ERC-20 standard addresses basic functionalities for the transfer and the spending of tokens, and the ERC-721 for the creation of NFTs (Xu et al., 2019; Yano et al., 2020; Fabian and Vitalik, 2015; William et al., 2018).

Finally, *digital currencies* or *protocol coins* (or *crypto-coin*) are cryptocurrencies, and are consequently used as a means of payment or, more generally, as a medium of exchange (Dorfleitner and Braun, 2019; Pillai et al., 2019; Tasca, 2019; Yano et al., 2020). Cryptocurrencies can be defined as the base currencies of blockchains, for instance Bitcoin is the currency of the Bitcoin blockchain and Ether is the currency of Ethereum. The blockchains monitor the ownership of the cryptocurrencies. The cryptocurrencies can be used to pay the transaction fees encountered by users (Xu et al., 2019). We can note that cryptocurrencies (or native coins) are fungible tokens.

Tokenisation is thus concerned with the release of a token representing a real asset. Multiple benefits of tokenisation have been recognised (Gupta et al., 2020), namely:

1 liquidity
2 faster and cheaper transactions
3 transparency
4 accessibility.

2.3 Literature review

Multiple works focus on the 'token economy', also coined 'tokeneconomics' or 'cryptoeconomics'. The term refers to the set of mechanisms implemented on a blockchain handling aspects such as service implementations and user rewards through program-based economic design. These mechanisms are implemented through the use of smart contracts (Lee, 2019). Two major works in the domain are Agrawal et al. (2014) and Catalini and Gans (2018). The former analyses the effect blockchain technology has on two types of cost, namely the cost of verification and the cost of networking (Agrawal et al., 2014). The latter addresses the ways entrepreneurs can use initial coin offerings (ICOs) to fund their start-ups (Catalini and Gans, 2018).

Other examples of works addressing this aspect of tokeneconomics include for instance: a focus on the token sales, where the authors explain its mechanism from an economic and technological perspectives, and highlight its potential influence on the way venture financing currently works (Kranz et al., 2019); an analysis of basic game theoretic token incentives in risk-aware blockchain technologies using the mean-field-type game theory (Barreiro-Gomez and Tembine, 2019); an analysis of the risks, opportunities, and implications for corporations and international organisations (Teichmann and Falker, 2019a, 2019b); a taxonomy of business models present in blockchain-based start-ups (Tönnissen et al., 2020); a framework for a scholarly journal, where tokens are used as incentives for quality curation of information (Kosmarski and Gordiychuk, 2020).

Other authors applied the principles of tokeneconomics to a case study. Examples include Kim et al. (2021), where the authors provide an application of tokeneconomics to a real life case study, namely for the permissionless blockchain insolar; and Treiblmaier (2021) where the author, in a research note, addresses the advantages of discussing tokens in tourism research.

Numerous works focus on the potential of tokenisation. Dorfleitner and Braun (2019) address the potential of blockchain and tokenisation for green finance. Specifically, the authors argue that tokenisation – through the use of ICO for instance – could simplify new forms of investment for green projects. Savelyev (2018) highlights two major risks regarding tokenisation of private law, namely:

1 a possible displacement of existing legal regimes of objects of civil rights by the legal regime of the token
2 the problem of definition of the nature of rights to tokens arises (in rem versus ad personam) as well as remedies for their violations.

Finally, multiple works propose an example of a tokenisation process in various domains, including: internet of things (IoT) (Arcenegui et al., 2020), finance (Davydov and Yanovich, 2020; Heryadi et al., 2021; Khan et al., 2020; Tian, 2020), supply chain

(SC) (Dietrich et al., 2020; ElMessiry et al., 2019; Westerkamp et al., 2018, 2020), real estate (Gupta et al., 2020), public governance (Martínez et al., 2019), and energy (Marchesi et al., 2019). These works will be further analysed in Section 3.

Our work differs from the existing literature because we focus on the tokenisation process, and not on tokeneconomics (Agrawal et al., 2014; Catalini and Gans, 2018; Kranz et al., 2019; Barreiro-Gomez and Tembine, 2019; Teichmann and Falker, 2019a, 2019b; Tönnissen et al., 2020; Kosmarski and Gordiychuk, 2020; Kim et al., 2021; Treiblmaier, 2021; Dorfleitner and Braun, 2019; Savelyev, 2018). Also, we do not address a particular case study or a particular application of a tokenisation (or its potential) (Arcenegui et al., 2020; Davydov and Yanovich, 2020; Heryadi et al., 2021; Khan et al., 2020; Tian, 2020; Dietrich et al., 2020; ElMessiry et al., 2019; Westerkamp et al., 2018, 2020; Gupta et al., 2020; Martínez et al., 2019; Marchesi et al., 2019), rather we try to analyse the recurring features of such a process. Finally, we believe this work is also different from Freni et al. (2020) – where the authors proposed a token classification framework where tokens can be analysed along 14 dimensions grouped into three categories, namely technology, behaviour and coordination – for two main reasons:

1 here, we address the process of tokenisation and not only the output, i.e., the token

2 we use different dimensions that the ones proposed in Freni et al. (2020).

3 Classification framework

In this section, we introduce the classification framework that will be used to analyse tokenisation approaches. The framework is composed of dimensions induced from the analysis of existing tokenisation approaches and from the background on tokenisation (Section 2).

Three main categories compose the framework. These categories are, in turn, broken down into multiple dimensions. Table 1 shows the overview of the framework. We explain the categories in detail next.

Table 1 Classification framework: overview

Categories	*Dimensions*
Context	Application domain
	Rationale
	Tokenised asset
	Token layer
	Token type
	Actors
Process	Type of blockchain
	Standard
	Static or dynamic
Evaluation	Implementation
	Strengths
	Weaknesses

3.1 Context

With the *context* category, we answer the following questions: *in which context does the tokenisation process occur?* and *what does the token represent?*

1 *Application domain:* What is the domain in which the tokenisation process occurs? The possible values include – but are not limited to:

- finance
- SC
- public governance
- IoT
- real estate
- energy.

2 *Rationale:* What is the rationale for the application of the tokenisation process? What is (are) the limitation(s) of the incumbent technologies that the tokenisation is trying to address? When switching to or trying another technology, one should attempt to address some limitations of the current solutions. This dimension is concerned with the 'why', i.e., why was the tokenisation approach chosen for the given application domain?

3 *Tokenised asset:* What is the input of the tokenisation process? Or, put another way, what is the asset being tokenised? The possible values are:

- physical asset
- digital asset.

4 *Token layer:* Following Yano et al. (2020), on which layer is the token issued? And consequently, what is the corresponding token type? The possible values are:

- security token
- utility token
- digital currency.

5 *Token type:* What is the output of the tokenisation process? The possible values are:

- fungible token
- NFT.

6 *Actors:* Who are the actors interacting with the token? Once the asset has been tokenised, various actors can use the token or participate in its lifecycle. This dimension identifies these participants.

3.2 Process

With the *process* category, we answer the following question: *how does the tokenisation process occur?*

1 *Type of blockchain:* On which type(s) of blockchain does (or can) the tokenisation process occur? The possible values are:

- permissioned blockchain
- permissionless blockchain
- consortium blockchains.

2 *Standard:* Which standard – if any – was used for the tokenisation? Following the two main standards used on Ethereum (mentioned in Section 2), the possible values are:

- ERC-20
- ERC-721
- other.

3 *Static or dynamic approach:* How do the authors introduce the tokenisation approach? Do they provide a workflow-like (i.e., dynamic) explanation of their approach (such as a UML activity diagram) or do they introduce it statically (such as a UML class diagram)? When designing a software product, it is important to have both perspectives. Hence, it is relevant here to assess the viewpoint of the authors. The possible values are:

- static
- dynamic
- both.

3.3 Evaluation

With the *evaluation* category, we answer the following question: *how does the tokenisation process perform?*

1 *Implementation:* Has the proposed tokenisation approach been tested or implemented? This is relevant to assess the following two dimensions, namely the strengths and weaknesses of the approach. If there has been an implementation of the process, then its evaluation is based on tangible results. On the other hand, if the tokenisation approach is purely conceptual and has not been implemented yet, then the performance evaluation can only be theoretical. Hence, the possible values for the Implementation dimension are:

- true
- false.

2 *Strengths:* What are the strengths of the proposed tokenisation approach?

3 *Weaknesses:* What are the weaknesses of the proposed tokenisation approach?

4 Application of the classification framework

In this section, we will apply the classification framework presented above to a series of works proposing a tokenisation process.

First, we will analyse the *context category*. As mentioned in Section 3, the *application domain* dimension identifies the domain in which the tokenisation process occurs. It is quite trivial and these domains are: IoT (Arcenegui et al., 2020), finance (Davydov and Yanovich, 2020; Heryadi et al., 2021; Khan et al., 2020; Tian, 2020), SC (Dietrich et al., 2020; ElMessiry et al., 2019; Westerkamp et al., 2018, 2020), real estate (Gupta et al., 2020), public governance (Martínez et al., 2019), and energy (Marchesi et al., 2019). As far as the *rationale* for the tokenisation is concerned, various desired properties were mentioned: secure data traceability (Arcenegui et al., 2020; Westerkamp et al., 2018, 2020), availability of financial products and services (Davydov and Yanovich, 2020; Khan et al., 2020), transparency (Arcenegui et al., 2020; ElMessiry et al., 2019), auditability (Arcenegui et al., 2020), liquidity (Gupta et al., 2020; Tian, 2020), price stability (Heryadi et al., 2021) and greater participation in public governance (Martínez et al., 2019). The tokenisation approach aimed to digitise (*tokenised asset*) a physical asset (Arcenegui et al., 2020; Davydov and Yanovich, 2020; Dietrich et al., 2020; ElMessiry et al., 2019; Heryadi et al., 2021; Marchesi et al., 2019; Westerkamp et al., 2018, 2020) or a digital asset (Davydov and Yanovich, 2020; Gupta et al., 2020; Khan et al., 2020; Martínez et al., 2019; Tian, 2020). The works we analysed here used security tokens (Arcenegui et al., 2020; Davydov and Yanovich, 2020; Dietrich et al., 2020; ElMessiry et al., 2019; Gupta et al., 2020; Heryadi et al., 2021; Khan et al., 2020; Marchesi et al., 2019; Tian, 2020; Westerkamp et al., 2018, 2020), and utility tokens (Marchesi et al., 2019; Martínez et al., 2019) (*token layer*); as well as fungible tokens (Arcenegui et al., 2020; Davydov and Yanovich, 2020; Gupta et al., 2020; Heryadi et al., 2021; Khan et al., 2020; Tian, 2020; Martínez et al., 2019) and NFTs (Davydov and Yanovich, 2020; Dietrich et al., 2020; ElMessiry et al., 2019; Marchesi et al., 2019; Westerkamp et al., 2018, 2020) (*token type*). We can notice that the majority of the tokenisation approaches deal with the digitisation of an asset in the physical world, i.e., propose a security token. The exception is Marchesi et al. (2019) where two actors – namely the prosumer and the smart metre – can sell, buy, consume, and recharge *crypto-trading energy tokens*. Finally, their process involved various types of *actors*, namely: users, physical objects and conceptual objects. More specifically, we group the following actors in the users category: suppliers (Dietrich et al., 2020), producers (Dietrich et al., 2020), service providers (Dietrich et al., 2020), customers (Dietrich et al., 2020), certifiers (Dietrich et al., 2020; Westerkamp et al., 2018, 2020), investors (ElMessiry et al., 2019; Gupta et al., 2020; Khan et al., 2020; Tian, 2020), asset owners (Gupta et al., 2020), assets vendors (Heryadi et al., 2021), vault service providers (Heryadi et al., 2021), auditors (Heryadi et al., 2021), obligator (Khan et al., 2020), citizens (Martínez et al., 2019), prosumers (Marchesi et al., 2019), issuers (Tian, 2020), issuance service providers (Tian, 2020), escrow service providers (Tian, 2020), legal firms (Tian, 2020), regulators (Tian, 2020), resource suppliers (Westerkamp et al., 2018, 2020), producers (Westerkamp et al., 2018, 2020), logistics and retail firms (Westerkamp et al., 2018, 2020), consumers (Westerkamp et al., 2018, 2020). We classify the following participant in the physical objects category: smart metre (Marchesi et al., 2019). And finally, we classify the following actor in the conceptual objects category: special purpose vehicle (SPV) (Gupta et al., 2020; Khan et al., 2020).

Table 2 Summary of the context category

Dimensions	*Values*	*Works*
Application	Finance	Davydov and Yanovich (2020), Khan et al. (2020), Tian (2020) and Heryadi et al. (2021)
Domain	Supply chain	Westerkamp et al. (2018, 2020), Dietrich et al. (2020) and ElMessiry et al. (2019)
	Public governance	Martínez et al. (2019)
	IoT	Arcenegui et al. (2020)
	Real estate	Gupta et al. (2020)
	Energy	Marchesi et al. (2019)
Rationale	Secure data traceability	Arcenegui et al. (2020) and Westerkamp et al. (2018, 2020)
	Availability of products	Davydov and Yanovich (2020) and Khan et al. (2020)
	Transparency	Arcenegui et al. (2020) and ElMessiry et al. (2019)
	Auditability	Arcenegui et al. (2020)
	Liquidity	Gupta et al. (2020) and Tian (2020)
	Price stability	Heryadi et al. (2021)
	Greater participation	Martínez et al. (2019)
Tokenised	Physical asset	Arcenegui et al. (2020), Davydov and Yanovich (2020), Dietrich et al. (2020), ElMessiry et al. (2019), Heryadi et al. (2021), Marchesi et al. (2019), Westerkamp et al. (2018, 2020)
Asset	Digital asset	Davydov and Yanovich (2020), Gupta et al. (2020), Khan et al. (2020), Martínez et al. (2019) and Tian (2020)
	Security token	Arcenegui et al. (2020), Davydov and Yanovich (2020), Dietrich et al. (2020), ElMessiry et al. (2019), Gupta et al. (2020), Heryadi et al. (2021), Khan et al. (2020), Marchesi et al. (2019), Tian (2020) and Westerkamp et al. (2018, 2020)
Token layer	Utility token	Marchesi et al. (2019); Martínez et al. (2019)
	Digital currency	✗
Token type	Fungible token	Arcenegui et al. (2020), Davydov and Yanovich (2020), Gupta et al. (2020), Heryadi et al. (2021), Khan et al. (2020) and Tian (2020)
	Non-fungible token	Davydov and Yanovich (2020), Dietrich et al. (2020), ElMessiry et al. (2019), Marchesi et al. (2019) and Westerkamp et al. (2018, 2020)
Actors	Users	Dietrich et al. (2020), Westerkamp et al. (2018), Westerkamp et al. (2020), ElMessiry et al. (2019), Gupta et al. (2020), Khan et al. (2020), Tian (2020), Heryadi et al. (2021), Khan et al. (2020), Martínez et al. (2019) and Marchesi et al. (2019)
	Physical object	Marchesi et al. (2019)
	Conceptual object	Gupta et al. (2020) and Khan et al. (2020)

Table 3 Summary of the process category

Dimensions	*Values*	*Works*
Type of blockchain	Permissioned	ElMessiry et al. (2019) and Khan et al. (2020)
	Permissionless	Arcenegui et al. (2020), ElMessiry et al. (2019), Gupta et al. (2020), Heryadi et al. (2021), Khan et al. (2020), Martínez et al. (2019), Marchesi et al. (2019), Tian (2020) and Westerkamp et al. (2018, 2020)
	Consortium	Khan et al. (2020)
Standard	ERC-20	Heryadi et al. (2021); Tian (2020)
	ERC-721	Arcenegui et al. (2020), Dietrich et al. (2020), Marchesi et al. (2019) and Westerkamp et al. (2020)
	ERC-777	Gupta et al. (2020)
	ERC-T	Davydov and Yanovich (2020)
Static or dynamic	Static	Davydov and Yanovich (2020) and Heryadi et al. (2021)
	Dynamic	Dietrich et al. (2020), ElMessiry et al. (2019), Gupta et al. (2020), Marchesi et al. (2019), Tian (2020), Westerkamp et al. (2018, 2020) and Martínez et al. (2019)
	Both	Arcenegui et al. (2020)

We continue with the *process category*. First of all, the majority of the tokenisation approaches analysed here operate on a permissionless blockchain (Arcenegui et al., 2020; ElMessiry et al., 2019; Gupta et al., 2020; Heryadi et al., 2021; Khan et al., 2020; Martínez et al., 2019; Marchesi et al., 2019; Tian, 2020; Westerkamp et al., 2018, 2020; ElMessiry et al., 2019; Khan et al., 2020) proposed a token that can potentially be used on a permissioned platform and Khan et al.'s (2020) approach also works on a consortium (*type of blockchain*). Various *standards* were used, which is consistent with the various types of tokens identified in Table 2, specifically: ERC-20 (Heryadi et al., 2021; Tian, 2020), ERC-721 (Arcenegui et al., 2020; Dietrich et al., 2020; Marchesi et al., 2019; Westerkamp et al., 2020), ERC-777 (Gupta et al., 2020), and ERC-T (Davydov and Yanovich, 2020). Finally, most authors proposed a dynamic documentation of their work (Dietrich et al., 2020; ElMessiry et al., 2019; Gupta et al., 2020; Marchesi et al., 2019; Tian, 2020; Westerkamp et al., 2018, 2020), using for instance sequence diagrams or flowcharts; while some authors proposed a documentation of some of the algorithms and/or providing some additional code to the standard (i.e., some additional functions) (Davydov and Yanovich, 2020; Heryadi et al., 2021; Arcenegui et al., 2020) propose both approaches.

Finally, we look at the *evaluation category*. Some authors proposed a sort of a proof of concept (POC) of their tokenisation approach (Arcenegui et al., 2020; Khan et al., 2020; Westerkamp et al., 2018, 2020); while the others proposed a theoretical or conceptual model of their process (Davydov and Yanovich, 2020; Dietrich et al., 2020; ElMessiry et al., 2019; Gupta et al., 2020; Heryadi et al., 2021; Martínez et al., 2019; Marchesi et al., 2019; Tian, 2020) (*implementation*). Following the implementation, the following *strengths* were identified: security and low gas consumption (Arcenegui et al., 2020); lowered costs (Khan et al., 2020); better data traceability, documentation of consumed resources and transparency (Westerkamp et al., 2018, 2020). Other strengths, following the rationale of the tokenisation or the analysis of the theoretical model, are: continuous administration of the SC (Dietrich et al., 2020), separation of financial aspect from real-world process allowing their simultaneous existence

ElMessiry et al. (2019), flexibility regarding the purchase of tokens (Gupta et al., 2020), the solution addresses the volatility (Heryadi et al., 2021), better management and more citizen engagement (Martínez et al., 2019), and transparency (Tian, 2020). Finally, following the implementation, some *limitations* were identified. These are missing or under-performing features: data security (Arcenegui et al., 2020), need for regulation (Khan et al., 2020); and additional features needed or desired (Westerkamp et al., 2018, 2020). Other limitations, following the rationale of the tokenisation or the analysis of the theoretical model, are: how to handle the changes in the SC (Dietrich et al., 2020); practical feasibility or experimental evaluation (Dietrich et al., 2020; ElMessiry et al., 2019; Martínez et al., 2019; Marchesi et al., 2019); need for regulation (Heryadi et al., 2021; Tian, 2020); volatility and limited adoption (Tian, 2020); and additional features needed or desired (Gupta et al., 2020; Heryadi et al., 2021).

Table 4 Summary of the evaluation category

Dimensions	*Values*	*Works*
Implementation	True	Arcenegui et al. (2020), Khan et al. (2020) and Westerkamp et al. (2018, 2020)
	False	Davydov and Yanovich (2020), Dietrich et al. (2020), ElMessiry et al. (2019), Gupta et al. (2020), Heryadi et al. (2021), Martínez et al. (2019), Marchesi et al. (2019) and Tian (2020)
Strengths	Security	Arcenegui et al. (2020)
	Low gas consumption	Arcenegui et al. (2020)
	Continuous administration of the SC	Dietrich et al. (2020)
	Separation of financial aspect from real-world process	ElMessiry et al. (2019)
	Flexibility regarding the purchase of tokens	Gupta et al. (2020)
	Less volatility	Heryadi et al. (2021)
	Lowered costs	Khan et al. (2020)
	Better management and more citizen engagement	Martínez et al. (2019)
	Better data traceability	Westerkamp et al. (2018, 2020)
	Documentation of consumed resources	Westerkamp et al. (2018, 2020)
	Transparency	Westerkamp et al. (2018, 2020) and Tian (2020)
Weaknesses	Data security	Arcenegui et al. (2020)
	Evolution	Dietrich et al. (2020)
	Practical feasibility or experimental evaluation	Dietrich et al. (2020), ElMessiry et al. (2019), Martínez et al. (2019) and Marchesi et al. (2019)
	Need for regulation	Heryadi et al. (2021), Khan et al. (2020) and Tian (2020)
	Volatility	Tian (2020)
	Limited adoption	Tian (2020)
	Additional features	Gupta et al. (2020), Heryadi et al. (2021) and Westerkamp et al. (2018, 2020)

5 Discussion

This section highlights and discusses some patterns identified after the application of the framework in Section 4. The practical implications, future research directions, and limitations are also discussed.

5.1 Results analysis

The application of the context category shows that the authors who tokenised a digital asset looked for an increased availability of the asset (Davydov and Yanovich, 2020; Khan et al., 2020), better liquidity (Gupta et al., 2020; Tian, 2020) or a greater participation in public governance (Martínez et al., 2019). On the other hand, the authors who tokenised a physical asset aimed for secure data traceability (Arcenegui et al., 2020; Westerkamp et al., 2018, 2020), more transparency (Arcenegui et al., 2020; ElMessiry et al., 2019), auditability (Arcenegui et al., 2020), and better price stability (Heryadi et al., 2021). We can also state that in the majority of cases, the tokenisation addressed (only) a security token.

The application of the process category shows that most tokenisation approaches are compatible or drew on permissionless blockchains (Arcenegui et al., 2020; ElMessiry et al., 2019; Gupta et al., 2020; Heryadi et al., 2021; Khan et al., 2020; Martínez et al., 2019; Marchesi et al., 2019; Tian, 2020; Westerkamp et al., 2018, 2020). Ethereum was mostly cited, and this is consistent with the fact that no digital currency was created. By proposing security tokens and building on Ethereum, the authors can take advantage of Ethereum's own digital currency, namely Ether. Thereby, the authors do not have to concern themselves with that specific layer.

Finally, from the application of the evaluation category, we can see that many approaches still need to be tested.

5.2 Implications and future research directions

This work, we believe, will be helpful for both researchers and practitioners because it can assist them to design new tokenisation approaches. This work features constructs that we think are relevant when designing a new token. Furthermore, this work can help interested readers understand tokenisation approaches, analyse them and compare them.

Additionally, the classification framework can act as a checklist or a process to follow when diving into a tokenisation endeavour. Specifically, if one wants to tokenise an asset, she can go through the different steps as depicted in Figure 1:

1 Carry out an initial assessment, i.e., appraise the various dimensions of the context category.

2 Determine the tokenisation process, i.e., determine the type of blockchain, the standard, and the nature of the approach to use.

3 Perform the implementation evaluation, i.e., execute the implementation and assess its strengths and weaknesses.

Finally, Figure 2 shows the works practitoners can use and researchers can build on to develop their own tokenisation approach. Depending on various factors – namely:

1 the asset to be tokenised
2 the token layer the researcher wants to address
3 the token type
4 the modelling approach – the researcher can identify the relevant work(s) she can consider to draw on.

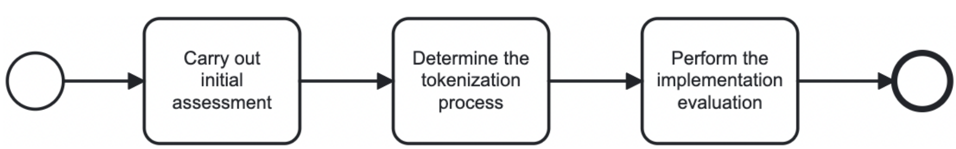
Furthermore, the decision tree points out the potential future research directions. Specifically, we can see that the following areas still need to be investigated:

- Digital asset tokenised as a security and fungible token and documented with a static model.
- Digital asset tokenised as a security and NFT and documented with a dynamic model.
- Digital asset tokenised as a utility and fungible token and documented with a static model.
- Digital asset tokenised as a utility and NFT.
- Physical asset tokenised as a security and NFT and documented with a static model.
- Physical asset tokenised as a utility and fungible token.
- Physical asset tokenised as a utility and NFT and documented with a static model.

These research directions highlight the need for software modelling specific to blockchain, which is aligned with Destefanis et al. (2018) where the authors advocate the need for a blockchain-oriented software engineering (BOSE) discipline. The work points to three areas that need to be addressed by BOSE:

1 best practices and development methodology
2 design patterns
3 testing.

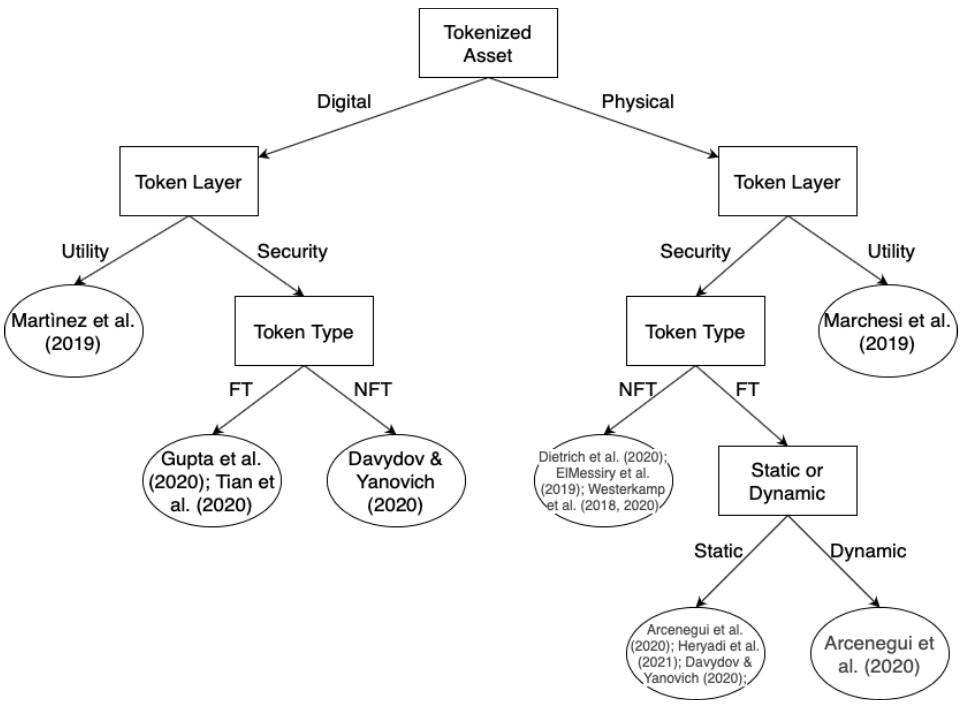
Figure 1 How to tokenise? Process



5.3 Limitations

This work suffers from three main limitations. Firstly, we deliberately excluded an important aspect related to tokens and the tokenisation, namely the *DApp*. We recognise that this aspect is important, however the primary objective of this study was to focus on the tokenisation and its outcome, the token. Hence, we analysed the How and the Why of the tokenisation but did not discuss the whole ecosystem in which the tokens unfold. This will be addressed in our future work. Secondly, this work does not provide an exhaustive list of the tokenisation approaches proposed in the literature. Nevertheless, we believe that if we had applied the framework to more articles, it would have strengthened the conclusions, but it would not have dramatically altered the trends identified here. Finally, the application of the framework was done by the author alone, which can lead to some bias or subjectivity. Nevertheless, we paid close attention to confront the studies we were analysing with the definition of the category and dimension; thereby, mitigating as much as possible the risk of subjective perception.

Figure 2 How to develop a tokenisation approach? Decision tree



6 Conclusions

In this paper, we aimed to provide an analysis and description of the existing tokenisation approaches. We believe this is relevant given the relative novelty of the phenomenon. Specifically, we aimed to:

G.1 Provide a landscape of tokenisation approaches.

G.2 Provide some recommendations for the appropriate tokenisation approaches – based on the current ones.

G.3 Identify future research directions.

Consequently, drawing on the literature, we devised a classification framework and analysed multiple tokenisation approaches through that framework (G.1). This application enabled us to conceive a process and a decision tree that can point out relevant works if researchers and practitioners want to draw on or build on an existing approach (G.2). Furthermore, the decision tree allowed us to identify potential research directions (G.3).

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Notes

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