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NFTs and the Metaverse Revolution: Research Perspectives and Open Challenges

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Introduction

Since its advent, the Web has passed from several evolution cycles and evolved from a static medium of Web resources into a dynamic medium of information sharing. The ability to interlink data sources with semantic metadata, the generation of large volumes of data from interlinked devices—with the emergence of the Internet of Things (IoT), and the ability to use artificial intelligence (AI) and machine learning (ML)

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techniques to infer useful insights from data sources—has transformed the Web into an enabler technology toward digital transformation.

Nowadays, the Web is experiencing a new evolution cycle in which the boundaries between digital content, physical objects, and their digital representations will be eliminated. In the literature, this evolution cycle is referred to as the *Spatial Web* (René & Mapes, 2019), which can be described as the coupling of virtual and real worlds through the user of advanced technologies. The Spatial Web introduces a multidimensional perspective to the Web fabric where digital information is interlinked, integrated, and fused with the physical world, generating a *unified reality*. Previous Web evolution cycles are mainly characterized by the layer of interconnected computers, the network of interlinked Web pages (e.g., text and media content), and the Semantic Web layer with the use of linked data and ontologies (Christodoulou et al., 2015; Lytras et al., 2003). The Spatial Web promises the creation of a dynamic "living" network, a virtual information layer on the Web, that merges the physical with the digital perspective for the user. Through the use of the next generation of user interfaces (e.g., holograms, smart wearables, or voice), users will be able to interact with real-time data and create interconnections with a virtual environment under some extended reality.

The vision of the Spatial Web will be fully realized by the unification of emerging technologies and the convergence of their ecosystems. Such technologies include virtual and augmented reality (VR/AR), geolocation, advanced cellular networks (e.g., 5G), IoT, AI/ML, and distributed ledger technologies (DLTs) (i.e., blockchain).

Although the opportunities for the Spatial Web are likely to be unprecedented both in scope and scale, this vision is still at the early stages. Many supporters of this idea argue that the Spatial Web should embody an open, interoperable, and democratic environment through the establishment of open standards and decentralization (Keller & Simon, 2002; René & Mapes, 2019). They argue that the "universality" property of the Web, as this was proposed by Tim Berners-Lee in the early days of the Web (Berners-Lee et al., 1992), has faded out and that today's Web comprises of centralization, walled gardens, and proprietary services governed by a small number of companies.

It is envisioned that the Spatial Web is set to create new experiences of reality to a degree that we have not imagined before. Such experiences are likely to create highly contextualized and personalized data; therefore, the Spatial Web should consider an infrastructure that can reliably store digitized objects, track their history, verify the authenticity of data within the virtual world, prevent the alternation of previously archived data, and, at the same time, enable users to freely collaborate, explore, and interact in mixed reality spaces (Ryskeldiev et al., 2018).

Setting the Scene

Although the realization of the Spatial Web is still under development, several downstream technological advances have been pushing for its evolution. Figure 6.1 summarizes the categories of emerging technologies that are considered as enablers toward the evolution of the Spatial Web.

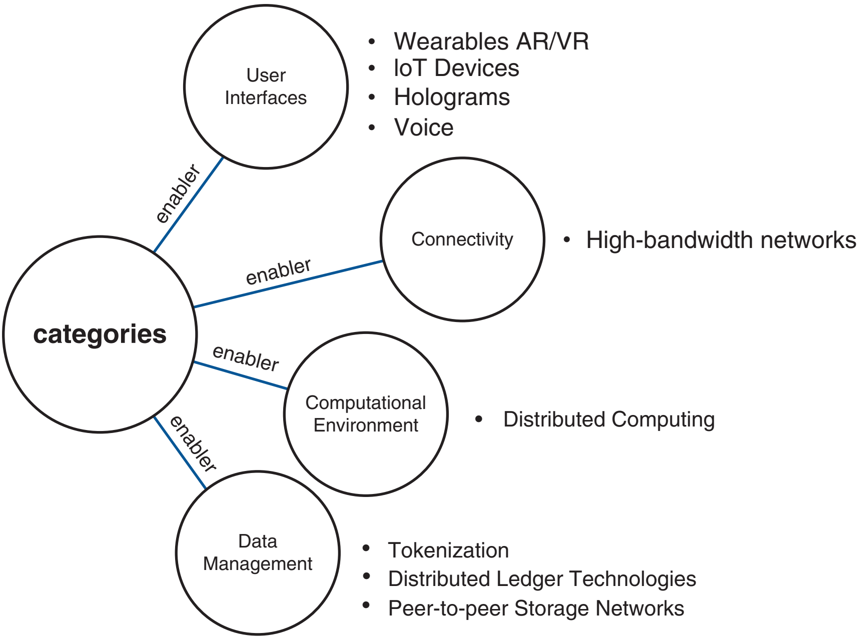

Fig. 6.1 Convergence of enabling technologies toward the Spatial Web

Next generation of user interfaces such as smart devices (interconnected with the IoT), wearables (e.g., haptic wearables), AR/VR devices (e.g., AR glasses) are offering new interfaces for user interaction and access to data.

On the other hand, the digitization of physical objects with computer vision and natural language processing (Malandrakis et al., 2013) generates large volumes of data that require significant processing power. Thus, technological advances in optimized AI/ML techniques are considered vital for supporting such an environment. Another technology which contributes toward the development of the Spatial Web is the advancement in network connectivity. Delivering to the user a seamless interaction experience over a mixed reality environment requires fast connectivity and high-bandwidth networks (e.g., 5G).

Furthermore, the development of browser-based 3D modeling and gaming rendering engines has matured into entire software ecosystems. Currently, several 3D modeling applications are utilized to capture entire cities (Billen et al., 2021). These applications offer 3D geolocation features and advanced real-time rendering with VR/AR and the ability for Web usage (i.e., with the use of WebGL technology). Lastly, at the core of this Web, evolution data management and data integration techniques are very important. Data generated by the process of digitization is structured and modeled with various types and high granularity. Therefore, the ability to handle such volumes of data will require a highly scalable computational environment, optimized methods for storage, and an architecture for preserving the integrity of the data.

This chapter argues that distributed ledger technologies like blockchain (Nakamoto, 2008) could enable a ubiquitous and persistent architectural layer for the Spatial Web. Blockchains combined with decentralized peer-to-peer (p2p) storage networks can enable a medium for a virtual world (or a "metaverse") where digital ownership, authenticity, identity, transferability, and data integrity are preserved. In more detail, a blockchain layer could offer a standardized infrastructure for tokenizing physical objects to their digital footprint in a manner that such tokens can be exchanged and shared. Tokens that represent virtual objects can be digitally owned, identified with unique digital identities, composed with other virtual objects, and characterized by a set of unique attributes and interaction rules. The activity of each object will be made persistent on the Web layer, and its history will be verifiable and traced over a blockchain layer.

The explosion in the development of blockchain-based metaverses (Tapora, 2021) triggered an explosive growth of the non-fungible tokens (NFTs) space (Wang et al., 2021) with top gaming platforms joining the space. Examples are the Atari gaming company, which announced a collaboration with Decentraland[1] and The Sandbox ecosystem[2] for creating a retro arcade. The first arcade station filled with classic Atari games will be offered to Decentraland users (Chaudhari et al., 2019), while Roller Coaster Tycoon, Centipede, Super Breakout, and other intellectual properties (IPs) owned by the Atari portfolio will be offered to The Sandbox. Similarly, Skybound Entertainment, which owns an estate in The Sandbox virtual environment, aims to enable users to experience The Walking Dead adventure. Such examples indicate that the portfolio of IPs of such game platforms will empower the development of theme-based NFTs, including game items, and other digital objects to characters. Such theme based NFTs will offer to players a completely new experience to play, create, socialize, and interact within a multiplayer gaming virtual world.

Blockchain networks are empowering the next generation of community-owned metaverses, obviating the need to trust opaque and centralized platform operators. Blockchains will play an integral role in supporting the economy layer over the virtual world where at the same time they provide a standardize and ubiquitous way to represent virtual items over a natively digital world. To the best of our knowledge, there is limited literature on blockchain-based metaverse, virtual worlds, and non-fungible tokens (NFTs), which leaves plenty of room for study and novel contribution. With this perspective in mind, this chapter aims to contribute by: (i) presenting and analyzing the current status of virtual worlds with a particular focus on the emerging blockchain-based metaverse and tokens, and (ii) articulating open challenges and research perspectives for the emerging space of blockchain-based metaverses.

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[1] https://decentraland.org/blog/announcements/dcl-x-atari/.

[2] https://bit.ly/3mkKIrp.

The rest of this chapter is structured as follows. The next section introduces the reader to existing blockchain-based metaverse environments by presenting and comparing the most frequently used environments. The analysis leads to the artifacts inferred from blockchain-based metaverses as well as to a synopsis of the features of a blockchain-based metaverse. Thereafter, the main tokens standards used in this ecosystem are summarized followed by the research perspectives and open challenges. Monetizing opportunities are then discussed, and challenges related to the governance, generation, and minting processes are identified and explained. The chapter concludes with conclusions and contribution.

Virtual Worlds Toward a Blockchain-Based Metaverse

With the emergence of augmented and virtual reality, researchers have been referring to the development of a unified virtual space as the *metaverse* for years. The vision of having a unified virtual world where a 3D virtual space is co-constructed by the interactions of many users was first expressed by the science-fiction writer Neal Stephenson in 1992[3] (Dionisio et al., 2013). The term metaverse refers to the creation of a "meta" (which means "beyond") to capture the creation of a virtual world beyond the physical reality and "verse" (which refers to a back-formation from "universe") to refer to a virtual utopia or nonplace (Greek: Οὐκ τόπος). At the technical level, a metaverse implements a computer network that supports an interactive "virtual reality" where users can join from multiple locations and interact in real time. The virtual environment comprises simulations of the physical world and digital representations of objects in 3D.

Existing metaverse platforms digitize objects (e.g., people, buildings, art) within a virtual world, enabling their monetization and utility (Terpstra & Huisinga, 2020). Virtual worlds predate computers

[3] The reader is referred to the novel titled *Snow Crash*. Activeworlds (http://www.activeworlds.com) describes a virtual world that is based on the vision described by the novel.

(Schnipper, 2017); however, their origins are disputed due to the difficulty to formulate a definition for an alternative existence. The first attempt that is characterized as the closest to the modern vision of virtual reality goes back to the fifties with the project known as the Sensorama machine. Many attempts for the creation of independent virtual worlds followed since then, including the development of a prototype virtual world known as Activeworlds. This virtual world expresses the vision described by the Neal Stephenson's novel. Other attempts proposed the creation of WorldsAway (Lyman & Wakeford, 1999), which led to a richer user experience, and the commercial virtual world called Second Life (Rymaszewski et al., 2007). Second Life presented a virtual world with enhanced in-world user interactions. More specifically, users utilized content creation tools to enrich content and co-create the virtual environment. Furthermore, Second Life introduced the development of a virtual economy and proposed several improvements to the computer-generated 3D environment. Similarly, CryEngine 2, proposed by Avatar Reality, attempted to provide a richer realism to the virtual environment. However, due to the demanding gaming engine and increased system requirements, the project was not fully adopted by the user base.

Following Second Life and CryEngine, the next generation of virtual worlds introduced features of openness and decentralization. For instance, Solipsis was the first virtual world that was built over a p2p architecture (Keller & Simon, 2002; Frey et al., 2008), followed by the development of open projects like Open Wonderland (Open Wonderland Foundation 2011). The decentralized feature introduced with such systems has led to the emergence and development of open-source viewers and server-side engines for virtual worlds. The decentralized character and open-source developments pushed toward the development of the next state-of-the-art of virtual worlds.

With the emergence of blockchain networks, a new fundamental layer to the creation of virtual worlds is introduced—a layer that provides support for the creation of digital identities, a universal and standardized representation layer for digital objects, and a layer that supports the digital ownership of data with the use of fungible and non-fungible standards. Additionally, blockchains offer a layer for the establishment of a self-sovereign financial system for the creation of a decentralized economy within the virtual environment.

Blockchain-Based Metaverse

Although the development of a blockchain-based metaverse is under heavy development, many attempts to build independent virtual environments have been explored. Yet, there is a lack of literature to present and analyze these environments. In an attempt to bridge this gap and enhance the body of knowledge and the reader understanding, we summarize and analyze the most popular virtual worlds with a focus on the emerging blockchain-based metaverse, namely, we discuss (i) Decentraland, (ii) The Sandbox, (iii) Somnium Space, (iv) Cryptovoxels, (v) Axie Infinity, and (vi) Neon District.

Decentraland proposes a decentralized virtual world that is evolved by its users (Ordano et al., 2017). It is considered as the "first fully decentralized virtual world," since the virtual environment is co-created by the users, and it is not controlled by any central authority. Decentraland was launched in 2017 and provides a virtual world which is built exclusively on the public Ethereum blockchain. In Decentraland, users can create their own avatars, interact with other users, and participate in social activities such as concerts and art shows. Furthermore, users can develop buildings and other structures on their digitally owned plots and monetize their creations. Decentraland's virtual world is divided into a limited number of parcels (i.e., 90,000, each measuring 16 × 16 meters). Parcels are represented as virtual content represented by ERC-721 non-fungible tokens (NFTs) known as LAND. Users can purchase LAND parcels using the MANA (ERC-20) token and have full control over the environment and applications they create within their land. All unique assets are made persistent through Ethereum smart contracts that enable users to prove the digital ownership of any virtual asset using the blockchain ledger. Through the available marketplace (i.e., market.decentraland.org), users can trade and manage their on-chain assets used by Decentraland's ecosystem. A recent update of the platform enables users to associate two or more directly adjacent parcels of LAND to create a LAND estate.

Furthermore, the platform enables users to create their own 3D models and import them in the virtual environment. Each piece of land or item in Decentraland is an NFT. Decentraland's governance is managed by a decentralized autonomous organization (DAO), which holds the smart contracts and Decentraland's assets (e.g., LAND contract, estate contract, wearables, content servers, marketplace). Decentraland's DAO governs issues like upgrades of LAND and Estates, dates for future LAND auctions, size of marketplace fees, and others. Such proposals are exposed to the community for voting. Decentraland's DAO is used in multiple cases like policy updates and future LAND auctions through voting by the community. The DAO in the Decentraland virtual world handles the voting through governance interface provided by Aragon. An abstract overview of Decentraland's profile is summarized in Table 6.1.

The Sandbox proposes a blockchain-based virtual world that provides a unique gaming experience to the players. The gaming platform comprises of a suite of integrated products: (i) the Voxel editor, (ii) the marketplace, an open market that allows the trading of in-game NFT assets, and (iii) the game maker. The latter enables users to build, share, and monetize 3D games. The game maker provides a set of visual scripting tools that requires no coding and allows users to develop 3D games for free. The Voxel editor is used for modeling, animation, and NFT creation and

Table 6.1 Decentraland

Decentraland	
Type	Decentralized Virtual World
Launched	2017
Marketplace	The marketplace enables the trading and managing of all on-chain assets. Accessed on: market.decetraland.org
Token types supported	MANA: ERC-20 token which is used to make in-world purchases. MANA holders can buy or exchange LAND parcels. Max supply: 2,644,403,343 MANA LAND: A scarce, NFT-based (ERC-721) token to represent the virtual plots (i.e., parcels)
Chains supported	Ethereum public blockchain
Community	9300+ active monthly users

[a]Data collected from https://www.dapp.com/ for the last 30 days (August 2021)

supports to develop 3D objects like humans, animals, vehicles, foliage, and tools.

The Sandbox ecosystem is based on the Ethereum blockchain. Digital creations are stored using the Inter Planetary File System (IPFS), and their digital ownership is registered onto the blockchain ledger. The platform users (i.e., players, creators, curators, and landowners) can populate the virtual world with their creations that are encapsulated by several token types that comprise the economy of The Sandbox. All assets are represented as fungible or non-fungible tokens with the use of the ERC-20, ERC-721, and ERC-1155 standards. In more detail, the utility token SAND (ERC-20) is used for transactions and interactions within the ecosystem. On the other hand, the LAND token (ERC-721) is used to represent a real estate parcel (96 × 96 meters) in The Sandbox. Each LAND can be populated with games, assets, and interactive experiences. Multiple LANDS can be combined to an ESTATE. Lastly, ASSETS represent a token that is created by players who build user-generated content (UGC). Such tokens utilize the ERC-1155 standard and can be traded on the marketplace. Currently, around 1 million active users have been interacting with The Sandbox metaverse since its inception. Similarly to Decentraland, The Sandbox platform is governed using a DAO where SAND holders can exercise their voting rights on various key elements of the platform. Sandbox's profile is summarized in Table 6.2.

Somnium Space (Somnium Space Ltd, 2021) introduces an open, social, and persistent VR metaverse built over a blockchain architecture. Compared to Decentraland and The Sandbox, Somnium Space offers a more realistic environment, and it is enhanced with VR where people can do almost everything similarly as in real life. A recent update enables access to Somnium Space from every Web browser.

Somnium Space metaverse was founded in 2017, and it is empowered by the Ethereum blockchain for tokenizing in-game assets and land parcels. The long-term vision for the Somnium Space project is to create a realistic user-generated virtual environment which will add a rich virtual layer to reality (Somnium Space Ltd, 2021). Economy in Somnium Space has three cornerstones: (i) tokenization of virtual land, (ii) tokenization of digital assets and experiences, and (iii) decentralized marketplaces. The in-world currency is CUBE, an ERC20 token with a total

Table 6.2 The Sandbox

The Sandbox	
Type	Decentralized Gaming Ecosystem
Launched	2018
Marketplace	Open market environment that allows trading of in-game tokenized assets (e.g., upload, publish, and sell NFTs).
Token types supported	• SAND: ERC-20 token used for all the transactions and interactions within The Sandbox ecosystem. There is a finite supply of 3,000,000,000 SAND. • LAND: Digital piece of real estate within The Sandbox metaverse. LAND is portion of the metaverse open to player ownership. Each LAND is an NFT based on ERC-721 standard. • Max Supply: 166,464 LANDS • ESTATE: Is a combination of multiple LANDS. • ASSET: Token created by players—user-generated content (UGC). ASSETS utilize the ERC-1155 standard. • GAMES: Represent bundles of ASSETS and scripting logic form an interactive experience. Also represented with the ERC-1155 standard.
Chains supported	Ethereum public blockchain
Community[a,b]	15,000+ users have connected their wallets to the project 750,000+ followers support the franchise across social media (e.g., Facebook, Discord, Telegram) 1400+ active monthly users

[a]Data collected from https://www.dapp.com/ for the last 30 days (August 2021)
[b]Data collected from https://medium.com/sandbox-game

supply of 100,000,000 tokens. CUBE allows users to issue transactions between each other or spend them for purchasing in-world assets and activities (e.g., visit museums, participate in arcade games). Various types of NFTs are generate in Somnium Space such as wearables for the in-game avatars, tickets that allow access to certain land parcels, land tokens, world tokens that can be dropped onto land, treasure hunts, or CUBE prizes. Somnium's client provides the ability to create and tokenize custom VR avatars.

NFTs in Somnium Space are encapsulated using the ERC-721 standard. Considering the p2p economy and the high gas fees in Ethereum, due to the multiple trading transactions, several features are implemented on the polygon layer 2 (L2) blockchain, which offers improved transaction speeds and close to zero transaction costs for in-world transactions.

Table 6.3 Somnium Space

Somnium Space	
Type	Decentralized virtual world with enhanced VR
Launched	2018
Marketplace	NFTs for Somnium Space world are available through OpenSea under: opensea.io/collection/somnium-space
Token types supported	• CUBES: In-word ERC-20 token which could be used to trade assets in Somnium Space or exchanges between in-word users. • WORLDS: Independent instances as blockchain-based NFTs (ERC-721) which allow users to upload certain amount of content on Somnium Space's servers (e.g., small-75MB, medium-200MB) • PARCELS: Represent digital plots in Somnium Space world as NFTs (ERC-721) • ETH: Used to buy in-world NFTs such as land PARCELS, WORLDS, ESTATES, and collectibles used to customize their digital avatars and digital world. • DAI: This ERC-20 token is available for Somnium Space users to trade their Blockchain Avatars on OpenSea
Chains supported	Ethereum public blockchain and Matic (L2)
Community[a]	200+ active monthly users

[a]Data collected from https://www.dapp.com/ for the last 30 days (August 2021)

The digital assets of the Somnium Space world are available through the OpenSea digital marketplace. Somnium Space is developed on UnitySDK, offering multiple tools for the users to create content and extend the virtual world with numerous options (e.g., Somnium Space Web, Builder SDK, Worlds SDK, and Blockchain Avatars). The Builder SDK allows users to upload their creations to their land parcels, and the Worlds SDK enables them to upload complete interactive and programmable scenes. An abstract overview of Somnium's profile is summarized in Table 6.3.

Cryptovoxels is a user-owned virtual world which runs over the Ethereum blockchain. Cryptovoxels offers a virtual environment like a Minecraft look and feel. Users in the Cryptovoxels metaverse can buy land where they are able to build buildings, stores, and art galleries. The Cryptovoxels virtual world was first released as a secret beta version in May 2018. The Cryptovoxels universe consists of a city referred to as the "Origin City" where users own their NFT parcels. Similar to other well-known virtual worlds, ownership of digital items is recorded over the

Table 6.4 Cryptovoxels

Cryptovoxels	
Type	Decentralized Virtual World
Launched	2018
Marketplace	Land parcels for the Cryptovoxel metaverse are available through their shop at OpenSea martketplace opensea.io/assets/cryptovoxels and collectibles that can be used to customize in-world avatars
Token types supported	ETH: Used to buy in-world NFTs such as land parcels (digital plots) and collectibles used to customize their digital avatars
Chains supported	Ethereum public blockchain
Community[a]	130+ active monthly users

[a]Data collected from https://www.dapp.com/ for the last 30 days (August 2021)

Ethereum blockchain using the ERC-721 standard. Parcel owners can add and remove blocks from their parcels, which are called "voxels." Voxels represent a value on a grid in three-dimensional space. During its early days, Cryptovoxels's environment used a native token $COLR to attribute color to voxels and images. $COLR is not used anymore in Cryptovoxels universe as it was deprecated in June 2020. Currently, users can buy parcels of land in different districts of the "Origin City" or collectibles to decorate their avatars (Cryptovoxels, 2021). An abstract overview of Cryptovoxel's profile is summarized in Table 6.4.

Axie Infinity: This virtual environment is an example of how the metaverse can offer unique opportunities for gamification and not just a digital realization of some virtual world. Axie offers a decentralized economy that is shaped by its players. In brief, users acquire tokens through gameplay and contribution to the Axie's ecosystem. Users are breeding their digital NFT pets (referred as "axies") and get compensated for their gameplay (e.g., battle, collect, raise, and build land-based kingdoms). Axie's metaverse was introduced in 2018, and since then Axie's user base increased to 250K+ daily active players. Sky Mavis is the company behind the development of the Axie Infinity Universe. Axie Infinity Shards (AXS) are an ERC-20 governance token used within the Axie Universe, enabling users to shape the future of the ecosystem by voting for upgrades, while Ethereum (ETH) is also used for purchasing in-world NFT tokens (e.g., Axies, land, items, and bundles). The total supply of AXS is 270M with almost 61M in circulation. The demand of AXS is driven by the Community Treasury, which aims to create base value for AXS tokens. Besides, Smooth Love Potion (SLP), another ERC-20 token used in the Axie Universe, is transferred to users for "breeding" Axies. Through Axie's marketplace (marketplace.axieinfinitiy.com), 42,877 sales were fulfilled, including 42,634 Axies (i.e., the creatures of the Axie Infinity Universe). As of July 2021, the volume of ETH invested in the Axie Infinity Universe in lands and virtual items is estimated at 11,524 ETH. In order to overcome Ethereum scalability issues and to decrease the gas fees, Axie built over the Ronin network which is an Ethereum sidechain. During Q2 of 2021 Axies migrated to Ronin as the whole Axie Universe passed in "Origin Alpha" phase. A summary of Axie Infinity's profile is shown in Table 6.5.

Neon District presents a virtual game universe crafted by Blockade Games. Neon District is classified as a role-playing game where NFT assets (e.g., unique cards) are earned by players and evolved through gameplay. In brief, players battle an authoritarian regime in a dystopian

Table 6.5 Axie Infinity

Axie Infinity	
Type	Decentralized Gaming Ecosystem
Launched	2018
Marketplace	Operated under: marketplace.axieinfinity.com Current sales volume is estimated at 11,524 ETH
Token types supported	AXS: ERC-20 governance token used withing the Axie Universe for staking and payments (e.g., in the Axie NFT marketplace) ETH: Used to buy in-world NFTs such as Axies, lands (digital plots), items, and bundles. SLP: An ERC-20 token which is transferred to users when they breed Axies (i.e., the creatures of the Axie Infinity ecosystem) Axies: NFT tokens based on ERC-721 which represent the creatures of the Axie Infinity Universe. Land: Tokenized plots of land which act as homes and bases of operations for Axies.
Chains supported	Ethereum public blockchain, Ronin Ethereum sidechain
Community[a]	250,000+ active daily users 315,000 active monthly users

[a]Data collected from https://axieinfinity.com

Table 6.6 Neon District

Neon District	
Type	Decentralized Gaming Ecosystem
Launched	2019
Marketplace	Operated under: opensea.io/collection/neon-district Current trading volume is estimated at 847 ETH
Token types supported	NEON: In-game currency which is used for upgrading characters, buying gear, and/or cards. It could be acquired with ETH, or as a reward with the completion of certain tasks and missions within the game progression. ETH: Used to trade in-world NFTs (ERC-721) such as characters and cards
Chains supported	Ethereum public blockchain, polygon (L2)
Community[a]	3120+ active monthly users

[a]Data collected from https://dappradar.com

future, as part of the rebellion, leveling up their characters to earn in-game assets. Neon District was launched in late October 2019, and it runs over the Ethereum blockchain which is used for tokenizing in-game assets using the ERC-721 standard. Neon District's marketplace page on OpenSea[4] reports over a billion of unique assets. The universe of Neon District is released in seasons. Currently, Season 1 is ongoing, which features full single-player gaming. Players acquire NEON (the in-game currency) by accomplishing certain tasks and missions or by swapping ETH with NEON. NEON is used by players to acquire in-game assets like characters, gear upgrades, and cards. Considering the increased gas fees on Ethereum, the game allows users to link their Polygon wallet as an alternative to the Ethereum main net. Neon District's profile is summarized in Table 6.6.

Table 6.7 compares the profiles of the virtual worlds reported previously. The sample examined shows that half of the virtual worlds offers a decentralized gaming ecosystem and the rest decentralized virtual worlds. All of them support the Ethereum blockchain, but there are cases like The Sandbox and Axie Infinity that also support polygon and Ronin Ethereum sidechain, respectively. The marketplace of these environments is mainly available through OpenSea.io except the case of Axie Infinity that offers

[4] https://opensea.io/collection/neon-district.

Table 6.7 Virtual worlds profiles comparison

		Virtual world					
		Decentraland	The Sandbox	Somnium Space	Cryptovoxels	Axie Infinity	Neon District
Type	*Decentralized Virtual World*	x		x	x		
	Decentralized Gaming Ecosystem		x			x	x
	Launched	2017	2018	2018	2018	2018	2019
	Marketplace available through	OpenSea	The Sandbox	OpenSea	OpenSea	Axie Infinity	OpenSea
	Token	MANA	SAND	CUBET DAI	–	AXS SLP	NEON
	NFT	LAND	LAND ESTATE GAMES ASSET	WORLDS PARCELS	–	AXIES LAND	ETH to trade characters and cards
	NFT standards	ERC-721	ERC-721 ERC-1155	ERC-721	ERC-721	ERC-721	ERC-721
	Chains supported	Ethereum	Ethereum, Polygon (L2)	Ethereum	Ethereum	Ethereum Ronin Ethereum sidechain	Ethereum
	Trading volume (period: July 26 to August 14, 2021)	N/A	N/A	Ξ21.600[a]	Ξ17.400	Ξ90.000	Ξ847

[a]Ethereum Currency Symbol

its own marketplace. All virtual worlds examined use the ERC-721 NFT standard. In addition to this, The Sandbox also uses ERC-1155.

Artifacts Inferred from Blockchain-Based Metaverses

Reflecting on the aforementioned blockchain-based metaverse developments, this section summarizes their essential artifacts. These artifacts characterize a state-of-the-art virtual world where blockchain is an essential architectural layer for its sustainability.

- *Standardized tokens*. Blockchains offer a standardized mechanism for tokenization with the use of various standards, both for the creation of fungible (e.g., ERC-20) and non-fungible tokens (e.g., ERC-721). NFTs are encapsulated using smart contracts with certain attributes and functions (e.g., owner, approved address, authorized operator) to capture the unique identification of such objects and their metadata.
- *Economy*. The platforms offer an economy that is based on (i) tokenization of virtual land, (ii) tokenization of digital assets and experiences, and (iii) decentralized marketplaces. All virtual environments use both a fungible token, that acts as the in-game cryptocurrency, and several non-fungible tokens (ERC-721 or ERC-1155) to capture the unique and non-interchangeable assets of the virtual world. Through the embedded economy, users can own and monetize their creations and express themselves by interacting with the virtual world. Interactions can take various forms from creating and building to monetizing their land (e.g., entrance fee, renting). Most platforms offer several monetization opportunities such as tokenizing and selling their creations (e.g., wearables, tickets) directly from the metaverse environment or participating in various gamification activities (e.g., treasure hunts, events). Travel is also monetized in this space since such environments can simulate several physical boundaries of the real world, for example, improve the speed of the gaming environment or lift-off in-word restrictions like gravity. For example, in Somnium Space, avatars can walk at 4 mph, whereas cars can travel at 25 mhp. There is also the paid option of teleportation which happens instantly.

The creation of cars and teleports (or teleportation hubs) enables an enhanced user experience and additional venues for monetization for creators.

- *Minting of assets*. Platforms enable users to mint their own creations as NFTs. Such digital creations could be their digital avatars, land parcels, buildings, and/or other constructions. Users can even mint wearables for their avatars or even tickets for allowing users to participate in events. All assets are created as NFTs, made persistent over a p2p storage, and verified by a blockchain architecture.
- *Marketplaces*. Open marketplaces represent another artifact of blockchain-based metaverses where users can manage and trade their digital items (e.g., avatars, nametags, virtual parcels). For such metaverses, the marketplace is becoming a centerpiece of the metaverse's economy. Decentralized marketplaces are utilizing a p2p storage network to store the digital information alongside with ownership proofs that are recorded over a blockchain network.
- *Digital avatars*. Digital identity across metaverses is represented as tokens that are made persistent over a blockchain network to provide a trustworthy proof of ownership for avatars. Platform users are represented by digital avatars. Such digital avatars enable users to adopt an identity and express a personality. In general, digital avatars are represented as NFTs. As discussed in subsequent sections, the challenge remains *of how these avatars can become liquid and transferable across multiple blockchains*. The realization of a complete metaverse environment will require a seamless transfer of such identification objects, which remains a challenge that relates to interoperability.
- *DAOs*. By design, blockchains are characterized by decentralization and the removal of any central authority for their governance. Decentralized metaverses naturally inherit these characteristics of decentralized governance to maximize user engagement and activity. Using the native token of a virtual environment, holders can publish proposals or vote on existing ones that relate with the governance and evolution of the virtual world. In addition, token holders are presented with incentives to participate in the evolution of a virtual world or delegate their tokens to other voters that share the same ideology to

support or reject a certain proposal. The community in a blockchain-based metaverse drives policy upgrades and content creation.
- *Decentralized community*. Part of the native tokenomics of a blockchain-based metaverse is focused on growing the community of the virtual world. This is to ensure that the community is incentivized to further develop and evolve the project. A common growth model is embedded on the tokenomics of such platforms. For example, the revenue made from fees is then evenly distributed to various token holders (e.g., users, or ecosystem developers and gamers) that participate in the continuous growth of the ecosystem.

Features of a Blockchain-Based Metaverse

To move toward the creation of a realistic blockchain-based metaverse, the following essential features need to be considered:

- *Realism* relates to how realistic the generation of the virtual environment is for the user. What are the experiences presented to the user by the interactions with the virtual world and what kind of interfaces are used to interact with the virtual environment? Furthermore, this feature relates with the realism of the virtual environment; how the environment is actualized, what experiences are explorable by the users, and what are the means of expression or social interactions provided (Dionisio et al., 2013).
- *Ubiquity* refers to the layer responsible to safeguard the digital representation and ownership of the digital assets. It relates with the decentralized governance model offered by the underlying blockchain architecture. Such virtual worlds should be characterized by openness and fairness, where users collaboratively interact to evolve the virtual environment and make decisions that relate to its governance without the need of some central authority.
- *Interoperability* is concerned with the ability of moving digital assets, in the form of fungible or non-fungible digital objects, between virtual worlds in a seamless and instantaneous manner. The user should be abstracted from this process and the underlying blockchain networks

should be bridged in such a way that the history of the information is traceable and that the ownership of the digital asset is made persistent and can be verified as one-of-a-kind.

- *Scalability* refers to the constantly changing virtual reality environment where multiple users can interact in real time. The dynamic user interactions in a metaverse space are expected to generate large volumes of data. As the data volume increases, the need to analyze the data and infer new context is thus likely to increase as well. It is therefore important that the architectural layers on which a metaverse is settled are both reliable and secure. Blockchains can provide such a layer where the reliability of the data is preserved. At the same time, the generation of large volumes of data, and the digital representations of the virtual assets can be stored in p2p storage networks (e.g., IPFS (Benet, 2014)). On the other hand, the converge with artificial intelligence could provide a dynamic engine for creating enhanced diversity and rich content to the metaverse. For instance, data generated by user interactions can be used to forecast future behaviors or guide the decision-making on several actions from the metaverse space.
- *Tokenization* can provide a standardized methodology for new forms of information value creation. Tokenization refers to the process of converting the value of a tangible or an intangible asset (any tradable object) into a digital form (i.e., the token) that can be algorithmically generated, digitally represented, and traded over a blockchain network. A well-known standard for creating tokenized forms of virtual assets is the technical documents proposed by Ethereum developers under ERCs (Ethereum Request for Comments). The next section provides an overview of the various standards proposed under different blockchain implementations.
- *Liquid identity* relates with the adoption of a blockchain layer (or a sidechain) to empower users to uniformly self-manage and control their digital identities and private data. These digital identities can take the form of digital avatars where the ownership is verifiable by blockchain-enabled digital credentials. We envision that with the realization of interoperable blockchains, any type of virtual representation

(e.g., tokens, avatars) will become liquid and transferable between different chains.

Token Standards

An important aspect of a blockchain-based metaverse is the development and use of tokens. This section presents an overview of the token standards proposed by major blockchain protocols to support the generation of NFTs including (i) Ethereum blockchain, (ii) Efinity blockchain, (iii) Near blockchain, (iv) Flow blockchain, (v) Hedera Hashgraph, (vi) Bitcoin Cash Binance, and (vii) Binance smart chain.

Ethereum Blockchain

The Ethereum blockchain utilizes ERC standards to generate fungible and non-fungible tokens. Apart from ERC-20, ERC-721, and ERC-1155 that are the most frequently used, there are other ECR standards available as summarized in the bullet list below:

- ERC-20: This refers to the standard interface for fungible tokens. It defines the basic implementation for tokens within smart contracts.
- ERC-721: NFTs were initially proposed by the ERC-721 standard (Entriken et al., 2018) which denoted the two main aspects that differentiate NFTs from fungible tokens, that is, their uniqueness and nondivisibility. The ERC-721 requires a separate contract to be deployed for each token or collection.
- ERC-809: This standard is proposed to enable NFT owners to rent access to their NFTs, thus enabling rental agreements. Some functions have been taken from the ERC-721 standard.
- ERC-994: It can be considered as an extension to ERC-721 specifically designed to accommodate the requirements of the registration of land and physical property. A tree-like format is proposed to arrange NFTs and connect them with other contracts, allowing for the creation of complex conditional agreements.

- ERC-998: It extents the ERC-721 proposal by enabling the composition of any non-fungible token, and thus a complex composition of NFTs can be traded using a single transfer.
- ERC-1155: This standard enables the management of multiple token types (e.g., fungible and non-fungible) in a single deployed contract, in an attempt to decrease redundant bytecode on the Ethereum network.

Table 6.8 presents a summary of established and upcoming token standards for the Ethereum public blockchain. For a complete list of ERCs and their current status, the reader is referred to https://eips.ethereum.org/erc

Efinity Blockchain

Efinity blockchain was built by Enjin, and it aims to become the primary network for NFTs by supporting NFTs from any blockchain to offer a network that brings NFTs to everyone. The Enjin blockchain ecosystem seeks to build a scalable cross-chain token network, known as the Efinity blockchain, a Polkadot parachain that uses a Polkadot Relay Chain (Wood, 2016; Web3, 2020).

- Paratokens standard: Enjin developed a token standard, referred to as the "paratokens standard," for the Polkadot and Kusama[5] parachains. Through the paratoken standard, Efinity accepts tokens (both fungible and non-fungible) from any other chain including well-known Ethereum-based standards (e.g., ERC-20, ERC-721, ERC-1155).

Near Blockchain

The Near protocol is a proof-of-stake (PoS) blockchain that was developed in 2018 as a decentralized platform. Compared to Ethereum, it is faster and has lower gas fees. These characteristics have attracted the

[5] https://kusama.network/.

attention of many developers and users, especially in the NFT space. Near supports its own standards for token generation, including:

- NEP-171: Current NFT standard for the NEAR blockchain, inspired by the ERC proposals.

Table 6.8 Summary of established and prominent token standards

Proposal	Title	Type	Status	Fungibility	Token Interface
EIP-20	Token Standard	Standards Track—ERC	Final	Fungible	*Methods:* name(), symbol(), decimals(), totalSupply(), balanceOf(), transfer(), transferFrom(), allowance() *Events:* Transfer, Approval
EIP-721	Non-fungible token standard	Standards Track—ERC	Final	Non-fungible	*Methods—similar to ERC-20:* name(), symbol(), totalSupply(), balanceOf(), approve(), transfer(), transferFrom(), *Additional Methods:* ownerOf(), safeTransferFrom(), setApprovalForAll(), onERC721Received() *Requires:* ERC721Metadata, ERC-721 Metadata JSON Schema *Events:* Transfer, Approval, ApprovalForAll
EIP-809	Renting standard for rival, non-fungible tokens	Standards Track—ERC	Draft[a]	Non-fungible	*Methods—similar to ERC-20:* name(), symbol(), totalSupply(), balanceOf(), approve(), transfer(), transferFrom(), *Additional Methods:* reserve(), access(), settle(), checkAvailable(), cancelReservation() *Events:* Transfer, Approval, Reserve, Cancel

(*continued*)

Table 6.8 (continued)

Proposal	Title	Type	Status	Fungibility	Token Interface
EIP-994	Delegated non-fungible token standard	Standards Track—ERC	Draft[a]	Non-fungible	*Methods—similar to ERC-721:* ownerOf(), safeTransferFrom(), setApprovalForAll(), onERC721Received() *Additional Methods:* origin(), gets(), returns(), allows(), emitted() *Events:* Transfer, Approval, Reserve, Cancel
EIP-998	Composable non-fungible token standard	Standards Track—ERC	Draft[a]	Fungible and non-fungible	*Methods:* implements methods from ERC-20, ERC-721, ERC165, and ERC223 *Additional Methods:* rootOwnerOf(), rootOwnerOfChild(),ownerOfChild(), transferChild(), safeTransferChild(), transferChildToParent(), getChild() *Events:* ReceivedChild, TransferChild, TransferToParent, TransferFromParent
EIP-1155	Multi-Token Standard	Standards Track—ERC	Final	Fungible, non-fungible, and semi–non-fungible	*Methods—similar to ERC-20:* name(), symbol(), totalSupply(), balanceOf(), approve(), transfer(), transferFrom(), *Additional Methods:* safeTransferFrom(), safeBatchTransferFrom(), balanceOfBatch(), setApprovalForAll(), isApprovedForAll() *Events:* TransferSingle, TransferBatch, ApprovalForAll, URI

[a]This is a draft proposal (under development), as of August 19, 2021

- NEP-177: An interface for a non-fungible token's metadata.
- NEP-178: This NFT standard introduces an approval management system (e.g., approval management systems in ERC-721) which allows a set of users or contracts to transfer specific non-fungible tokens on behalf of the owner.
- NEP-181: Standard interfaces for counting and fetching tokens for an entire NFT contract or for a given owner. This standard adds essential functionality that is frequently required by marketplaces, and/or wallets when they need to show all tokens owned by a given account. The standard also has provisions to present statistics for all tokens included within a given contract.
- NEP-199: This standard provides an interface allowing non-fungible token contracts to request from financial contracts to pay-out multiple receivers, enabling flexible royalty implementations.

Flow Blockchain

Like Near blockchain, Flow uses a PoS consensus mechanism. Flow has its own standard for NFTs.

- Non-Fungible Token: The Flow blockchain supports NFT generation by providing a comparable standard to ERC-721 and ERC-1155. Each NFT on the Flow blockchain network is written using the Cadence programming language.

Hedera Hashgraph

Hedera is another blockchain that is based on PoS that achieves fast transaction speed and low fees. Hedera assists the generation of token through its token service.

- Hedera Token Service (HTS): Provides the ability to issue tokens (both fungible and non-fungible), which are native to Hedera adopting the same performance, security, and efficiency as HBAR (i.e., the utility token of the Hedera Hashgraph network), without a smart contract. Native tokens issued on HTS are minimizing upfront infrastructure costs, slow transactions speeds, complexity in managing governance, and regulatory obstacles (Baird et al., 2019).

Bitcoin Cash

Bitcoin Cash uses the Simple Ledger Protocol (SLP) to manage the issuance of tokens.

- Simple Ledger Protocol enables the creation, management, and transfer of NFTs on the Bitcoin Cash blockchain. Using this token system, custom token behavior could be embedded using the Bitcoin script programming language. Similar to the ERC-721 standard, the metadata for each token are stored off-chain. Each NFT created in SLP can have a unique token identifier, and collections of NFTs can be issued from the same address for easy classification.

Binance Smart Chain

The Binance Smart Chain, which is similar to the other chains reported above, has its own standard for tokens.

- BEP-721: Based on one of the first and most commonly used NFT standards of Ethereum (i.e., ERC-721), this standard allows the creation of NFTs on the Binance Smart Chain.

Other Chains

The improvement proposal framework introduced by the Ethereum community inspired other chains to create their own token standards.

- *Cardano:* The CIP-721[6] is proposed as the NFT standard for minting non-fungible tokens. Minting NFTs on Cardano requires the tokens to be linked to metadata with a unique link that is attached to the transaction where the token was created. This is different from the approach followed on Ethereum. In Cardano, token creation does not require a smart contract but is treated similarly to Cardano's native token.
- *Solana:* Minting NFTs on Solana requires the invocation of the Solana Program Library (SPL[7]) which provides on-chain code and common interface for minting fungible and non-fungible tokens. There is also the Metaplex Token Metadata contract[8] for supporting the linkage of metadata with SPL tokens.
- *Avalanche:* This layer-1 blockchain offers native capabilities of minting NFTs directly from its online wallet with the use of the NFT Studio.[9] The Avalanche's C-Chain runs the Ethereum Virtual Machine, and thus it supports all the ERC standards. On another note, Avalanche implements the Avalanche-Ethereum bridge[10] to enable a seamless bidirectional flow of tokens across the two ecosystems. Such attempts demonstrate how tokens of any type could become liquid from one blockchain network to another.

Research Perspectives and Open Challenges

As discussed in previous sections, the metaverse is defined as a shared, virtual, computer-generated space that is evolved by the collaborative actions of its users (i.e., content creators). The realization of a metaverse requires the convergence of a mixed reality that is composed of virtual and augmented reality over the Internet layer. We also argued that

[6] https://github.com/cardano-foundation/CIPs/blob/8b1f2f0900d81d6233e9805442c2b42aa1779d2d/CIP-NFTMetadataStandard.md.

[7] https://spl.solana.com/.

[8] https://docs.metaplex.com/nft-standard.

[9] https://docs.avax.network/build/tutorials/smart-digital-assets/wallet-nft-studio.

[10] https://bridge.avax.network/.

blockchains can provide an infrastructure that is ubiquitous and persistent for supporting the next generation of metaverses.

Developing a metaverse requires the representation of virtual and physical elements in a standardized manner. Blockchains by nature can provide the foundational layer for tokenizing all the things that need to be unique and nonreplicable. At the same time, the technology provides a unique way for creating digital representations and certificates of ownership with the use of NFTs. Furthermore, the open philosophy for creating the various fungible and non-fungible standards (e.g., ERC-20, ERC-721) allows the blockchain community to define new standardized token forms and develop a dynamic tokenization system. For example, the Ethereum community offers a unique life cycle for proposing such standards and approving them.

In this section, we discuss the various open challenges and research perspectives that pertain to (i) the creation of the metaverse, (ii) new innovative services and monetization opportunities, and (iii) regulation and alternative governance models that are likely to emerge in such virtual worlds.

Creation of the Metaverse

Interoperability. The current landscape of blockchain-based metaverses is still at the genesis stage and is composed of many fragmented, siloed, and independent virtual worlds. This landscape offers different perspectives to realism (e.g., social and psychological environment), scope, and user interactions. Although the majority of the virtual worlds are utilizing the same blockchain backbone for minting NFTs (securing their digital ownership and authenticity) and allow for the creation of the virtual characters or in-game assets (refer to Table 6.7), such environments are not interoperable. The realization of a cross-chain metaverse is currently a challenge and not yet realized.

To enable a "Universe" of metaverses, the following challenges need to be considered. Firstly, and as far as the technology part is concerned, the interoperability of blockchain protocols needs to be realized (Sunyaev et al., 2021). This will enable a unique and scalable infrastructure for building decentralized applications with immense capabilities. Imagine a blockchain layer where multiple blockchain protocols are communicating seamlessly with each other. Interoperability should therefore concern the transfer of smart contracts' states and allow users to be able to initiate transactions on other networks and transact with the deployment of contracts on other chains. Efinity[11] is an example of a cross-chain blockchain network for NFTs that is built on Polkadot[12] as a parachain. Another example is Flow (Hentschel et al., 2020) that enables a highly scalable blockchain architecture for NFTs and blockchain gaming by improving on consensus by splitting the responsibilities of each validator according to its type. On another note, interoperability should also be concerned with information sharing not only between public blockchain networks but also with private deployments. We further note that interoperability in blockchains is not only concerned with the protocol architecture but also with the challenges of having a shared economy, data ownership, and governance (Belchior et al., 2020).

Secondly, metaverses should be interoperable in terms of creating a global economy for both fungible and non-fungible assets. A user that is represented by a digital identity (e.g., an NFT avatar) should be able to be identified in Decentraland and at the same time using the same identity to teleport to The Sandbox ecosystem. The teleportation of any virtual asset should be seamless to the user. Similarly, minting virtual items on some chain should enable users to create shared experiences across multiple ecosystems and platforms. In other words, the *roaming* of characters and any virtual item should be made possible between independent virtual worlds. We argue that a seamless integration of the virtual worlds is likely to unlock several social and economic breakthroughs. Characters can teleport from one ecosystem to another and participate in various activities. For example, it should be possible for Decentraland users to visit a VR art exhibition in Somnium Space. Blockchain technology could provide the architectural layer for the integration of many virtual worlds under a "Meta-Universe." This will eventually build a utopian

[11] https://efinity.io/whitepaper/company.

[12] https://polkadot.network/.

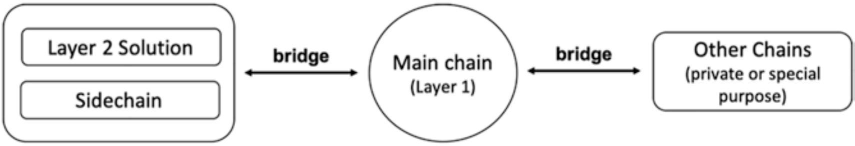

Fig. 6.2 Convergence of enabling technologies towards the Spatial Web

space that will realize the Spatial Web vision where physical interactions will be enhanced with the virtual dimension.

Gas fees. In a blockchain-enabled metaverse, all items (e.g., characters, virtual assets, in-game items) are registered as tokens on a blockchain network to provide a tamper-evident distributed ledger that ensures scarcity and allows users/players to own and trade their virtual assets. Due to the high throughput of transactions and in order to enable interoperability on blockchains and at the same time decrease gas fees, several projects are implementing their platforms utilizing high scalable layer-1 solutions (e.g., Avalanche, Solana), Ethereum layer-2 solutions (e.g., Polygon [previously known as Matic][13]), or sidechains (Gudgeon et al., 2020). For example, Axie Infinity is utilizing an Ethereum-based sidechain (i.e., Ronin[14]) to accommodate the high demand of issuing in-game transactions and transactions for minting, sharing of virtual assets with low transaction fees. Figure 6.2 proposes a blockchain stack for enabling interoperability between chains with the use of bridges. The sidechain enables users to deposit token transfers between Ronin and Ethereum. A blockchain bridge provides a bidirectional connection between different chains to allow for the transfer of data and/or tokens. They have been proposed as solutions to blockchain interoperability (e.g., Polkadot).

Visual environment. The creation of the next generation of metaverses will further enhance computer-generated visuals. This will enable a close to reality realistic environment for the user and further improve the user's experience. It is important for such environments to present a realistic environment to the user where the actions of a virtual avatar

[13] https://polygon.technology/.

[14] https://whitepaper.axieinfinity.com/technology/ronin-ethereum-sidechain.

simulate the user's physical actions. The degree of realism, which is embedded in a virtual world, is concerned with the sensory features offered by each ecosystem. In brief, these are concerned with richer visuals, detailed 3D modeling, realistic rendering, sound effects, and gesture-based interfaces.

Innovative Products and Services

NFT appraisals. Enabling real-time appraisals of individual NFTs or collections of NFTs (e.g., CryptoPunks[15]) is a challenge. Such appraisal models should consider several parameters to determine a close to realistic value of a given NFT. Technically speaking, the value of an individual NFT should consider at least the following: (i) its unique attributes and properties, (ii) the scarcity of individual attributes within a collection, (iii) demand that corresponds to the desire of ownership for a particular NFT, (iv) historic sales data, (v) floor price trend, (vi) the utility of the NFT, and (vii) the transferability of the ownership rights.

Another challenge relates with establishing a robust methodology for determining market capitalizations for entire NFT collections. NFTValuations[16] developed by the University of Nicosia proposes a robust methodology that builds on ML techniques to determine market capitalizations on an ecosystem basis. Currently, a beta version of the platform provides market capitalization data for CryptoPunks. Alternatively, UpShot[17] proposes the use of a prediction market that utilizes the wisdom of the crowd to incentivize people to predict the value of an NFT. A challenge that these platforms are likely to face is the high-risk exposure of these assets to the interest of the community, which, in reality, classifies such assets as highly volatile.

NFT oracles. Oracle services have been valuable in the decentralized finance (DeFi) space by enabling smart contracts to determine real-time price feeds of assets. For example, such Oracles have been proposed for

[15] https://www.larvalabs.com/cryptopunks. The main CryptoPunks contract can be found at: 0xb47e3cd837dDF8e4c57F05d70Ab865de6e193BBB.

[16] https://nftvaluations.com/about.

[17] https://upshot.io/.

the development of stable coins as well as to prevent arbitrage opportunities in various DeFi protocols. Similarly, Oracles that determine real-time appraisals of NFTs or forecast the value of NFTs could enable interesting and innovative open financial products and services. It is critical for the ecosystem to have an automated methodology to provide NFT appraisals that can be fed through Oracles to various smart contracts.

DeFi composability. DeFi indicates a movement of alternative financial services that are inclusive, fair, transparent, and composable. NFTs can be turned into liquid assets that can be used for providing, borrowing, and lending services. Drops[18] is a platform that allows users to use their NFTs as collateral to obtain thrustless loans. In general, Drops aims to bring more utility to NFTs by enabling idle assets to be used as liquidity to lending pools.

On another note, Pandora Finance[19] aims to bridge the gap between off-chain assets and the on-chain ecosystem by allowing asset owners to turn their real-world illiquid assets to a liquid state. There is a potential for innovative financial products and services by leveraging on the composability between DeFi and the NFT space. The ERC-1155 standard aims to enable fractional ownership of individual NFTs in an attempt to improve their liquidity. This will give the opportunity for micro-investors to own part of an NFT, including the royalties generated. Fractionalized NFTs can then be traded in decentralized exchanges (DEXes) like Uniswap.[20] An example of a platform that enables users to buy, sell, and mint fractions of NFTs is fractional art.[21] Overall, a new research dimension emerges from the composability of DeFi with NFTs as an expansion that goes beyond artwork into creating the next generation of tangible financial instruments.

Rarity tools. Many data analytic monitoring web services exist to monitor the market capitalization of cryptocurrencies. NFTs enabled a new generation of rarity tools that report real-time data on NFT collections. Such data include not only the market capitalization of each collection, but also estimates on market capitalization, sale volumes, total supply, number of

[18] https://drops.co/.

[19] https://pandora.finance/.

[20] https://uniswap.org/.

[21] https://fractional.art/.

owners, and so forth. An interesting feature of such services is the rarity score for each individual NFT based on the attributes of its collection. Rarity.tools[22] implements an example of a ranking of NFTs based on their rarity.

Indexing and search engines for NFTs. The ecosystem of NFTs is expected to grow, especially with the emergence of several metaverses. A challenge that remains open is how to search this space on individual NFT items or their collections. Implementing such a search engine will require an indexer to run on all chains and read data from smart contracts on the fly.

Marketplaces. We envision the new generation of NFT marketplaces that enable users to fractionalize their NFTs. Such marketplaces will also enable users to rent ownership rights on an NFT to other users or delegate the ownership of NFTs to investors who could then use the NFTs as part of their investment strategy (e.g., an NFT index fund).

Neobanks and NFT custody. Neobanks will be considering offering innovative services to NFT holders. Such services include custody of NFTs in digital vaults and offering high-yield products to users. A research challenge remains on what are the best techniques to provide a secure mechanism for the custody of NFTs or fractionalized tokens, and the cryptographic management of the private keys. At the same time, we are expecting a rise in the use of multi-NFT wallets for users to enable the self-custodianship of NFT assets cross-chain.

Business opportunities. In general, it is expected that the metaverse will create many business opportunities, especially for businesses that are interested in establishing deep customer relations and offer alternative user interaction experiences. Users will be offered an entire new environment for engaging with businesses, having full control of their private data and of their identities.

Monetization Opportunities

The emergence of metaverses with embedded crypto economies and participation incentives let people to socialize and earn money by monetizing their virtual assets (e.g., renting parcels of land) while at the same

[22] https://rarity.tools/.

time guaranteeing interoperability and genuine ownership. Other monetization opportunities relate with the organization of virtual events in the metaverse. Users can join the event using NFT tickets which demonstrate their entitlement to access the event. In general, anyone can generate NFT items without programming experience and mint them in some marketplace like OpenSea.[23] Such marketplaces directly connect creators and consumers without the need of any intermediary. Also, a smart contract could be utilized to govern the IP rights and distribute royalties to the creator automatically.

The creation of social tokens can enable the next generation of social platforms where creators are monetizing their creations and IP rights, as well as royalties are governed with the use of smart contracts over a transparent and decentralized blockchain network. This will enable the development of mini economies. For example, Pandora Finance (Vohra, 2021) permits users to tokenize their social skills with the use of NFTs and then trade them in their cross-chain DEX.

Play-to-earn (P2E) is the new trend in the metaverse gaming arena. Axie Infinity is such an example in which players from developing countries are sponsored to cover the costs of "breeding" Axies and play the game. In brief, Axie owners are lending their Axies to sponsored players that are then playing the game on their behalf to earn in-game reward tokens.[24] Such examples indicate how blockchain-based gaming enables an open P2E financial ecosystem.

DAOs and fractionalization of NFTs provide another monetization opportunity. Users that hold fractionalized ownership of NFT items get their royalties or rewards from selling an NFT. Furthermore, a fractionalized NFT can be governed by a DAO that will be responsible for its financial future and users are incentivized to participate in such a DAO with the use of a secondary token.

[23] https://opensea.io/.

[24] Tokens are received in Smooth Love Potions (SLP)—https://etherscan.io/token/0x37236cd05b34cc79d3715af2383e96dd7443dcf1.

Challenges on Governance, Generation, and Minting Processes

In this section, we present significant challenges associated with the governance, the generation, and the minting process of blockchain-based metaverse environments. These include (i) digital fingerprints, (ii) generation methods, (iii) token standards, (iv) regulation, and (v) taxation.

Digital fingerprints. This challenge relates to how to determine and verify the authenticity of each NFT. In most cases, a physical object is digitized and then pushed to some p2p storage network, whereas its digital fingerprint, which is generated by calculating the hash (e.g., SHA256) of its digital representation, is pushed on the blockchain (e.g., in a smart contract state or on the block using an OPcode). To verify the authenticity of the digital representation, one needs to calculate the hash of a given object and then compare it to the hash stored on the blockchain. Thus far, most digital fingerprints have been generated with the use of one-way hash functions (aka message digests). In computer vision, descriptors are used to describe the visual features of images, videos, and algorithms (Vassou et al., 2017). In this research direction, we suggest the utilization of such visual descriptors to provide a unique identification scheme based on the features that are used to describe each digital object. In cases where smart devices (e.g., VR glasses) are used to verify the authenticity of some visual information, having a visual descriptor will enable the verification algorithm to determine the feature vector that characterizes the object with a method that is invariant to rotation or sensitive to light conditions.

Generation methods. Avatar collections like CryptoPunks are created with the use of programmable generators[25] that are parameterized to generate unique collectible characters over a range of features in 2D. Each feature is unique, and its scarcity is determined as a parameter to the generation algorithm and according to the rareness degree. In a fully realistic metaverse environment, such digital objects can represent characters/avatars in 3D, virtual world objects or constructs, and in-game assets. A research challenge toward this direction relates with exploring various

[25] https://github.com/larvalabs/cryptopunks.

methodologies for programmable generators specifically designed for creating building blocks or items in a metaverse environment. The generators can be used for digitizing physical objects and annotating them with unique metadata or features. In addition, such generators can be used to evolve a virtual space dynamically if certain conditions are met. In addition, such generators could be driven by AI techniques. Lastly, visualization techniques, 3D modeling tools (e.g., 3DS Max[26]), and gaming engines (e.g., Unity[27]) currently used for the development of computer games could be further utilized and improved.

Token standards. The generation of fungible (ERC-20) and non-fungible tokens (e.g. ERC-721, ERC-1155) are following certain standard proposals that have been published by the community. It is expected that more standards will be proposed as part of accommodating unique properties and functions for virtual assets. Currently, several Ethereum virtual machine (EVM)-enabled blockchain networks (e.g., VeChain, Avalanche) and others like Bitcoin Cash, Solana, Cardano are publishing their own standards for minting NFTs.

Regulation. The rise of virtual worlds is generating a new virtual economy comprising many different virtual assets of intrinsic value. At the same time, the composability of NFTs with DeFi is likely to generate new investment opportunities in an open financial system. Evaluating the legal and regulatory risks in such an environment is a challenge. How is regulation reacting to this new environment? Some of the key legal questions that need to be answered include the following: How are NFTs categorized? How are intellectual property rights preserved? What anti-money laundering (AML) mechanisms should be in place? What are the sanction implications? What cybersecurity concerns exist? What are the state laws governing such virtual assets? Lastly, we highlight that the decentralized nature of NFTs and the lack of a standardized way to estimate their valuations is likely to create manipulation opportunities for AML. For example, NFTs could be potentially leveraged by illicit actors in masking the real value of financial transactions or other business activities.

[26] https://www.autodesk.eu/products/3ds-max/overview.

[27] https://unity.com/.

Taxation. The current legal framework in most jurisdictions treats royalties from IP (e.g., from art, books, software) as taxable property. In this space, sales from NFTs that encapsulate such royalties remain a gray area in terms of their tax treatments. With NFTs remaining below the radar, there is a high likelihood that financial crimes will deliberately use NFTs as a vehicle for money laundering and for conducting other illicit activities. Tax treatments from NFT sales, royalties, or other profits that relate with IP from NFTs should therefore be considered by governments.

Concluding Remarks

The vision of the Spatial Web will eventually eliminate the boundaries between digital content and objects from the physical world and enable new user interactions. Although we cannot predict whether and when this vision will reach maturity, several downstream technologies are pushing for its evolution. This chapter focuses on how DLTs, such as blockchains, can provide a ubiquitous layer to authenticate and decentralize information for the Spatial Web. More specifically, we discuss how blockchains can contribute to such an environment with providing an architectural layer for data integrity, and act as a standardization mechanism for creating and tokenizing virtual assets. Furthermore, this chapter presents an analysis of several blockchain-based metaverses (e.g., Decentraland, The Sandbox) and decentralized gaming platforms (e.g., Axie Infinity) in an attempt to understand their features, and how far blockchains, as a technology, could be utilized to support the vision of the Spatial Web—for the creation of a unified metaverse where physical reality is fused with the virtual world. Our analysis showed that blockchains can be considered as an enabler technology for the realization of the Spatial Web vision and that early signs of blockchain-based metaverses are examples of how the technology could be instantiated for the creation of virtual worlds with build-in immutability, authenticity, and digital ownership. The property of decentralization, offered by blockchains, spurs the hope that next-generation virtual worlds will be truly open and democratized. In addition, and considering the current status of blockchain-based metaverses, the chapter discusses several open challenges and research perspectives in an attempt to provide guidance on what needs to be considered to further evolve the space and push toward the realization of a metaverse that converges with the physical reality. Lastly, we consider and discuss opportunities that are likely to emerge in this space with the creation of new innovative products and services. The chapter contributes and enhances the existing body of literature on this interesting and complicated area by collecting, presenting, and analyzing rapidly evolving state-of-the-art technologies and environments like blockchain-based metaverse, NFTs, and virtual worlds. It also discusses main research perspectives and open challenges in this area.

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