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Review

From NFT 1.0 to NFT 2.0: A Review of the Evolution of Non-Fungible Tokens

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Abstract: Non-fungible tokens (NFT) represent one of the most important technologies in the space of Web3. Thanks to NFTs, digital or physical assets can be tokenised to represent their ownership through the usage of smart contracts and blockchains. The first generation of this technology, called NFT 1.0, considers static tokens described by a set of metadata that cannot be changed after token creation. The static nature prevents their wide spread as they do not support any meaningful user interaction. For this reason, its evolution, called NFT 2.0, has been proposed to make tokens interactive and dynamic and enhance user experience, opening the possibility to use NFTs in more ways and scenarios. The purpose of this article is to review the transition from NFT 1.0 to NFT 2.0, focusing on the newly introduced properties and features and the rising challenges. In particular, we discuss the technical aspects of blockchain technology and its impact on NFTs. We provide a detailed description of NFT properties and standards on various blockchains and discuss the support of the most important blockchains for NFTs. Then, we discuss the properties and features introduced by NFT 2.0 and detail the technical challenges related to metadata and dynamism. Lastly, we conclude by highlighting the new application scenarios opened by NFT 2.0. This review paper serves as a solid base for future research on the topic as it highlights the current technological challenges that must be addressed to help a wide adoption of NFTs 2.0.

Keywords: non-fungible tokens; NFTs; blockchain; dynamic NFTs

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Citation: Guidi, B.; Michienzi, A. From NFT 1.0 to NFT 2.0: A Review of the Evolution of Non-Fungible Tokens. *Future Internet* **2023**, *15*, 189. https://doi.org/10.3390/fi15060189

Academic Editor: Franco Davoli

Received: 5 April 2023
Revised: 12 May 2023
Accepted: 22 May 2023
Published: 24 May 2023

1. Introduction

One of the most groundbreaking ideas in the Web3 space and the metaverse is the non-fungible token (NFT). As their name suggests, NFTs are blockchain tokens that are distinguishable one from the other, and therefore can be used to represent the property of a unique digital or physical asset. Their popularity is growing, rapidly reaching a global scale, with millions of active traders [1] and a market volume worth billions of USD yearly [2]. Whilst initially proposed for the art industry as a means to represent the ownership of unique pieces of art with provably scarce traits, they have found applications in many fields, for example, as tools to prevent the unauthorised forwarding of private content [3] or the tokenisation of metaverse goods [4] and lands [5]; as a way to model an in-game character [6]; or as proof of purchase of expensive cars or clothes [7].

NFTs can be uniquely identified by the address of the smart contract that manages the collection and a unique identifier. Each token also has some associated metadata that describe the asset whose property is being represented by the token. Typically, metadata are organised according to JavaScript Object Notation (JSON), and include a name, description, a link that points to the location where a media file is stored, and a series of traits that describe the asset. The media file can be a picture, a video, a website, a piece of code, or any arbitrary data [8]. Metadata are an important aspect of the NFTs, as they are used by NFT marketplaces to describe the characteristics of each NFT and to compute the rarity of a token [9].

In the first generation of NFTs, known as *static* NFTs or NFT 1.0, the metadata were defined when the token was generated and could not be changed afterwards. An example is the Boring Ape NFT, which contains only the Boring Ape picture, and its traits as a JSON object and cannot be changed (An example of the metadata associated with a Bored Ape NFT: https://ipfs.io/ipfs/QmeSjSinHpPnmXmspMjwiXyN6zS4E9zccariGR3jxcaWtq/0, accessed on 23 May 2023). Having static metadata is great for artwork and collectible NFTs. However, to build a robust and open NFT system that goes beyond artwork and collectibles, many attributes in the metadata need to be updated. For example, players' performance in games can affect their character levels. Looking beyond static images and simple collectibles is crucial to truly enhance user experience with NFTs. From healthcare and passports to real estate and art verification, the endless possibilities of NFTs are slowly emerging. However, for NFTs to truly shine and realise their potential, application builders must reimagine what these tokens represent. Indeed, they should focus more on the users' needs and on real-world applications so that people will fully benefit from this technology.

For this reason, NFTs have kept evolving, and lately, an evolution of the technology, called NFT 2.0, has been proposed. NFT 2.0, also known as *dynamic* NFTs, introduces the possibility to interact with NFTs, compose and enhance them, update their metadata, and add a degree of randomness in order to widen the scope of their application; enable new use cases, such as video games, dynamic collectibles and ID cards; and improve the user experience.

Dynamic NFTs, as the name suggests, refer to a type of NFT that changes its behaviour according to certain external circumstances or inputs supplied by the owners. While in the earlier version of NFT technology, NFTs could not be altered once generated, in NFT 2.0, the dynamism feature has been introduced, which has made the NFTs interactive and more engaging by providing them with special commands that help in modifying the nature of the tokens. NFTs can interact with the protocol in the way specified in the smart contract, and the metadata contain all the key data that defines the asset. So, by adding more programmability and functionality, NFTs will go beyond artwork and collectibles and change the way we use metadata.

The metadata of a dynamic NFT can change due to user interaction. For instance, some game model monsters can be bred as NFTs, and the number of breeds can be stored in the NFT. Some NFTs are also often referred to as "Living NFTs", and can have their characteristics change because of a special event or a real-world occurrence, as well as seeing their value and demand shift. One such example is NFTs that evolve based on real-world data changes delivered to the blockchain via oracles [10] or via user interaction as the NFT changes its state [11]. For instance, an NFT card representing a basketball player can show additional data and even unlock traits according to the player's performance [10] (https://blog.chain.link/how-lamelo-ball-dynamic-nfts-redefine-player-fan-experience/, accessed on 23 May 2023). Authenticity in dynamic NFTs makes them applicable in various areas. For instance, NFTs could replace passports to travel across the globe without paperwork or stamps [12]. All changes are reflected in the NFT's code, with no chance of fraud or scamming. The same can be carried out for banking accounts, educational certificates, insurance, and any other documentation that gets instantly updated once you input new data. Another crucial aspect related to dynamism is the possibility of introducing randomness fairly and in a provable way through verifiable random functions (VRF). In particular, randomness greatly enhances user experience in play-to-earn games, where players enjoy the fair and random distribution of rare assets and power rankings during in-game campaigns and engagement activities [13].

Considering the societal impact of NFTs on society, it has become of paramount importance to review the evolution of the technology from its 1.0 version to 2.0. This evolution is critical because it completely changes several key properties of NFTs, in particular the possibility to have dynamic metadata, thus opening the opportunity to apply the technology in innovative ways. NFT 2.0 is a complex system that involves the solution of many technical challenges, and it is important to describe its evolution. Therefore, the purpose of this paper is to deliver a complete evolution of NFTs, mentioning what was there before the concept of NFT became a standard, what is the current state of the technology (NFT 1.0), and where NFT 2.0 is leaning. Additionally, we include a discussion concerning the technical challenges related to their on- and off-chain implementation. Shortly, our contribution can be summarised as follows:

- A review of the technological support offered by the blockchain to NFTs, focusing on the various blockchain network types, their consensus protocols, and their impacts on NFT projects;
- An analysis of NFT 1.0, including a discussion of their properties and standards proposed;
- A comparison between NFT-supporting blockchains in terms of six key properties that define the blockchains' support for NFTs;
- Highlighting innovations of NFT 2.0 with respect to NFT 1.0;
- Pointing out the sources of dynamism for NFT 2.0 metadata, and how metadata can be stored;
- Showcasing the most promising NFT 2.0 applications.

The concept of NFT with dynamic metadata is not new to the scientific literature [14]; however, it has not been tackled with the due amount of detail. Indeed, some documents present the topic at a very high level and focus only on arts [15], while others discuss the topic without delving deeper into the technical details, challenges, and opportunities around NFT 2.0 [10]. This paper improves on the literature because it provides a review of all technical aspects and includes discussions on various technological aspects, such as the support offered by blockchain technology, NFT standards, and NFT metadata dynamism, focusing on the evolution of NFTs from 1.0 to 2.0.

The paper is structured as follows. In Section 2, we present the background information concerning blockchains and NFTs, while in Section 3, we propose a comparison of blockchains that support the deployment of NFTs. In Section 4, we describe the transition between NFT 1.0 and NFT 2.0, and we describe the new scenarios of NFT 2.0. Section 5 summarises the contribution of the paper.

2. Background and Preliminaries

In the rest of this Section, we propose an overview of blockchain technology and details concerning non-fungible tokens.

2.1. Blockchain Technology

A blockchain is an immutable digital ledger, maintained by a distributed network, that facilitates the process of recording transactions. Each participant node within the network maintains the ledger by storing a copy and approving and managing new transactions. A blockchain can be described as a chain of logically linked blocks, as shown in Figure 1. The block is the data structure used to store information, and it contains a block header, which comprises the metadata that help verify the validity of a block; and a block body, which contains all the transactions included in the block. Each block header contains the hash of the block and the hash of the previous block. In this way, each block is connected to the previous one, enhancing the security of the blockchain. The body of each block contains a list of transactions, and a transaction generally consists of a sender address, a receiver address, a value, and a fee dedicated to their confirmation. When a transaction is created, it is broadcast to all the nodes participating in the blockchain network, so that they can perform the required step to put them in a block. To reach an agreement regarding which transactions should be included in blocks, and in which order, nodes have to execute a consensus protocol.

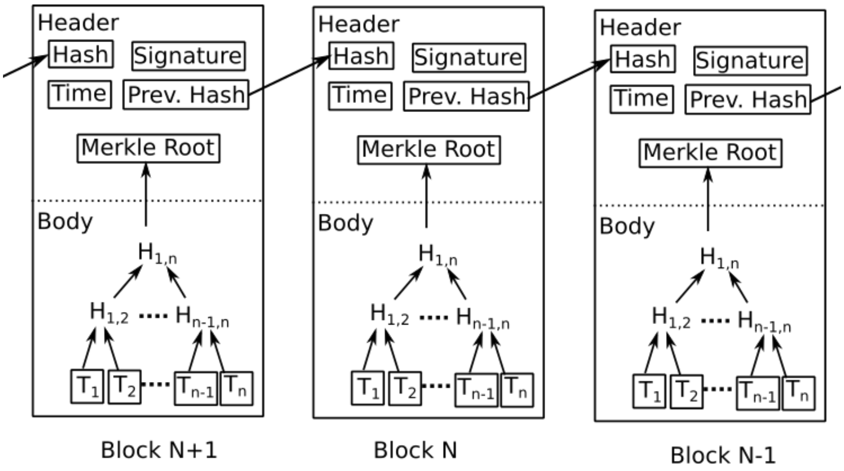

Figure 1. Blockchain structure.

Thanks to its cryptographically linked structure, a blockchain is tamper-resistant because it is extremely challenging to modify the data already stored in the blockchain. Additionally, blockchains provide data auditability in the sense that the data stored in the blockchain are publicly visible to all peers in the network. Finally, while adding data to a blockchain is a complex task solved by a consensus protocol, checking whether a transaction belongs to a block or a block belongs to the blockchain is very easy.

Blockchain technology is principally known thanks to Bitcoin [16], which supports only cryptocurrency transactions. Since then, new blockchains that support code execution, known as smart contracts, have been proposed, such as Ethereum [17]. Thanks to the introduction of smart contracts, blockchains have fuelled the emergence of new ideas, including decentralised finance (DeFi) [18] and the tokenisation of goods, which, combined, gave birth to non-fungible tokens (NFTs).

2.2. Blockchain Classification

The most well-known blockchain classification divides them into two categories: permissionless and permissioned [19]. Permissionless blockchains allow any user to join the blockchain network, while in permissioned blockchains, nodes must be authenticated. Both categories have some benefits and drawbacks. Indeed, permissionless blockchains are considered more secure than permissioned blockchains because they have many nodes that participate in the validation of transactions. However, they usually have long transaction processing times due to a large number of nodes and the large size of the transactions [19].

In the literature, four types of blockchain structures have been identified [20] (see Figure 2). We provide a comparison of the blockchain structures in Table 1. Briefly, the four blockchain structures are the following:

- **Public blockchains** . Public blockchains are permissionless and completely decentralized, and are primarily used for exchanging and mining cryptocurrencies, such as bitcoin and Ethereum.
- **Private blockchains**. Private blockchains are permissioned blockchains fully controlled by a single organization. A famous private blockchain is Hyperledger [21].
- **Consortium blockchains**. Consortium (or federated) blockchains [22] are permissioned blockchains governed by a group of organizations instead of only a single organization; therefore, they are more decentralized than private blockchains.
- **Hybrid blockchains**. A hybrid blockchain is defined as a blockchain that attempts to use the best part of both private and public blockchain solutions. Indeed, hybrid blockchains are controlled by a single organization, but with a level of oversight performed by the public blockchain, which is required to perform certain transaction validations.

Table 1. A comparison of the types of blockchain structures and their properties.

Property	Public Blockchain	Private Blockchain	Consortium Blockchain	Hybrid Blockchain
Consensus determination	All miners	One organisation	Multiple organisations	One organisation
Consensus process	Permissionless	Permissioned	Permissioned	Permissioned
Read permission	Public	Public or Restricted	Public or Restricted	Public or Restricted
Immutability	Almost tamper-proof	High potential for tampering	Medium potential for tampering	Low potential for tampering
Efficiency	Low	High	High	Medium
Centralised	No	Yes	Partial	Partial
Example	Bitcoin	Hyperledger	Quorum	IBM Food Trust

Both private and public blockchains have drawbacks: public blockchains tend to have longer validation times for new data than private blockchains, and private blockchains are more vulnerable to fraud and bad actors. To address these drawbacks, consortium and hybrid blockchains have been developed. Current NFT projects are proposed on public blockchains, which are preferred, considering that all the projects are public and they try to include a huge amount of users. However, there are many benefits to running an NFT platform on a private chain. First of all, it allows the NFT team to have control over the entire blockchain with fewer risks concerning decentralisation. Furthermore, it allows them to use the chain and token as payment methods for their services. Additionally, private blockchains benefit from a lower running cost, faster transaction confirmation, and increased data privacy.

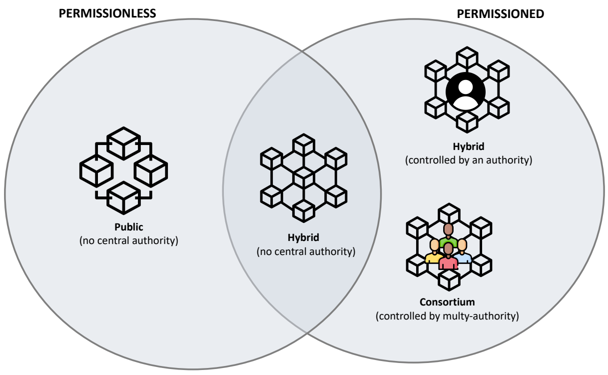

Figure 2. Blockchain Classification.

2.3. Consensus Protocols

There are numerous consensus protocols available for a blockchain network. The most important ones are summarised in Table 2. The first protocol proposed, called proof of work (PoW) [23], establishes that to add a new valid block to the blockchain, a node must solve some sort of computationally hard problem. For this problem, PoW blockchains usually require the node to find a value (called a *nonce*) to concatenate to the block header, so that by applying a cryptographic hash function, a value with a certain number of leading bits equal to 0 is found. Since a brute force approach is the most effective known method, nodes are expected to perform a lot of computation before finding a valid nonce for their candidate block.

Table 2. Comparison of the blockchain consensus protocols.

Acronym	Decide Block Creators	Confirmation Time
PoW	Solve a computationally hard problem	High
PoS	Stake cryptocurrency to have a chance	Medium
DPoS	Staking gives rights to vote	Low
LPoS	Mix of PoS and DPoS	Medium
PoA	Chosen by an authority	Low
PoSA	Authority choses from a pool of DPOS-elected nodes	Low
PoH	Compute a sequence of values	Medium

Since PoW requires immense computational power, other protocols, such as proof of stake (PoS) [24], have been proposed. PoS requires each node that wants to participate in the block creation process to put some cryptocurrency at stake. The next block creator is chosen proportionally to the amount of cryptocurrency and the time it has put at stake. To prevent nodes from acting maliciously, if the block proposed by a node is not valid, part of the stake of that node is lost. A variation of the PoS, called delegated proof of stake (DPoS) [25], tries to address the fact that to be able to confirm blocks in a PoS, one needs to put a lot of cryptocurrency at stake. Indeed, DPoS works like an indirect democracy, where cryptocurrency holders can put some at stake, and vote for their favourite block validators. The top validators, based on the votes weighted by the stake of the voter, are scheduled to produce blocks in round-robin at fixed time intervals. Liquid proof of stake (LPoS) [26] is a combination of PoS and DPoS, because according to this consensus protocol, token holders can either stake their token for themselves or delegate their stake to other nodes. Therefore, in an LPoS network, large token holders can become block creators, but smaller holders can also become block creators by seeking support from other holders.

The proof of authority (PoA) [27] consensus protocol instead leverages the value of identities of nodes, meaning that block validators put their reputation at stake, rather than their cryptocurrency. Therefore, in PoA blockchains, block creator nodes are entities considered trustworthy by the network. Since the number of block creators is low, PoA blockchains are usually highly scalable. The proof of staked authority (PoSA) [28] consensus algorithm is a hybrid between DPoS and PoA, where a set of candidate validator nodes is elected via DPoS, and among them, an authority elects the designated block creator. Finally, proof of history (PoH) [29] consists of a sequence of computations that can provide cryptographic proof that some time passed between two events. It carried this out by concatenating the output of one computation to the input of the next. In the scenario of NFTs, consensus protocols play an important role because they determine the throughput and transactions per second (tps) supported by the blockchain. In addition, NFT projects tend to prefer blockchain networks that use consensus protocols that introduce less centralisation.

2.4. Non-Fungible Tokens (NFTs)

NFT stands for non-fungible token [8], and they are used to identify digital or physical assets uniquely. Tokens are cryptographic assets on a blockchain, and they have unique identification codes to distinguish them from each other. Traditional cryptocurrencies (e.g., bitcoin or ether), are like fiat currencies, meaning that each token of the same currency has the same value, making them fungible. Instead, each NFT is unique and irreplaceable. The meaning of their non-fungibility is that one NFT can not be equal to another. Additionally, NFTs can not be divided or merged [30]. For all these reasons, they present unique properties.

NFTs enable a variety of new use cases and application scenarios, such as digital artwork, virtual gaming assets, and software licenses. In particular, it makes possible the tokenisation of individual digital or physical assets, which is not feasible with fungible tokens. Table 3 summarises the most important differences between fungible and non-fungible tokens.

As concerns the idea for NFTs, it was generated from 'Coloured Coin' [31], initially distributed on the Bitcoin network. Coloured coins are tokens that represent real-world assets and can be used to establish the ownership of anything [32].

In 2014, Counterparty, a peer-to-peer distributed financial system built on the Bitcoin blockchain, was founded. Counterparty is an open-source protocol that allows users to create new digital tokens and establish smart contracts that are performed within the Bitcoin blockchain. Spell of Genesis was the first game built using Counterparty. It was only in 2016, with the release of Rare Pepe NFTs [33] on the Counterparty platform [31], that the concept of NFTs started being applied to pictures and digital art.

Thanks to the introduction of the Ethereum blockchain in 2014, a set of token standards was introduced to allow the creation of NFTs by developers. Rare Pepes started to be exchanged on Ethereum in early 2017, and later on, other important initiatives were proposed. Two of the most famous are Cryptopunks and CryptoKitties [34]. Cryptopunks is one of the earliest examples of NFT deployed on top of the Ethereum blockchain. Although these NFTs do not follow any token standard, the developers of the ERC-721 (Ethereum's Request for Comment) standard took deep inspiration from the Cryptopunks smart contract for the definition of the standard. Cryptopunks NFTs consist of 9999 algorithmically generated portraits that can be collected or used as profile pictures. CryptoKitties NFTs are instead fully-fledged ERC-721 compliant tokens. They are a virtual game that lets players adopt, breed, and trade virtual cats using Ethereum. There are already more than 2 million Cryptokitties NFTs circulating on the Ethereum blockchain [35].

Between 2018 and 2022, NFTs slowly moved into public awareness before exploding into mainstream adoption in early 2021, mostly via NFT gaming and metaverse initiatives [36].

Table 3. Comparison between fungible and non-fungible tokens.

Parameter	Non-Fungible Token	Fungible Token
Interchangeability	Non-Interchangeable	Interchangeable
Uniformity	Unique	Identical
Divisibility	Non-Divisible	Divisible
Standard	ERC-721	ERC-20

2.5. NFT Key Properties

At a high level, NFTs contain two parts: the smart contract and the metadata for the digital artwork [37]. The smart contract exists on a blockchain, and contains a set of rules or standards that facilitates the transaction and serves as a digital description of the content. NFT smart contracts also keep track of the owner of each token using appropriate data structures. Each token, stored in the smart contract, includes a link that uniquely identifies the asset represented. NFTs can represent any asset with specific characteristics [38]. In the following, we highlight the key properties of NFTs (Figure 3):

- Indivisibility. NFTs have been tailored to be indivisible by default for serving their utility. Indeed, this property comes from the non-fungible nature of NFTs, and means that NFTs can not be divided into smaller tokens, but the whole NFT can be purchased for owning an item.
- Scarcity and uniqueness. These properties are strictly related to the previous one. Indeed, NFTs are unique by definition. This means that NFTs cannot be replicated or reproduced, which provides a verifiable scarcity property that is notoriously difficult to obtain online.

- Security. The support of blockchain technology guarantees a high security level. Indeed, NFTs are stored on the blockchain network, and for this reason, they are tamper-proof. Furthermore, the blockchain can be used to verify ownership.
- Traceability. When an NFT is issued, the holder is recorded on the blockchain, and all the transactions are also recorded. For this reason, all the history involved in a specific NFT can be retrieved.
- Interoperability. NFTs can be easily moved across multiple systems.

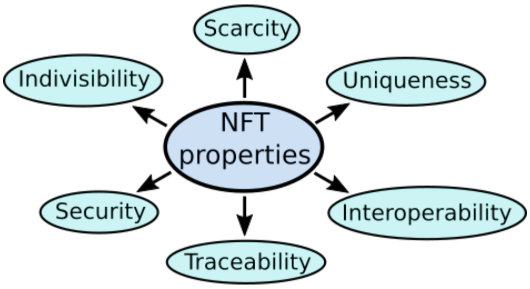

Figure 3. NFT key properties.

2.6. NFT Standards

NFT standards describe how to build non-fungible tokens on a particular blockchain protocol. Ethereum was the first blockchain protocol to create and launch NFTs, but it is not the only one [39]. We can divide the NFT standards into Ethereum standards and non-Ethereum standards.

The two main pieces of an NFT are the smart contract, which contains the logic and decentralised storage, such as the InterPlanetary File System (IPFS) [40], to store the metadata and assets that the smart contract points to. Traditionally, there are two ways NFT smart contracts such as the ERC-721 and ERC-1155 variants can store information:

- The contract stores a universal resource identifier (URI) that is accessible via the tokenURI() function. This URI points to a decentralised storage location such as IPFS or Arvweave [41], and applications such as Opensea can query these data directly from the source.
- The smart contract stores the data needed to recreate the asset. Generally speaking, the data are composed of a few bytes per token, and the smart contract also has a function that recreates the asset. This approach is more commonly used in generative art NFTs.

The metadata for most existing NFTs contain names, descriptions, and content identifiers (CIDs) that point to media files. However, due to the flexibility of the metadata described above, metadata can be used to specify many things: expiration date, the underlying asset, strike price, yield, fixed interest rate, depreciation rate, accessibility, etc. Metadata can also contain functional attributes, such as specifying in-game character levels, recording the number of scans of a QR code on a membership pass, or specifying irreplaceable details in financial information. As an example, Uniswap uses NFTs to keep track of liquidity provider (LP) positions. When someone adds liquidity to a liquidity pool, it receives an NFT that contains the pool identifier, the number of tokens added to the pool, the earned fees, and other information in its metadata.

2.7. Ethereum Standards

The current concept of NFT was first introduced in Ethereum with EIP-721 (Ethereum Improvement Protocol) in 2017 (https://eips.ethereum.org/EIPS/eip-721, accessed on 23 May 2023). EIP-721 defines a standard, ERC-721 [42], for unique tokens significantly different from the ERC-20 standard, which is the one adopted by Ethereum for fungible tokens.

Ethereum's ERC-721 standard contains an interface that must be implemented by a smart contract to let users mint and trade ERC-721-compliant NFTs. NFTs are identified by a unique, 256-bit-long, unsigned integer identifier stored inside the smart contract, which cannot change. However, different contracts may use the same identifiers for their tokens, meaning that each NFT can be globally and equivocally identified by the pair (contract_address, tokenId). When a new NFT is minted, some ERC-721 smart contracts [43] find it convenient to use incrementally generated tokenIds for each new NFT; however, no safe assumption can be made because the standard does not set a specific rule for the tokenId creation. On top of that, NFTs may be destroyed on specific occasions, thus requiring additional functions for enumeration [8].

The interface proposed by the ERC-721 standard provides functionalities to transfer tokens among Ethereum's addresses. The main functions are the following:

- `transferFrom` allows the change of ownership of an NFT;
- `approve` allows the owner of an NFT to let another address transfer the NFT;
- `getApproved` returns the approved (via the `approve` function) addresses of an NFT;
- `balanceOf` returns the number of NFTs owned by an address;
- `ownerOf` returns the owner address of an NFT.

On top of the interface that a contract must implement, the ERC-721 also supplies an interface that addresses what must be implemented to receive NFTs, and contains a callback method to handle the receipt of a token being transferred. Optionally, ERC-721 tokens can have a metadata extension that specifies the name and symbol of the tokens, and a function that, given a tokenId as input, returns a JSON object with metadata assigned to a specific token. The JSON object contains the name of the token, and can also contain a URI to a resource tied to the NFT. Examples of resources that can be tied to the NFT are images and gifs, sound and songs, virtual resources and characters, digital items, tickets to physical events, and more.

Another Ethereum standard is the ERC-1155, called the Multi-Token Standard. It offers the possibility to define "semi-fungible" tokens, or in other words, NFTs for which there are multiple circulating copies. While in the ERC-721 standard, a unique ID represents a single asset, in the ERC-1155 standard, a unique ID represents a class of assets. For each class, an additional field represents the number of tokens. All the tokens that have the same ID are interchangeable, and the user can transfer any amount of assets to others (https://eips.ethereum.org/EIPS/eip-1155, accessed on 23 May 2023).

Lastly, ERC-998 is the standard that provides composable tokens. Thanks to this standard, it is possible to group ERC-721 and ERC-20 tokens into specific structures and manage their ownership atomically. A structure has a single owner address and can contain an arbitrary set of fungible and non-fungible tokens. Managing the ownership of such a structure is easier than managing each token individually because the owner can be changed with a single transaction (https://eips.ethereum.org/EIPS/eip-998, accessed on 23 May 2023).

2.8. Non-Ethereum Standands

Other blockchains have proposed standards for NFTs. Flow proposes an NFT standard that allows users to delegate their stakes to professional operators. Flow employs the "Upgradeable Smart Contract", a contract that can be updated by its authors. Authors can propose changes to the code of the smart contract, and when all authors agree on its final form, it is recorded on the blockchain and becomes immutable. The non-fungible token contract defines a set of functionalities that must be included in each implementation. Contracts that implement this interface are required to implement two resource interfaces: NFT, a resource that describes the structure of a single NFT; and Collection, a resource that can hold multiple NFTs of the same type (https://github.com/onflow/flow-nft, accessed on 23 May 2023).

Another standard is called FA2, proposed from the Tezos blockchain, which includes support for single or multiple token types, enabling batch transfers and atomic swaps of the tokens. FA2 enables developers to create custom token contracts and supports arbitrarily complex interactions with tokens. In particular, FA2 can have hybrid implementations where multiple token kinds (fungible, non-fungible, non-transferable, etc.) can coexist (e.g., in a fractionalised NFT contract). TF2 also specifies the standard of the metadata attached to a token, which includes an optional JSON string to describe each NFT.

Moreover, the EOS and WAX blockchains support the deployment of NFTs. An important standard is dGoods (https://docs.eosstudio.io/contracts/dgoods/standard.html, accessed on 23 May 2023), an open-source and free standard for handling the virtual representation of items, both digital and physical. The standard focuses on semi-fungible tokens; however, it is flexible, so it can be used also for strictly fungible or non-fungible tokens. The non-fungible tokens also have a metadata field, represented as a JSON object, which contains the type of asset associated with the token, a description of the asset, and various URIs to link the appropriate resources. However, the two blockchains also support other standards, including Atomic Assets (https://atomicassets.io/, accessed on 23 May 2023), which focuses on gaming applications and reducing the cost for the end users; and Simple Assets (https://simpleassets.io/, accessed on 23 May 2023), which focuses on artistic NFTs.

An interesting standard is the Token Metadata (https://docs.metaplex.com/programs/token-metadata/, accessed on 23 May 2023) program proposed for the Solana blockchain. Its main goal is to attach additional data to fungible tokens or NFTs on Solana. It achieves this using program derived addresses (PDAs), which are addresses derived from the addresses of other accounts. NFTs in Solana are Mint Accounts with the following characteristics:

- They have a supply of 1, meaning only one token is in circulation.
- The token has 0 decimals, so it cannot be divided.
- They have no Mint Authority, meaning that it is impossible to mint additional tokens.

Mint Accounts are responsible for storing the global information of a token, and Token Accounts store the relationship between a wallet and a Mint Account, such as the number of tokens held by the wallet it is linked to. Via a PDA, Metaplex defines a Metadata Account that stores data useful for applications and marketplaces, such as the list of creators of a token. Metadata Accounts also have a URI attribute that points to a JSON file stored off-chain, which provides additional storage without incurring on-chain storing fees. Additionally, the Token Metadata program offers another PDA derived from the Mint Account, specifically proposed for NFTs, called the Master Edition Account. This account substitutes the Mint Authority and acts as proof of non-fungibility for the Mint Account. Indeed, this way, no account can create other copies of the NFT, but thanks to the Master Edition Account, it is possible to update the tokens in case the standard changes.

Lastly, other blockchains have standards similar to Ethereum standards. For instance, TRC-721 (https://developers.tron.network/docs/trc-721, accessed on 23 May 2023) is analogous to Ethereum's ERC-721 for the TRON blockchain, while BEP-721 (https://academy.binance.com/en/glossary/bep-721, accessed on 23 May 2023) is analogous for the Binance Smart Chain (BSC) blockchain.

3. Blockchain and Solutions for NFT

During the last few years, several blockchain platforms have been proposed. The choice of the right platform to develop an NFT application can affect the functionalities of the application itself. First of all, we identify the principal criteria to consider before developing an NFT platform:

- **Transaction speed and confirmation time.** Transaction speed plays an important role in the success of an NFT project. It is not feasible for blockchains with lower transaction speeds to perform a bigger number of transactions per second [44]. Additionally, transaction speed has also a big impact on transaction costs. Indeed, if a blockchain has a low throughput, users have to pay higher fees to make sure that miners prioritize their transactions over others [45].
- **Transaction fee.** To speed up the adoption of NFTs, the market needs lower fees. Indeed, low transaction costs are crucial to the wider adoption of NFTs. The high fees for the minting process, but also for buying and selling NFTs, means that people can

easily lose money. For this reason, the chosen blockchain used to implement the NFT project should have no fee or a small fee, such as in Algorand [46].

- **Smart contract functionality.** The functionalities of an NFT are based on the underlying smart contracts. Indeed, all NFT platforms rely on smart contracts for verifying ownership and handling the transfer of tokens. For this reason, NFT smart contracts are important, and a current NFT project should be implemented by using a blockchain with robust and reliable smart contract functionality. Furthermore, the blockchain's smart contract programming language is important because it impacts the time and cost of confirming a transaction.
- **Consensus algorithm.** A consensus algorithm is a basis for a blockchain to achieve an agreement. The chosen blockchain technology and its consensus algorithm can have an impact on the NFT environment. Blockchains based on the PoW consensus mechanisms normally have to deal with numerous issues related to scalability and the time required to reach a consensus. A good alternative is projects based on PoS consensus algorithms, such as the Ethereum blockchain. Another way to reduce the issues, in particular those related to energy consumption, is to use layer 2 solutions that help reduce the number of transactions.

In the rest of the Section, we analyse the most used Blockchain platforms for NFT applications, as well as new solutions such as layer 2 and other protocols, by taking into account the features mentioned.

3.1. Blockchain for NFTs

In this Section, we provide an overview of the main used blockchain for NFT projects to highlight their characteristics, by taking into account the required criteria listed above. Table 4 reports the comparison of the platforms by also showing the NFT standards used by each blockchain. The comparison proposed takes into account transaction speed (transactions per second, tps), confirmation time (time required to confirm a new block), transaction cost fee (fee for a standard transaction that transfers an NFT), smart contract programming language, consensus protocol, NFT standards available on the blockchain, and the application field. To determine the application field, we evaluated the top trending collections (by number of NFT transfers and volume) in the largest marketplace for each blockchain, and reported the most common ones.

Most NFT projects are proposed on *Ethereum*, which has the two popular token standards ERC-721 and ERC-1155, described above. NFTs are compatible with anything built using Ethereum. To implement smart contracts, Ethereum uses Solidity [17], an object-oriented programming language compiled by the Ethereum Virtual Machine (EVM). The blockchain also features its crypto, called ether (or ETH). The Ethereum transaction fees are based on the network congestion [47] and are usually between USD 20 and USD 60 per transaction (the highest average transaction fee of USD 200 was registered on 1 May 2022) (https://etherscan.io/chart/avg-txfee-usd, accessed on 23 May 2023), which is higher compared to other blockchains. Moreover, Ethereum suffers from low throughput. Indeed, it permits 13–15 transactions per second. Nowadays, the top NFT marketplaces have been created on Ethereum, such as OpenSea, Rarible, and SuperRare [48], which explains why the blockchain supports a wide range of application fields.

The *Flow* blockchain (https://www.onflow.org/, accessed on 23 May 2023) is referred to as a good alternative to Ethereum. It is a new blockchain built to support arts- and sports-related NFTs. Flow started because of the popular game CryptoKitties. Indeed, the creators of CryptoKitties went to work on fixing issues, and in the process, they created Flow. The FLOW blockchain improves Ethereum's ERC-721 and ERC-1155 standards to provide an NFT implementation that can offer more support to applications. It was proposed in 2020, and it uses a PoS consensus algorithm capable of powering several application categories, such as games. Flow blockchain provides smart contracts programmed in Cadence, the programming language developed by Flow developers, and it ensures greater scalability. Indeed, it can execute more than 10,000 transactions per second. Flow has two fees: the first one is for creating an account, which starts at FLOW 0.001 (the native token), and the other is a transaction fee that is about FLOW 0.000001.

Cardano is a PoS blockchain [49] to create a convenient environment for developers. Cardano has two layers: the Cardano Settlement Layer (CSL), used for transferring its crypto value ADA between accounts and recording transactions; and the Cardano Computation Layer (CCL), which contains the data on how values are transferred [50]. Plutus is the smart contract platform of Cardano, and it is based on Haskell [51]. Haskell is also used for Marlowe, the domain-specific language used for creating financial smart contracts [52]. Cardano is capable of processing more than 250 transactions per second. As far as fees are concerned, it reaches about ADA 0.16–0.17 (https://www.statista.com/statistics/1278720/gas-price-cardano/, accessed on 23 May 2023). Furthermore, Cardano uses the standard CIP-721 to define an NFT metadata standard for native tokens, and mostly focuses on collectible and videogame NFTs.

EOS is a DPoS blockchain launched in 2017 that aims to implement a decentralised operating system [53]. It was designed to support the rapid development of decentralised applications at the industrial level by solving three of the most challenging problems of blockchain technology: transaction cost, confirmation time, and commercial scalability. EOS transactions are free, but to create them, a small upfront investment is required in the form of EOS token staking to acquire some blockchain-specific resources [54]. Concerning confirmation time, EOS can support over 4000 transactions per second, and the consensus protocol lets block creators create one block every 0.5 s. The blockchain uses C++ as the programming language for its smart contract, thus enabling scalable and high-performing decentralised applications. Among the most prominent NFT projects on the EOS blockchain, you can find AtomicMarket (a shared liquidity NFT market smart contract), Upland (the earth's metaverse mapped to the real world and accessible via web, iOS, and Android), Crypto Dynasty (an RPG&PvP dApp game), and other NFT-based games.

Tezos [55] is a self-amending, PoS-based blockchain with a strong emphasis on formal verification. Self-amending refers to the fact that Tezos uses a protocol to validate blocks and implement the consensus that can change itself. To be able to amend itself, Tezos uses a multi-step on-chain voting system, where its users can propose changes to the protocols, and after a testing phase, a final vote decides whether to accept or reject the modifications proposed. As consensus protocols, it uses the liquid proof of stake, a variation of PoS, where users can delegate their liquidity to other nodes to increase the chance they have of creating a block. To ensure the blocks are created without cheating, block creators, also called *bakers*, have to lock some funds for 2 weeks. This fund is used as a deposit in case the block becomes irreversible and contains illegal transactions. Since the focus of the blockchain is on having a strong governance system, it only supports around 40 transactions per second, with transaction fees of about 10 cents. Tezos is written in OCaml, with some functionalities related to the cryptographic aspect of the blockchain written in C. It adopted Michelson as a domain-specific smart contract language, but also supports other languages [56]. Tezos is mostly used for artistic NFTs and collectibles.

Binance Smart Chain (BSC) is a general-purpose blockchain that adopts a proof-of-staked-authority (PoSA) consensus mechanism. BSC and Binance chain are two projects that run in parallel and have built-in cross-chain compatibility. BSC block creators can create a new block approximately every 3 s, supporting fewer than 100 transactions per second. BSC has support for NFTs in the form of the BEP-721 standard, which is analogous to the ERC-721 standard, which are mostly collectibles. The fees for minting an NFT are about BNB 0.005 (around USD 3 (https://ycharts.com/indicators/binance_smart_chain_average_transaction_fee_es, accessed on 23 May 2023)), which is considerably cheaper concerning Ethereum. BSC uses Solidity and Vyper languages for smart contract development to provide advanced smart contract functionality [57].

Algorand is a highly efficient blockchain that is designed to overcome the major problem of the blockchain technology It adopts the pure proof-of-stake (PPoS) consensus protocol, meaning that block validators are chosen among all the token holders at random, proportionally to the amount of token held. Thanks to its aspect of randomness, this protocol grants a high level of decentralisation and protection from malicious attacks. It only requires minimal computation, which is independent of the number of participating nodes, making the blockchain extremely scalable. It supports over 1000 transactions per second with a small fee of ALGO 0.001. Algorand's smart contracts are written in TEAL, a programming language that resembles assembly, and that can be interpreted by the Algorand Virtual Machine. To help developers, a wrapper for TEAL is provided for the Python language, called PyTEAL, that simplifies writing and deploying smart contracts [46]. The most common NFTs available on Algorand are collectible items.

Solana is an open-source blockchain project aiming to provide a scalable, fast, cheap, and decentralised blockchain solution [58]. As a layer 1 blockchain like Bitcoin, Solana offers a basic infrastructure, such as processing transactions. Its whitepaper was released in 2017 by Anatoly Yakovenko, and the network launched three years later, in March 2020. Solana is based on proof of history (PoH), which greatly improves the scalability of the system [29]. In Solana, the most important NFT collections are related to arts and collectibles.

3.2. Other Solutions

Other solutions have been proposed to support the development of NFTs. In particular, the future of NFTs seems to be going towards the implementation of layer 2 and sidechains. Layer 2 [59] refers to a framework or protocol that is built to run in parallel to a blockchain system, and has periodical synchronisation phases. The primary motivation for developing layer 2 is to solve some of the problems that affect current mainstream blockchain protocols, including transaction confirmation rates and costs, as well as scaling difficulties. Among the most prominent layer 2s for Ethereum, we can find Immutable X, designed specifically for NFTs, utilising zero-knowledge rollups to eliminate gas fees for transactions.

On the other hand, a sidechain [60] is a separate blockchain that runs independently on the main chain. It usually defines its own rules, including the consensus protocol to be used by its nodes. The connection between the main chain and one of its side chains is usually implemented by the means of two-way bridges, which are smart contracts that bridge one asset between the two blockchains back and forth. The main difference between layer 2 and sidechain solutions is that layer 2 solutions rely on the security of the layer 1 network. Sidechains, on the other hand, rely on their security model. *Polygon*, also known as the Matic Network, is a sidechain with a PoS consensus algorithm [61]. It offers scalable and instantaneous transactions. Each Polygon sidechain can theoretically achieve 2^{16} transactions per block. The protocol has achieved up to 7000 transactions per second (TPS) on a single sidechain on an internal testnet. The most important NFT applications use Polygon for collectible NFTs.

Worldwide Asset eXchange (WAX) (https://wax.api.atomicassets.io/atomicmarket/docs/swagger/, accessed on 23 May 2023) is the most important sidechain of EOS [62], specifically designed to support the deployment of videogame NFTs and applications using them. It adopts the DPoS consensus protocol, and thanks to its characteristics, it supports over 8000 transactions per second. Its smart contracts are written in C++ to provide maximal flexibility and high potential efficiency. WAX charges a fee on all NFT transactions executed equally to 2% of the price to fund its model, and awards participants for their contribution.

NFTSBL is a secure blockchain proposed for general-purpose NFTs that adopts a voting system to establish consensus and confirm new transactions [63]. The blockchain is public and includes low latency by kernel cache, voting for confirming the ownership of nodes, and escrow accounts to avoid the mistake of token transfer. The threshold value for a true transaction is to have more than 66% of votes. NFTSBL generates reward tokens for all selected nodes as a PoW concept if the transaction is confirmed. It can be considered a sidechain implemented by using Ethereum smart contracts.

Table 4. Blockchain for NFTs—A comparison.

Platform	Transaction Speed	Confirmation Time	Transaction Cost Fee	Smart Contract Language	Consensus Algorithm	NFT Standards	Application Fields
Ethereum	15–25 tps	~12 s	≈USD 4–USD 5.5	Solidity	PoS	ERC-721, ERC-1155, ERC-988	General purpose
Flow	1000 tps	~2.5 s	~USD 0.03	Solidity	PoS	ERC-721, ERC-1155	Arts and sports collectibles
Cardano	250 tps	5–60 s	≈USD 0.15–USD 0.3	Plutus	PoS	CIP-721	Collectibles and videogames
EOS	4000 tps	1.5 s	No fees	C++	DPoS	dGoods SimpleAssets, AtomicAssets	Videogames
Tezos	40 tps	30 s	USD 0.001	Michelson	LPoS	FA2	Arts and collectibles
BSC	300 tps	3 s	≈USD 0.1–USD 0.2	Solidity and Vyper	PoSA	BEP-721	Collectibles
Algorand	6000 tps	3.7 s	ŨSD 0.00022	TEAL	Pure PoS	Algorand Standard Assets (ASAs)	Collectibles
Immutable X	~9000 tps	-	No fees	Solidity	PoW	ERC-721	Videogames
WAX	8000 tps	30 s	No fees	C++	DPoS	SimpleAssets, AtomicAssets	Videogames
Polygon	7200 tps	2 s	≈USD 0.01–USD 0.05	Solidity	PoS	ERC-721, ERC-1155, ERC-988	Collectibles
Solana	8500	0.4 s	ŨSD 0.0002	Rust, C, and C++	Proof of history and proof of stake	Metaplex	Arts and collectibles
Ronin	200	3 s	ŨSD 0.0016	Solidity	Byzantine fault-tolerant proof of authority	ERC-721, ERC-1155, ERC-988	Videogames
NFTSBL [63]	15–25 tps	~5 min	-	Solidity	PoW	ERC-721, ERC-1155, ERC-988	General purpose

4. From NFT 1.0 to NFT 2.0

The previous version of NFTs, commonly referred to as NFT 1.0, needed better accessibility and legitimacy to improve and find more uses. NFT 2.0 is an evolution of the capabilities included in NFT 1.0, by embedding new ones and introducing novelties concerning ownership. While NFT 1.0 enables ownership of unique, tokenised digital assets, NFT 2.0 creates more possibilities. Indeed, NFT 2.0 enables owners to perform more things with their tokenised assets, including co-ownership, interactivity, composability, and more.

4.1. Properties and Features of NFT 2.0

NFT 2.0 will allow users to interact and play around with their digital assets. The ultimate goal of NFT 2.0 is to create a smart and realistic NFT with which users can interact in composite ways.

The most important properties of NFT 2.0 are as follows:

- **Interactivity**. NFTs of this kind can take input from users and other sources (i.e., servers or oracles). Based on the type of inputs, NFTs can change their behaviour, and even reflect the change on the asset represented.
- **Generativity and randomness**. NFT 2.0 can integrate randomness in digital assets, so that new interactions are always possible. Additionally, thanks to the introduction of artificial intelligence (AI), NFTs can be personalised and build connections with users.
- **Composability**. This refers to the ability to personalize an asset or create a new one. Furthermore, this property lets collectors explore new possibilities by bundling different assets together as one. NFT holders can expand the utility of their NFTs by embedding additional digital assets.
- **Experientiality**. NFTs can capture true user experience, or generate NFTs based on how a user interacts with the application, thus creating new ways to experience an NFT.

A comparison of the properties of NFT 1.0 and NFT 2.0 is reported in Table 5. On top of the aforementioned properties, we can see that NFTs 2.0 can have multiple owners and are oriented to use cases where the tokens can add utility to applications by introducing interactions between the token itself and its owner. On the contrary, NFT 1.0 was mainly proposed as a tool to tokenise assets and to only represent ownership of the asset, without the possibility to have any meaningful interaction and see it change or evolve.

Table 5. NFT 1.0 vs. NFT 2.0: a summary.

	NFT 1.0	**NFT 2.0**
Behaviour:	Immutable	Dynamic
Structure:	Separate	Composable
Application:	Traditional	Experimental
Ownership:	Single owner	Multiple owners
Scope:	Tokenisation	Utility
Goal:	Ownership	Interaction

We can identify several features of NFT 2.0 that gives it more opportunities to be applied in several scenarios. The most important ones are as follows:

- **Enhanced metadata**. NFT 2.0 allows for the creation of enhanced metadata, providing greater context and information about an asset. This can include information about the artist, the history of the asset, and even its environmental impact.
- **Nested NFTs**. NFT 2.0 introduces the nesting feature, which enables the NFT to own several other NFTs. An NFT can be considered a “parent” NFT, which contains one or more “child” NFTs. These child NFTs can themselves contain other child NFTs, creating a nested hierarchy of digital assets. These nested NFTs are more commonly

used in the gaming industry, as it makes it easy for the token holder to own the rights over several digital assets or to bundle NFTs together.

- **Customised NFTs**. Unlike in NFT 1.0, the customized property of NFT 2.0 not only supports use cases such as buying and selling on the exchange platforms, but also allows each NFT to have a multi-faceted ability, thus supporting various use cases and applications.
- **Rental NFTs**. An NFT can be considered a "rental" NFT, which represents a digital asset that can be rented or leased. For example, an NFT representing a digital artwork or collectible could be rented out to a collector for a specified period, allowing them to enjoy the asset without owning it outright. One potential application of rental NFTs 2.0 is in the creation of rental marketplaces for digital assets. These marketplaces would allow owners of digital assets to rent them out to others, creating a new source of revenue. This could include anything from digital artwork and collectibles to virtual real estate in the metaverse and other digital assets.
- **Smart NFTs**. The NFTs can be linked to upgradable smart contracts, thus enabling complex and automatic interactions with other blockchain assets as well.
- **Co-Owned NFTs**. An NFT can be considered a "co-owned" NFT, which represents a digital asset that is co-owned by multiple individuals. A potential application of co-owned NFTs 2.0 is in the creation of fractional ownership marketplaces for digital assets. These marketplaces would allow multiple individuals to co-own a digital asset, with each owner holding a fraction of the asset's value or ownership rights. Another application is the creation of investment opportunities for digital assets. By co-owning an NFT, investors can gain exposure to the asset's value without having to purchase the entire asset outright. This could help small investors to team up and invest in pricey assets together.
- **DAO NFTs**. DAO NFTs is a concept that combines the power of NFTs with decentralized autonomous organizations (DAOs), allowing for the creation of community-governed digital assets. This creates a new level of flexibility and versatility for NFTs, allowing for the creation of new forms of decentralised ownership and governance. The DAO itself is represented by a smart contract on a blockchain, and it allows community members to vote on key decisions related to the asset, such as its use, sale, or distribution. A potential application is the creation of community-governed digital art collections. By creating a DAO that owns and governs a collection of NFTs, community members can collectively make decisions about how to manage and distribute the collection. Another application is the creation of decentralised ownership and governance structures for virtual real estate. By creating a DAO that owns and governs a virtual world or virtual real estate, community members can collectively make decisions about how to manage and develop the space.

4.2. NFT 2.0 Metadata

Metadata refers to data that provide crucial information about the properties of an NFT, such as its name, description, and other relevant details. These data may also include links to the images and other digital assets that contribute to the value of the NFT. The metadata are usually stored in JSON format, although the specific details contained within the metadata may vary based on the NFT standard being used. The most widely used standards for NFTs are ERC-721 and ERC-1155, and their respective metadata typically include details such as a name, description, image sources, and attributes or traits.

ERC-721 defines metadata as `tokenURI` which is referring to IPFS or other storage providers' links. In ERC721 metadata extension is optional. Providing asset metadata allows applications such as the OpenSea marketplace to pull and show them. OpenSea supports metadata that are structured according to the official ERC721 metadata standard or the Enjin Metadata suggestions.

The ERC-1155 standard extends the features of ERC-721 by adding a multi-token standard. This standard makes it easier to store multiple items in a single smart contract with the minimum possible amount of data needed to distinguish a token from others.

4.3. Generativity and Randomness

An important feature unique to NFTs 2.0 is dynamism. A dynamic non-fungible token (dNFT) [10] is an NFT whose metadata can be modified by smart contracts. Indeed, changes in a dNFT are based on conditions, and a smart contract is responsible for metadata changes. Metadata changes can be either off-chain or on-chain. For this reason, smart contracts provide instructions on how the dNFT's metadata should be changed given a triggering event based on external data through an oracle or an on-chain event [14].

A dNFT is minted by a smart contract with a set of metadata, usually provided by third-party services, such as web APIs, Internet of Things (IoT) devices, or any other source of verified data. A dNFT can be linked to multiple sources of data, documents or images. Currently, dNFTs can be both ERC-721 and ERC-1155, depending on the use case [64]. When tokens are built on the ERC-1155 standard, it creates a semi-fungible token set that has the same token ID for each token but is still different from any other set of tokens that exists.

To create a dNFT, the initial NFT is minted using a specific smart contract. The same or another smart contract provides instructions to the dNFT regarding updating its metadata if specified external events trigger the change. The metadata can be updated by using blockchain data or oracles, which collect off-chain data. As shown in Figure 4, when a user asks for an NFT, the following steps summarise the actions needed.

- First, an NFT request is sent to a smart contract, as shown in Figure 4, Step 1.
- The smart contract processes the request according to its code.
- The smart contract makes a call for on-chain data, and/or it uses an oracle to make a call for off-chain data, as highlighted in Figure 4, Step 2. The results obtained by these calls are then used to personalise the answer.
- The smart contract then sends back the media necessary to show the current state of the NFT, as shown in Figure 4, Step 3.

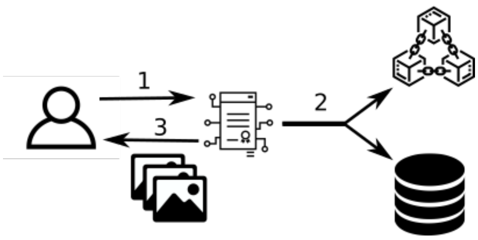

Figure 4. Generativity and randomness in dNFTs.

A dNFT essentially needs two pieces of information to know how to update metadata:

- Providing the underlying NFT with instructions on when and how to change the metadata;
- Accessing relevant external data sources.

Dynamic elements other than metadata changes can also exist, for instance, allowing dNFTs to be minted based on specific external conditions, such as minting a certain dNFT when a real-life team wins a game, and adding metadata to the NFT concerning how the game went. dNFTs can also contain "hidden features" generated by user interactions. For example, the transfer function may be disabled after scanning a QR code, which is useful for using NFTs as tickets.

Concerning the oracles, they are a collection of nodes capable of validating or supplying external data. In the context of NFTs, the main purpose of oracles is to act as a bridge between the blockchain and an external source of information. For instance, an oracle can be used to modify an NFT according to a set of conditions provided by the oracle. However, the usage of oracles can compromise the NFT because users trust that the oracle behaves correctly and that the data it supplies are correct. If it is not the case, the smart contract execution will produce erroneous results. Smart contracts expose ad hoc methods to change the pointer to metadata files for their NFTs, so that oracles can change the metadata autonomously [10].

For this reason, another way to introduce dynamism in the NFTs is through randomness. Randomness can be implemented using verifiable random functions (VRF), which is a provably fair and verifiable random number generator that enables smart contracts to access random values without compromising security or usability. Since VFR is verified, no one can influence the randomness in their favour, and the outcomes are verifiable on the blockchain. Randomness is especially useful in gaming contexts, where, as an example, NFTs can be used to represent playable characters, and randomness can be used to initialise the values of the character.

4.4. On-Chain vs. Off-Chain Metadata

When NFT metadata exists on-chain, the metadata are built directly into the smart contract, and metadata are stored on-chain. The benefits of representing metadata on-chain are principally related to the availability of the information. Indeed, they permanently reside with the token, and they can change following on-chain logic.

Despite these benefits, most projects store their metadata off-chain simply due to the current storage limitations of the Ethereum blockchain. In detail, off-chain NFTs host their smart contracts on the blockchain, but metadata are off-chain. Usually, off-chain NFTs use centralised (such as Google Drive, Dropbox, etc.) or decentralised storage to store metadata (i.e., IPFS). Such storage options, however, have two major challenges:

- Risk of losing the NFT. In particular, with any centralised server or storage, the owner can shut down the system or delete the file stored on it anytime. Furthermore, the link will break, and the file will be lost.
- Security risk. Principally, due to server hacking.

IPFS provides a more secure method of storing data by using a peer-to-peer network. Some benefits of having off-chain NFTs are the possibility to buy NFTs without having much blockchain experience and purchasing and trading NFTs on on-chain marketplaces without a gas fee.

4.5. NFT 2.0: Applications

NFT 2.0 has the potential to be used in a wide range of applications, from art and music to sports and real estate. Some of the potential applications of NFT 2.0 include:

- **Music.** NFT 2.0 can be used to create unique digital music assets that can be traded and owned by fans. Music NFTs are considered certificates of ownership for identifying owners of a piece of musical work. Artists can sell the music NFT to anyone while retaining the rights to make any changes to its content. Furthermore, the artist can have complete discretion over how the buyer uses the piece of music.
- **Gaming.** NFTs can have a significant impact on gaming, and in particular, on play-to-earn (P2E) games. Game developers can create customised NFTs that represent in-game items or achievements, allowing players to own and trade unique digital assets that are tied to the game's ecosystem. NFT 2.0 has the potential to transform the gaming industry by providing new ways for players to own and transfer in-game assets, verifying authenticity and rarity, enabling interoperability, and providing tangible representations of rewards and achievements.
- **Sports.** The sports industry is benefiting much from this evolution. NFT 2.0 can be used to create unique digital collectibles that represent ownership of sports memorabilia. They also can be used to create digital tickets and fan experiences, or to represent athletes and their sponsorships, allowing for new forms of revenue and endorsement deals. Finally, NFT 2.0 can be used to represent digital assets used in fantasy sports and gaming, such as virtual teams and players that mirror the performance of the athlete.

- **Metaverse.** NFT 2.0 can be used to represent ownership of real estate assets, allowing for the fractional ownership of high-value properties [65]. This opens up new opportunities for investment and ownership of real estate assets. For instance, an NFT representing a property should be dynamic enough to reflect the maintenance history, age, market value, and much more in real time.
- **Token gating.** Token gating is a way of restricting access to something and using NFTs as a way to unlock access. NFT 2.0 can be used in the practice of "token gating", which involves requiring users to hold a specific NFT to access certain content or services. This concept can be used to create exclusive communities or provide access to premium content. Thanks to their dynamic nature, NFTs 2.0 can be used to grant access only once to an event, and even reveal additional properties [64].
- **Art.** NFT 2.0 has several applications in the art industry, as it allows for the creation of unique and verifiable digital assets that can represent artwork and provide new ways for artists to monetise their work [66]. NFT 2.0 can be used to represent fractional ownership of artwork, allowing multiple owners to own a portion of a piece of art. This can create new opportunities for investment in art and provide a new revenue stream for artists. Furthermore, NFT 2.0 can be used to represent licenses or royalties for artwork, allowing artists to receive ongoing revenue for their work. This can also create new opportunities for secondary markets and provide a new way for artists to monetise their work.
- **Healthcare.** Healthcare is another field that could benefit widely from digital twin NFTs 2.0. For instance, in an organ donation scenario, NFT 2.0 can be used to keep track of the donor, and the organ. Additionally, IoT devices can be employed to periodically monitor the condition of the organ (i.e., temperature, humidity) while it is transported. Lastly, NFT 2.0 has been employed to trace refurbished medical devices: each part of the machine is modelled as a separate NFT that keeps track of its condition, and the medical devices are composable and dynamic NFTs [11].

4.6. Upgrading from NFT 1.0 to NFT 2.0

With the rise of NFT 2.0 and its wide spread, we anticipate that some applications will seek a smooth transition from one implementation to the other. In this section, we discuss what are the challenges to take into account to encourage the wide spread of NFT 2.0. For those applications that foresee changing their NFTs from 1.0 to 2.0, we reckon that there are two key aspects to manage. The first one is the underlying blockchain. Implementing a gradual transition is extremely important so as to not increase the transactions' confirmation time and blockchain fees by clogging the blockchain networks with too many transactions. This can be performed by letting the applications manage the transition via a lazy transition scheme (i.e., changing the NFT to 2.0 only when really needed). The second aspect to take into account is forward compatibility. Since a transition period could bring disruption to the service, it is important to design systems that can stand the test of time. To this end, developers could take into account programming strategies such as proxy smart contracts that let updates roll out with minimal disruption of the service.

5. Final Remarks

The emergence of NFT 2.0 represents a significant evolution of the original NFT concept, introducing new features and capabilities that expand the potential use cases and value of NFTs. Our survey of NFT 2.0 has highlighted several key properties and features of NFT 2.0 and pointed out the areas where NFT 2.0 offers advantages over traditional NFTs. Enhanced metadata, composability, dynamicity, and interactivity are just a few of the key features that set NFT 2.0 apart from earlier versions and improve user experience. These new features enable greater flexibility, creativity, and functionality for creators and owners of NFTs, and contribute to the broader adoption and use of NFTs in various industries and applications. These advances will help drive further innovation and adoption of NFTs, contributing to the growth of the blockchain ecosystem and the broader digital asset economy. In particular, NFT 2.0 is adaptable to numerous scenarios, such as in the music industry, to manage the rights of a song; in gaming, for representing characters that evolve or tools that get used; in the sports industry, to manage access to events and create collectible digital memorabilia; in the metaverse, to represent land parcels or buildings that age over time, thus gaining historical value; or even in medical and engineering fields, as a means to represent and certify the current status of a refurbished machine.

In summary, this paper lays the foundation for further research in the field of NFTs by providing a comparison between NFT 1.0 and NFT 2.0, highlighting, in particular, the innovative aspects of the latter. We also discuss how NFT 2.0 can be made dynamic, employing the concepts of generativity and randomness, and how metadata can be managed on- and off-chain. Finally, we provide a list of application scenarios that will greatly benefit from this technological evolution and its societal impact, and discuss the challenges related to transitioning a project from NFT 1.0 to NFT 2.0.

This review paper serves as a solid base for future research on the topic of NFT 2.0. One crucial aspect is that connected to cross-chain compatibility and standardisation, partially addressed via token standards and bridging services. Thanks to token standards, such as ERC-721 or ERC-1155, the methods of smart contracts that manage the collection can be standardised. These Ethereum standards have been adopted by Ethereum layer 2 or sidechains, such as Polygon and Ronin, and serve as inspiration for other blockchains, such as Binance smart chain and Tron. Although some standards already exist, we reckon that future standards should take into account the inherent properties and features of NFT 2.0 showcased in this paper and leverage them, possibly transcending the underlying blockchain. Bridging services are instead services that let NFTs be transferred from one blockchain to another. Users can lock an NFT in a smart contract on the source blockchain, and a second smart contract issues a certificate of ownership on the target blockchain. The only way to redeem the NFT on the source blockchain is through the certificate of ownership on the target blockchain. The bridging is not yet standardised, and as is, requires the development of numerous smart contracts. Moreover, the source of dynamic metadata is an important aspect that needs to be standardised. Our review, which highlighted the different sources of metadata, and showcased their typical interaction with NFT 2.0, could help speed up the standardisation process. Additionally, the application of NFT 2.0 should be explored more in-depth in scenarios such as entertainment (videogames and the metaverse), collectibles (arts, music, sport), and digital twins (healthcare, engineering, IoT). Lastly, the numerous challenges identified in our work do not have a clear and definitive solution; therefore, future work could focus on devising strategies to solve them.

Author Contributions: Conceptualisation, B.G. and A.M.; methodology, B.G. and A.M.; investigation, B.G. and A.M.; writing—original draft preparation, B.G. and A.M.; supervision, B.G.; project administration, B.G. and A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Pinto-Gutiérrez, C.; Gaitán, S.; Jaramillo, D.; Velasquez, S. The NFT hype: What draws attention to non-fungible tokens? *Mathematics* **2022**, *10*, 335. [CrossRef]
2. Nadini, M.; Alessandretti, L.; Di Giacinto, F.; Martino, M.; Aiello, L.M.; Baronchelli, A. Mapping the NFT revolution: Market trends, trade networks and visual features. *arXiv* **2021**, arXiv:2106.00647.
3. Franco, M.; Gaggi, O.; Guidi, B.; Michienzi, A.; Palazzi, C.E. A decentralised messaging system robust against the unauthorised forwarding of private content. *Future Gener. Comput. Syst.* **2023**, *145*, 211–222. [CrossRef]
4. Lee, J.; Kwon, K.H. Novel pathway regarding good cosmetics brands by NFT in the metaverse world. *J. Cosmet. Dermatol.* **2022**, *21*, 6584–6593. [CrossRef]

5. Guidi, B.; Michienzi, A. Social games and Blockchain: Exploring the Metaverse of Decentraland. In Proceedings of the 2022 IEEE 42nd International Conference on Distributed Computing Systems Workshops (ICDCSW), Bologna, Italy, 10 July 2022 ; IEEE: Piscataway, NJ, USA, 2022; pp. 199–204.
6. Muthe, K.B.; Sharma, K.; Sri, K.E.N. A Blockchain Based Decentralized Computing And NFT Infrastructure For Game Networks. In Proceedings of the 2020 Second International Conference on Blockchain Computing and Applications (BCCA), Virtual, 3 November 2020; pp. 73–77. [CrossRef]
7. Wang, D.; Ren, Q.; Li, X.; Qi, Y.; Zhou, Q. Defining Consumers' Interest and Future of Nft Fashion. In Proceedings of the 2022 International Conference on Social Sciences and Humanities and Arts (SSHA 2022), Nanjing, China, 25–27 February 2022; Atlantis Press: Amsterdam, The Netherlands, 2022; pp. 584–594.
8. Wang, Q.; Li, R.; Wang, Q.; Chen, S. Non-fungible token (NFT): Overview, evaluation, opportunities and challenges. *arXiv* **2021**, arXiv:2105.07447.
9. White, B.; Mahanti, A.; Passi, K. Characterizing the OpenSea NFT marketplace. In Proceedings of the Companion Proceedings of the Web Conference 2022, Virtual, 25–29 April 2022; pp. 488–496.
10. Solouki, M.; Bamakan, S.M.H. An In-depth Insight at Digital Ownership Through Dynamic NFTs. *Procedia Comput. Sci.* **2022**, *214*, 875–882. [CrossRef]
11. Gebreab, S.A.; Salah, K.; Jayaraman, R.; Zemerly, J. Trusted Traceability and Certification of Refurbished Medical Devices Using Dynamic Composable NFTs. *IEEE Access* **2023**, *11*, 30373–30389. [CrossRef]
12. Bellagarda, J.; Abu-Mahfouz, A.M. Connect2NFT: A Web-Based, Blockchain Enabled NFT Application with the Aim of Reducing Fraud and Ensuring Authenticated Social, Non-Human Verified Digital Identity. *Mathematics* **2022**, *10*, 3934. [CrossRef]
13. Zaucha, T. Gaming the Systems: Non-Fungible Tokens and the Blurring of Gambling and Finance in Play-to-Earn Games. Ph.D. Thesis, University of Minnesota, Minneapolis, MN, USA, 2022.
14. Karapapas, C.; Pittaras, I.; Polyzos, G.C. Fully decentralized trading games with evolvable characters using NFTs and IPFS. In Proceedings of the 2021 IFIP Networking Conference (IFIP Networking), Virtual, 21–24 June; IEEE: Piscataway, NJ, USA, 2021; pp. 1–2.
15. Gumelar, M.S.; Gumelar, M. *What Is NFT for Beginners: NFT, NFT 2.0, NFT 3.0 Explore the Future of NFT Art*; An1mage: South Tangerang, Indonesia, 2023.
16. Nakamoto, S.; Bitcoin, A. A Peer-to-Peer Electronic Cash System. *Bitcoin* **2008**, *4*, 1–9.
17. Dannen, C. *Introducing Ethereum and Solidity*; Springer: Berlin/Heidelberg, Germany, 2017; Volume 1.
18. Jensen, J.R.; von Wachter, V.; Ross, O. An introduction to decentralized finance (defi). *Complex Syst. Inform. Model. Q.* **2021**, *26*, 46–54. [CrossRef]
19. Helliar, C.V.; Crawford, L.; Rocca, L.; Teodori, C.; Veneziani, M. Permissionless and permissioned blockchain diffusion. *Int. J. Inf. Manag.* **2020**, *54*, 102136. [CrossRef]
20. Attaran, M.; Gunasekaran, A. Blockchain Principles, Qualities, and Business Applications. In *Applications of Blockchain Technology in Business: Challenges and Opportunities*; Springer Nature: Cham, Switzerland, 2019; pp. 13–20.
21. Aggarwal, S.; Kumar, N. Hyperledger. In *Advances in Computers*; Elsevier: Amsterdam, The Netherlands, 2021; Volume 121, pp. 323–343.
22. Yao, W.; Ye, J.; Murimi, R.; Wang, G. A survey on consortium blockchain consensus mechanisms. *arXiv* **2021**, arXiv:2102.12058.
23. Gervais, A.; Karame, G.O.; Wüst, K.; Glykantzis, V.; Ritzdorf, H.; Capkun, S. On the security and performance of proof of work blockchains. In Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security, Vienna, Austria, 24–28 October 2016; pp. 3–16.
24. Nguyen, C.T.; Hoang, D.T.; Nguyen, D.N.; Niyato, D.; Nguyen, H.T.; Dutkiewicz, E. Proof-of-stake consensus mechanisms for future blockchain networks: fundamentals, applications and opportunities. *IEEE Access* **2019**, *7*, 85727–85745. [CrossRef]
25. Hu, Q.; Yan, B.; Han, Y.; Yu, J. An improved delegated proof of stake consensus algorithm. *Procedia Comput. Sci.* **2021**, *187*, 341–346. [CrossRef]
26. Dimitri, N. Liquid Proof-of-Stake in Tezos: An Economic Analysis. *Information* **2022**, *13*, 556. [CrossRef]
27. Wang, Q.; Li, R.; Wang, Q.; Chen, S.; Xiang, Y. Exploring unfairness on proof of authority: Order manipulation attacks and remedies. In Proceedings of the 2022 ACM on Asia Conference on Computer and Communications Security, Nagasaki, Japan, 30 May–3 June 2022; pp. 123–137.
28. Busayatananphon, C.; Boonchieng, E. Financial technology DeFi protocol: A review. In Proceedings of the 2022 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI DAMT & NCON), online, 26–28 January 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 267–272.
29. Pierro, G.A.; Tonelli, R. Can solana be the solution to the blockchain scalability problem? In Proceedings of the 2022 IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER),Honolulu, HI, USA, 15–18 March 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 1219–1226.
30. Regner, F.; Urbach, N.; Schweizer, A. NFTs in practice–non-fungible tokens as core component of a blockchain-based event ticketing application In Proceedings of the 40th International Conference on Information Systems, (ICIS) Munich, Germany, 15–18 December 2019; Association for Information Systems: Atlanta, GA, USA, 2019; pp 1–17

31. Steinwold, A. The History of Non-Fungible Tokens (NFTs). 2019. Available online: https://medium.com/@Andrew.Steinwold/the-history-of-non-fungible-tokens-nfts-f362ca57ae10 (accessed on 23 May 2023).
32. Dowling, M. Is non-fungible token pricing driven by cryptocurrencies? *Financ. Res. Lett.* **2022**, *44*, 102097. [CrossRef]
33. Choudhary, V.V. *Non Fungible Token (NFT): Delve into the World of NFTs Crypto Collectibles and How It Might Change Everything?* Independently published: Chicago, IL, USA, 2022.
34. Liebi, L.J. *Book Review: Decentralized Finance after Bitcoin & Ethereum*; Springer: Berlin/Heidelberg, Germany, 2022.
35. Serada, A.; Sihvonen, T.; Harviainen, J.T. CryptoKitties and the new ludic economy: How blockchain introduces value, ownership, and scarcity in digital gaming. *Games Cult.* **2021**, *16*, 457–480. [CrossRef]
36. Kiong, L.V. *Metaverse Made Easy: A Beginner's Guide to the Metaverse: Everything you need to know about Metaverse, NFT and GameFi*; Independently published: Chicago, IL, USA, 2022.
37. Das, D.; Bose, P.; Ruaro, N.; Kruegel, C.; Vigna, G. Understanding Security Issues in the NFT Ecosystem. *arXiv* **2021**, arXiv:2111.08893.
38. Popescu, A. Non-Fungible Tokens (NFT)-Innovation Beyond the Craze. In Proceedings of the 5th International Conference on Innovation in Business, Economics and Marketing Research, Online, 27–29 May 2021.
39. Chohan, U.W. Non-Fungible Tokens: Blockchains, Scarcity, and Value. Critical Blockchain Research Initiative (CBRI); Working Papers. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3822743 (accessed on 23 May 2023).
40. Guidi, B.; Michienzi, A.; Ricci, L. Data persistence in decentralized social applications: The ipfs approach. In Proceedings of the 2021 IEEE 18th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 9–12 January 2021; IEEE: Piscataway, NJ, USA, 2021; pp. 1–4.
41. Karnatak, A.; Suseela, G. Preserving Data Integrity in Legal Documents Using On-Chain NFTs. *Adv. Sci. Technol.* **2023**, *124*, 628–634.
42. Di Angelo, M.; Salzer, G. Tokens, types, and standards: Identification and utilization in Ethereum. In Proceedings of the 2020 IEEE International Conference on Decentralized Applications and Infrastructures (DAPPS), Oxford, UK, 3–6 August 2020; IEEE: Piscataway, NJ, USA, 2020; pp. 1–10.
43. Arora, A.; Kanisk; Kumar, S. Smart Contracts and NFTs: Non-Fungible Tokens as a Core Component of Blockchain to Be Used as Collectibles. In *Proceedings of the Cyber Security and Digital Forensics*; Khanna, K., Estrela, V.V., Rodrigues, J.J.P.C., Eds.; Springer: Singapore, 2022; pp. 401–422.
44. Quasim, M.T.; Khan, M.A.; Algarni, F.; Alharthy, A.; Alshmrani, G.M.M. Blockchain Frameworks. In *Decentralised Internet of Things*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 75–89.
45. Bamakan, S.M.H.; Motavali, A.; Babaei Bondarti, A. A survey of blockchain consensus algorithms performance evaluation criteria. *Expert Syst. Appl.* **2020**, *154*, 113385. [CrossRef]
46. Micali, S. ALGORAND: The Efficient and Democratic Ledger. *arXiv* **2016**, arXiv:1607.01341.
47. Donmez, A.; Karaivanov, A. Transaction fee economics in the Ethereum blockchain. *Econ. Inq.* **2022**, *60*, 265–292. [CrossRef]
48. Dowling, M. Fertile LAND: Pricing non-fungible tokens. *Financ. Res. Lett.* **2022**, *44*, 102096. [CrossRef]
49. Damsgaard, J. The Real Value of Cryptocurrency. 2022. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4034312 (accessed on 23 May 2023).
50. Lamela Seijas, P.; Thompson, S. Marlowe: Financial contracts on blockchain. In Proceedings of the International Symposium on Leveraging Applications of Formal Methods, Limassol, Cyprus, 5–9 November 2018; Springer: Berlin/Heidelberg, Germany, 2018; pp. 356–375.
51. Bruhwiler, P.; Cachin, C.; Zanolini, L.; Micic, J. A Concurrent DEX on Cardano. Bachelor's Thesis, University of Bern, Barn, Switzerland, 2021.
52. Lamela Seijas, P.; Nemish, A.; Smith, D.; Thompson, S. Marlowe: Implementing and Analysing Financial Contracts on Blockchain. In *Proceedings of the Financial Cryptography and Data Security*; Bernhard, M., Bracciali, A., Camp, L.J., Matsuo, S., Maurushat, A., Rønne, P.B., Sala, M., Eds.; Springer International Publishing: Cham, Switzerland, 2020; pp. 496–511.
53. Grigg, I. Eos—An Introduction. White Paper. 207. Available online: https://whitepaperdatabase.com/eos-whitepaper (accessed on 23 May 2023).
54. Zheng, W.; Zheng, Z.; Dai, H.N.; Chen, X.; Zheng, P. XBlock-EOS: Extracting and exploring blockchain data from EOSIO. *Inf. Process. Manag.* **2021**, *58*, 102477. [CrossRef]
55. Allombert, V.; Bourgoin, M.; Tesson, J. Introduction to the tezos blockchain. In Proceedings of the 2019 International Conference on High Performance Computing & Simulation (HPCS), Dublin, Ireland, 15–19 July 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 1–10.
56. Bernardo, B.; Cauderlier, R.; Pesin, B.; Tesson, J. Albert, an intermediate smart-contract language for the Tezos blockchain. In *Proceedings of the Financial Cryptography and Data Security: FC 2020 International Workshops, AsiaUSEC, CoDeFi, VOTING, and WTSC, Kota Kinabalu, Malaysia, 14 February 2020*; Revised Selected Papers 24; Springer: Berlin/Heidelberg, Germany, 2020; pp. 584–598.
57. Luong, H.H.; Huynh, T.K.N.; Dao, A.T.; Nguyen, H.T. An Approach for Project Management System Based on Blockchain. In *Proceedings of the Future Data and Security Engineering. Big Data, Security and Privacy, Smart City and Industry 4.0 Applications*; Dang, T.K., Küng, J., Chung, T.M., Takizawa, M., Eds.; Springer: Singapore, 2021; pp. 310–326.

58. Li, X.; Wang, X.; Kong, T.; Zheng, J.; Luo, M. From bitcoin to solana–innovating blockchain towards enterprise applications. In *Proceedings of the Blockchain–ICBC 2021: 4th International Conference, Held as Part of the Services Conference Federation, SCF 2021, Virtual Event, 10–14 December 2021*; Proceedings; Springer: Berlin/Heidelberg, Germany, 2022; pp. 74–100.
59. Sguanci, C.; Spatafora, R.; Vergani, A.M. Layer 2 Blockchain Scaling: A Survey. *arXiv* **2021**, arXiv:2107.10881.
60. Singh, A.; Click, K.; Parizi, R.M.; Zhang, Q.; Dehghantanha, A.; Choo, K.K.R. Sidechain technologies in blockchain networks: An examination and state-of-the-art review. *J. Netw. Comput. Appl.* **2020**, *149*, 102471. [CrossRef]
61. Besançon, L.; Da Silva, C.F.; Ghodous, P.; Gelas, J.P. A Blockchain Ontology for DApps Development. *IEEE Access* **2022**, *10*, 49905–49933. [CrossRef]
62. Yantis, W.Q.J.; CasSelle, M. Worldwide Asset eXchange White Paper. Technical Report. Available online: https://github.com/worldwide-asset-exchange/whitepaper (accessed on 23 May 2023).
63. Takahashi, H.; Lakhani, U. Voting blockchain for High Security NFT. In Proceedings of the 2021 IEEE 10th Global Conference on Consumer Electronics (GCCE), Kyoto, Japan, 12–15 October 2021; pp. 358–361. [CrossRef]
64. Yang, L.; Dong, X.; Zhang, Y.; Qu, Q.; Tong, W.; Shen, Y. Generic-NFT: A Generic Non-Fungible Token Architecture for Flexible Value Transfer in Web3. Available online: https://www.techrxiv.org/articles/preprint/Generic-NFT_A_Generic_Non-Fungible_Token_Architecture_for_Flexible_Value_Transfer_in_Web3/20486610 (accessed on 23 May 2023).
65. Serrano, W. Real estate tokenisation via non fungible tokens. In Proceedings of the 2022 4th International Conference on Blockchain Technology, Shanghai, China, 25–27 March 2022; pp. 81–87.
66. Marias, M. I Want My NFT!: How an NFT Creative Commons Parallel Would Promote NFT Viability and Decrease Transaction Costs in NFT Sales. *NYU J. Intellect. Prop. Entertain. Law* **2022**, *12*, 1–35. [CrossRef]