Web3 Metaverse: State-of-the-Art and Vision

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The metaverse, as a rapidly evolving socio-technical phenomenon, exhibits significant potential across diverse domains by leveraging Web3 (a.k.a. Web 3.0) technologies such as blockchain, smart contracts, and non-fungible tokens (NFTs). This survey aims to provide a comprehensive overview of the Web3 metaverse from a human-centered perspective. We (i) systematically review the development of the metaverse over the past 30 years, highlighting the balanced contributions from its core components: Web3, immersive convergence, and crowd intelligence communities, (ii) define the metaverse that integrates the Web3 community as the Web3 metaverse and propose an analysis framework from the community, society, and human layers to describe the features, missions, and relationships for each community and their overlapping sections, (iii) survey the state-of-the-art of the Web3 metaverse from a human-centered perspective, namely, the identity, field, and behavior aspects, and (iv) provide supplementary technical reviews. To the best of our knowledge, this work represents the first systematic, interdisciplinary survey on the Web3 metaverse. Specifically, we commence by discussing the potential for establishing decentralized identities (DID) utilizing mechanisms such as profile picture (PFP) NFTs, domain name NFTs, and soulbound tokens (SBTs). Subsequently, we examine land, utility, and equipment NFTs within the Web3 metaverse, highlighting interoperable and full on-chain solutions for existing centralization challenges. Lastly, we spotlight current research and practices about individual, intra-group, and inter-group behaviors within the Web3 metaverse, such as Creative Commons Zero license (CC0) NFTs, decentralized education, decentralized science (DeSci), and decentralized autonomous organizations (DAO). Furthermore, we share our insights into several promising directions, encompassing three key socio-technical facets of Web3 metaverse development.

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CCS Concepts: • **General and reference** → **Surveys and overviews**; • **Information systems** → **Multimedia information systems**; • **Human-centered computing** → **Collaborative and social computing theory, concepts and paradigms**; **HCI theory, concepts and models;**

Additional Key Words and Phrases: Metaverse, Web3, human-centered, definition and framework, survey

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1 INTRODUCTION

The rapid expansion of next-generation Internet technologies has fostered significant growth across diverse domains, including finance, entertainment, education, and social interaction. The metaverse, epitomizing these socio-technical advancements, has experienced substantial growth. The metaverse industry began its ascendance in 2020, reaching a market size of $478.7 billion and swiftly growing to approximately $550 billion in 2021, with an annual compound growth rate of 13.1% [103]. Although the industry entered a cooling-off period in 2022, experts believe it will continue to offer opportunities due to the growing demand from Gen-Z and Gen-Alpha and predict an impact of $270 billion on the academic learning market, a $206 billion impact on the advertising market, and a $125 billion impact on the gaming market by 2030 [56, 139]. Correspondingly, an increasing volume of academic literature explores various facets of the metaverse. As evidenced by Google Scholar data, publications related to the metaverse began surfacing in 1992, with a marked surge noted in 2021. Roughly 14,700 relevant works were published in 2022, amounting to about 33,000 over the past three decades (Figure 1).

The metaverse thrives by amalgamating diverse communities. These include the immersive convergence community, which focuses on sensory-rich experience consumption (e.g., **mixed reality** (**MR**), **augmented reality** (**AR**), **virtual reality** (**VR**), and digital twins), and the crowd intelligence community, which is devoted to digital content production (e.g., **user-generated content** (**UGC**) and **AI-generated content** (**AIGC**)). Notably, metaverse development should adopt a human-centered approach to enhance social good [64] and to ameliorate societal structures [40]. The human-centered principle entails addressing challenges such as ensuring digital sovereignty, empowering creators, and fostering positive social interactions, which were overlooked during the centralized Web2 era [197, 202]. In this context, the integration of the Web3 (a.k.a. Web 3.0) community (e.g., blockchain, smart contracts, and **non-fungible tokens** (**NFTs**)) to provide a decentralized infrastructure, coupled with immersive and content-rich experiences, represents a new paradigm that enriches the continually evolving metaverse landscape (Figure 2). According to the above-mentioned compositions, the Web3 metaverse is the convergence of technologies and scientific knowledge regarding multimedia computing (e.g., VR/AR/MR, AI, and data processing), multimedia communications (e.g., multi-access connection, blockchain network, and ubiquitous sensing), and multimedia applications (e.g., immersive experience, digital identity, and social interaction). Therefore, the emergence of the Web3 metaverse has boosted the combination and development of cutting-edge multimedia technologies and demonstrated significant potential within both the industry and the academic communities.

The vast potential of the metaverse has inspired about 282 survey articles on Google Scholar. From the perspective of the **immersive convergence community**, the earliest survey appeared in 2012 [61]. Like other early works, these surveys conceptualize the metaverse as a

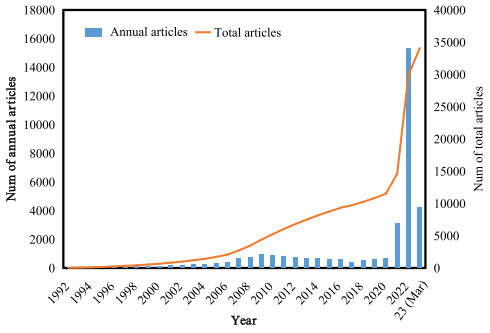


Fig. 1. The number of metaverse articles retrieved through Google Scholar.

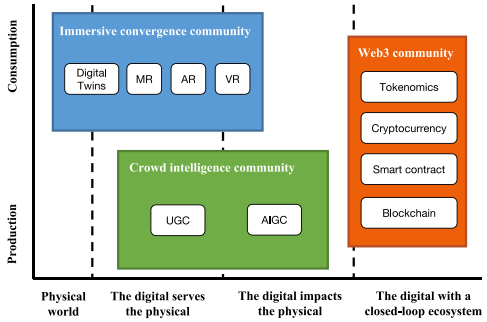


Fig. 2. The comparison of constituent communities of the metaverse.

3D virtual world, emphasizing its technical principles and applications in immersive experiences [59, 147, 148]. Regarding the combination with Web3, the immersive convergence community's studies discuss the positive impact on increasing immersive experiences [52] and promoting algorithm development [119]. From the viewpoint of the **crowd intelligence community**, researchers scrutinize the value and security implications of user-generated data within the metaverse [177]. Additionally, they probe the potential of AI technology for content production [95] and user identification tracking [219] within the metaverse. Regarding the combination with Web3, Kral et al.[120] review how blockchain can promote worker production. Cao[29] describes the significance of a blockchain-based AI system for the metaverse. From the **Web3 community**'s perspective, research has surveyed the importance of Web3 for the metaverse in privacy and security [85], digital asset management [189], and financial areas [46, 213]. Additionally, some **comprehensive surveys** cover these three communities. For instance, Lee et al.[124] survey eight types of fundamental metaverse technologies and their applications. Wang et al.[201] demonstrate the mutual complementary relationship between these technologies. However, many works consider Web3 merely supplementary to the metaverse, primarily focusing on technological aspects. As a result, they often overlook multidisciplinary achievements and lack a comprehensive, human-centered investigation.

In contrast to previous studies (see Table 1), our survey recognizes the coequal importance of the Web3 community in conjunction with others. We first define the mature metaverse that integrates the Web3 technology as the **Web3 metaverse**:

> *A decentralized, closed-loop society system utilizes Web3 technologies for distribution and exchange, granting users increased autonomy and control over their digital assets, experiences, and relationships. This system promotes social progress by integrating Web3 technologies with content creation technologies at the production and immersive technologies at the consumption.*

The definition elucidates the attributes and objectives of the Web3 metaverse. In the closed-loop system of the Web3 metaverse, the collective intelligence community produces diverse content, the immersive convergence community facilitates experience consumption of content, and the Web3 community ensures decentralized distribution and exchange. We propose an analytical framework to explain the interrelationships among these components further.

We then introduce a systematic and human-centered taxonomy, grounded in social identity theory [180], to probe the state-of-the-art in industry and academia within the Web3 metaverse. Our framework encompasses three aspects of human existence in the metaverse: **Identity, Field, and Behavior**. Figure 3 illustrates our proposed taxonomy. Specifically, the identity aspect

Table 1. Comparison with Previous Surveys

Surveys	Year	Perspective	Technical	Human-centered
[61]	2013	IC	Moderate	Moderate
[147]	2021	IC	Basic	Basic
[148]	2021	IC	Moderate	Basic
[59]	2022	IC	Moderate	Moderate
[52]	2022	IC-Web3	Moderate	Moderate
[119]	2022	IC-Web3	Moderate	Moderate
[177]	2022	CI	Moderate	Basic
[95]	2022	CI	Moderate	Basic
[219]	2022	CI	Moderate	Moderate
[120]	2022	CI-Web3	Moderate	Moderate
[29]	2022	CI-Web3	Moderate	Moderate
[85]	2022	Web3	Moderate	Moderate
[189]	2023	Web3	Moderate	Moderate
[213]	2022	Web3	Basic	Basic
[46]	2022	Web3	Moderate	Moderate
[124]	2021	IC-CI-Web3	Comprehensive	Moderate
[201]	2022	IC-CI-Web3	Comprehensive	Basic
Ours	2023	Web3	Moderate	**Comprehensive**

IC: Immersive convergence, CI: Crowd intelligence.

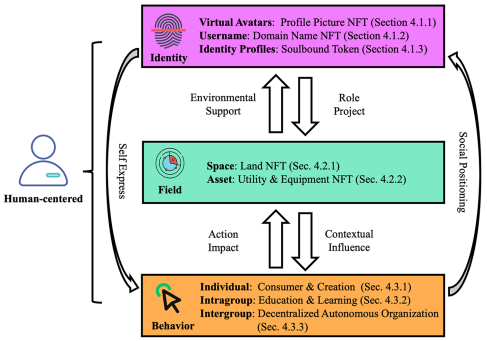


Fig. 3. The taxonomy of this work.

concentrates on **profile picture** (**PFP**) NFTs, which are prevalently employed as social avatars for metaverse participants; domain name NFTs, which pertain to the ownership of digital assets; and **soulbound tokens** (**SBTs**), which establish innovative identity profiles. The field aspect examines the field that serves as the foundation for human identity expression and social behaviors in the metaverse, encompassing the basic land NFTs and the advanced assortment represented by utility and equipment NFTs. The behavior aspect reviews consumer behavior and creation behavior at the individual level, education and science at the intragroup level, and behaviors within the **decentralized autonomous organizations** (**DAO**) at the intergroup level. As a response to the socio-technical evolution within the metaverse, our taxonomy offers a distinct human-centered lens for examining the metaverse, concurrently aligning with the decentralization from the Web3 community.

The organization of our work is as follows: The development of the metaverse and its constituent three communities is in Section 2. Our definition of the Web3 metaverse and proposed analysis framework are in Section 3. The comprehensive survey on the Web3 metaverse from a human-centered perspective is in Section 4. We also give a moderate technical study on the Web3 metaverse as a supplement to clarify our view in Section 5. Our insights into several challenging but promising directions are in Section 6, followed by the conclusion in Section 7.

2 TRACING THE FOOTSTEPS: THE DEVELOPMENT OF THE METAVERSE

The metaverse concept is typically credited to the 1992 science fiction novel, Snow Crash, authored by Neal Stephenson [175]. This novel envisaged a virtual realm parallelling the physical world. Due to its forward-looking proposition, the term "metaverse" has been progressively embraced by a broad spectrum of industrial and technical communities, thus, transitioning from purely literary discourse to tangible industrial development and rigorous academic research. However, prior bibliometric surveys on the metaverse have concentrated on a single domain [188] or cover a limited time span [148]. This section aims to provide a comprehensive view of the metaverse by delineating the industrial and academic trajectory spanning over three decades (1992–2023). This analysis also sets the stage for the subsequent definition of the Web3 metaverse.

2.1 Industrial Development of the Metaverse

To comprehend the industrial development of the metaverse, we conducted a quantitative survey by extracting pertinent news articles from the Dow Jones Factiva.[1] To ensure representativeness

[1]Dow Jones Factiva is a leading news database providing access to premium content from over 30,000 sources in 200 countries. https://www.dowjones.com/professional/factiva

Table 2. Top 10 Industries and their News Numbers in Each Community (Descending Order by Number)

Web3	Num	Crowd Intelligence	Num	Immersive Convergence	Num
Cryptocurrencies	12,331	Artificial Intelligence Technologies	5,226	Virtual Reality Technologies	8,325
Blockchain Technology	9,985	Social Media Platforms/Tools	4,794	Mobile Telecommunications	5,824
Banking/Credit	1,954	Online Service Providers	2,717	Personal Electronics	1,368
Exchanges	1,952	Dolls/Toys/Games	2,097	Wearable Technology	1,326
E-commerce	1,858	Design	2,027	Passenger Cars	1,321
Management	1,739	Media/Entertainment	1,720	Health Care/Life Sciences	1,241
Financial Technology	1,613	Internet Search Engines	1,633	Graphics Processing Units	1,099
Private Equity	1,562	Streaming Services	1,475	Internet-of-Things Technologies	1,092
Art Dealing	1,463	Data Centers/Colocation Services	1,468	Construction	934
Legal Services	1,283	Education	1,198	Tourism	870
Others	7,109	Others	16,697	Others	20,296
Sum	42,849	Sum	41,052	Sum	43,696

and operationalization, our filtering criteria encompassed global regions, all sources, and English-based news from January 1992 to March 2023. We obtained 127,597 metaverse-related news, including headlines, release dates, abstracts, and Dow Jones industry categories to which the news content is related. Our data spanned 100 industries and 139 regions. Two researchers independently coded the news' industrial categories belonging to Web3, crowd intelligence, and immersive convergence communities. Considering individual cognition limitations, we also incorporated the ChatGPT-4[2] to perform the coding. Based on prior knowledge, we categorized industries supporting immersive experiences as the immersive convergence community, industries enabling content creation as the crowd intelligence community, and industries facilitating digital ownership and production relations as the Web3 community. Following pre-coding, the manual results were compared to ChatGPT's, and iterative adjustments were made until the three coding outcomes aligned. Table 2 displays the top 10 industries in the final classification results for the three communities, along with the corresponding news article counts. Leveraging the industry class distribution of the three communities, we generated Figure 4 in conjunction with the news release dates. Similarly, we constructed Figure 5 based on the regional distribution of news articles. Notably, we consolidated news events occurring within a city, province, or state into their respective regional categories.

Data analysis from Table 2 shows similar news article counts across the Web3 community (42,849), the crowd intelligence community (41,052), and the immersive convergence community (43,696). This implies the equal significance of these three communities in driving the industrial development of the metaverse. Specifically, in the **Web3 community**: "Cryptocurrencies" and "Blockchain Technology" hold dominant positions, indicating that decentralization, secure digital asset management, and trustless transactions are currently critical concerns within the metaverse. The presence of "Banking/Credit," "Exchanges," "Financial Technology," and "Private Equity" underscores the financial sector's role in integrating metaverse technologies for novel products and services. The inclusion of "E-commerce," "Management," "Art Dealing," and "Legal Services" signifies that the Web3 community is transforming traditional business and governance operations, generating new opportunities in the virtual world's production and consumption, and showcasing the metaverse's socio-technical potential. In the **crowd intelligence community**: "Artificial Intelligence Technologies" and "Social Media Platforms/Tools" are at the forefront, suggesting that AI-driven content creation, crowdsourced collaboration, and personalized experiences are essential for the metaverse. Industries such as "Design," "Media/Entertainment," and "Education" reflect the metaverse's potential to revolutionize engagement with creative works, content consumption, and learning experiences. In the **immersive convergence community**: "Virtual Reality

[2]https://chat.openai.com/

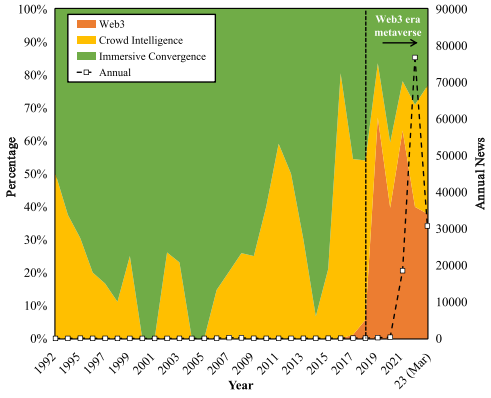


Fig. 4. Different communities' news of the metaverse (1992–2023).

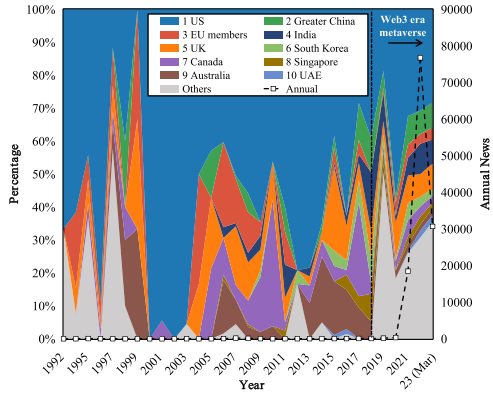


Fig. 5. Industrial news and hot regions of the metaverse (1992–2023).

Technologies" and "Mobile Telecommunications" lead the way, emphasizing the importance of immersive experiences and seamless connectivity in shaping the metaverse. The presence of "Personal Electronics," "Wearable Technology," "Health Care/Life Sciences," and "Internet-of-things Technologies" indicates that the metaverse impacts various aspects of daily life, with this community serving as the interface between the virtual and physical realms.

Moreover, as Figure 4, since 1992, metaverse has often been used interchangeably with VR, corresponding to the long-standing dominance of the immersive convergence community. Then, in a blog post in 2017, Ehrsam [67] might have been the first industrial expert to advocate the vital role of blockchain in the metaverse. Blockchain provides decentralized control over assets, identity, and governance, thus hindering monopolization or manipulation. In the same year, we found a piece of news on a metaverse company's collaboration with a crypto bank [99]. Following 2018, an increasing number of news began to underscore the potential of the Web3 community in shaping the metaverse. For instance, artist Marguerite deCourcelle argued that the most crucial aspect of the metaverse should be the currency's value in both real and virtual worlds: "Blockchain is a treasure trove of unexplored potential for how information transcends a virtual existence and can be simultaneously rooted in the real world" [155]. Meanwhile, 2018 marked the advent of the Web3 metaverse with the launch of Voxels (formerly Cryptovoxels)[3] and Decentraland[4] [16, 64]. These blockchain-based metaverse projects offer users opportunities to engage in the digital space while contributing to a thriving ecosystem surpassing traditional virtual worlds.

This burgeoning growth is reflected in the prevalence of metaverse news from the Web3 community starting in 2019 (Figure 4). In particular, although the public often considers Facebook's name change to Meta in 2021 and its promotion of VR products as critical indicators of the metaverse development [121], it's noteworthy that news from the Web3 community accounted for 51.64% in the same year. Secondly, the development and deployment of technologies have long been centralized, leading to "digital divides" and exacerbating inequalities. However, blockchain has significantly impacted many developing countries' economies, helping to alleviate global inequality through enhanced trust, security, transparency, and traceability [88]. Figure 5 shows that before 2018, developed regions such as the United States, European Union countries, and Canada dominated the development of the metaverse industry. Subsequently, the metaverse diversified globally with the

[3]https://www.voxels.com/
[4]https://decentraland.org/

Table 3. Top 5 Metaverse Keywords from 1992 to 2023, Triennial Sampling from 1992 to 2016, and Annual after 2016

1992	...	**1995**	...	**1998**	...	**2001**
science fiction		multimedia developers		satellite network		wrong turn
snow crash		marketers		controlled news		important question
freelance hackers	...	virtual places	...	absolute junk	...	corporate labs
greatest sword fighter		web news		celebrity crime		particular database
amoral high-tech corporations		virtual intercourse		non-stop hype		nice graphics
2004	...	**2007**	...	**2010**	...	**2013**
top scientist		virtual world		club scene		cyborg-like spectacles
virtual body		real life		virtual world		science-fiction writer
virtual culture	...	virtual world services	...	dark time	...	technological inventions
video gamers		real world		digital evil		post-apocalyptic tale
cyberpunk genre		virtual property		new user accounts		virtual reality
2016		**2017**		**2018**		**2019**
virtual reality		programmable bacteria		virtual reality		virtual world
start-up ecosystem		virtual reality tool		visual work		**blockchain network**
virtual reality company		gold-sniffing camera		science fiction		real world
science fiction		market value		virtual city		trade show
digital humanism		visual works		virtual real estate		safety technology
2020		**2021**		**2022**		**2023**
virtual world		**land asset**		horizon world		artificial intelligence
non-fungible token		market prediction		artificial intelligence		**artwork asset**
blockchain game		**floor price**		goblin mode		**decentralized platform**
block producer		**non-fungible token**		**blockchain**		job cut
autonomous community		**collection**		magic leap		**token value**

Web3 community relevant words are bold.

participation of the Web3 community. Third, the keywords of annual news (Table 3) suggest that the development trends in the metaverse have evolved from a fundamental technology-centered level to an advanced human-centered level. The early focus on immersion technological advancements has gradually shifted toward social and community aspects. This trend also signifies a shift from an emphasis on individual experience towards a concentration on social collaboration and production.

In summary, our survey of metaverse-related news over the past 30 years reveals that the Web3, crowd intelligence, and immersive convergence communities are all vital contributors to metaverse development. The immersive convergence community spearheaded the metaverse industry, which significantly prospered and diversified with the involvement of the Web3 community after 2018. This growth led to a shift from a technology-centered approach to a more human-centered one, emphasizing social collaboration and production, and relieving global inequalities.

2.2 Academic Research on the Metaverse

Metaverse is an emerging combination of industrial development and academic research. Following a bibliometric survey of industry developments, we now focus on the academic area. To identify pertinent academic articles, we utilized Google Scholar and the Publish or Perish tool,[5] employing "metaverse" as the keyword. We collected various data, such as article titles, abstracts, and publication citation counts spanning January 1992 to December 2022. After de-duplication, a total of 29,895 relevant works were obtained. We used Citespace[6] to do further analysis and visualization. Owing to the limited dimensions of data available through Google Scholar, our mapping of the co-occurrence network of articles is based on title and abstract information. The

[5]https://harzing.com/resources/publish-or-perish
[6]https://citespace.podia.com/

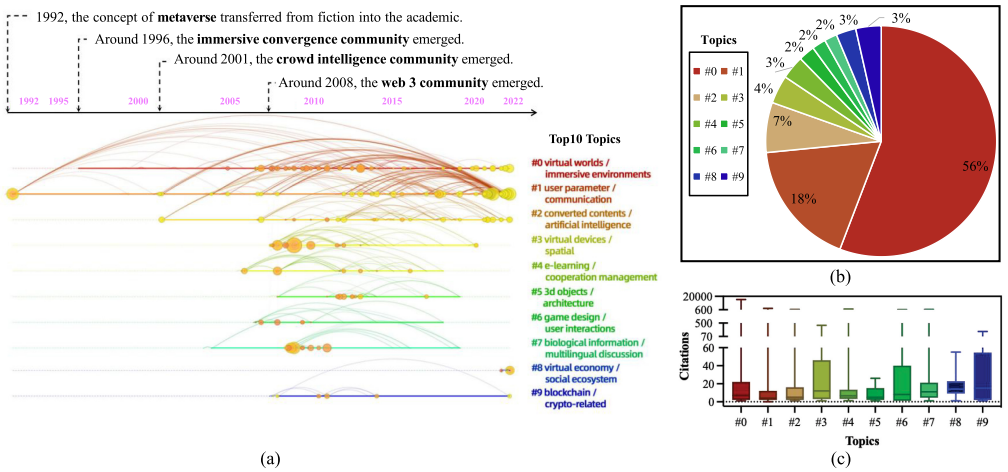


Fig. 6. (a) The timeline of academic research on the metaverse. (b) The distribution of articles across different academic topics. (c) The citation distribution of different academic topics.

resulting timeline, presented in Figure 6(a), consists of horizontal axes that represent research topics, clustered and labeled via the Latent Semantic Indexing algorithm. We identified ten major research topics within the metaverse, with corresponding keywords listed to the right of each horizontal axis. Nodes signify key articles that have garnered substantial citations. The size of each node correlates with the article's citation count, while lines connecting nodes indicate the co-occurrence of words within the titles and abstracts of the linked articles. The visualization provides insights into the interconnectedness of various research topics and influential publications within the rapidly expanding metaverse.

Academic research on the metaverse mirrors corresponding trends and themes observed in its industrial development. As depicted in Figure 6(a), the academic exploration of the immersive convergence community in the metaverse emerged around 1996, preceding other communities. Subsequently, research on crowd intelligence aspects of the metaverse surfaced around 2001. Finally, the advent of crypto applications such as Bitcoin in 2008 gave rise to research in the Web3 community within the metaverse. Several groundbreaking works have significantly contributed to the development of the Metaverse. The term "metaverse" was first introduced into the technological realm as an inspiration for designing VR technologies encompassing visual, auditory, and haptic perception, drawing from its depiction in science fiction. Early influential works in VR [169] and AR [8] helped propel metaverse studies forward. Stone [176] is possibly the first technical philosopher to systematically analyze the socio-technical dimensions of the metaverse. Although Stone's work primarily focuses on the "virtual" aspect, it highlights the challenges that novel modes of interaction, socialization, and behavior pose to traditional notions of identity and society, emphasizing the importance of a human-centered perspective in metaverse research. Jarvenpaa [106] introduced the concepts of cooperation and creation in metaverse studies, arguing that trust is a significant challenge in virtual worlds. Some works paved the way for research in diverse areas, such as healthcare [24], game design [211], and artificial intelligence [47], further expanding the scope of metaverse academic research. Regarding the Web3 community, the earliest study explicitly advocating for the construction of the metaverse based on blockchain technology appeared in 2018 [165], simultaneously with industry developments. This work aimed to reduce the cost of user interaction through decentralized technologies.

However, it is notable that the distribution of article numbers greatly varies across various research topics, as illustrated in Figure 6(b). In contrast to the nearly equal contributions of the three communities in metaverse industrial development, the immersive convergence community has been the predominant contributor to academic research in this area. For instance, Topic 0 (virtual worlds/immersive environment), directly linked to the immersive convergence community, comprises 56% of the research. In contrast, Topic 8 (virtual economy/social ecosystem) and Topic 9 (blockchain/crypto-related), directly related to the Web3 community, collectively represent only about 6%. To assess the influence of these research topics, we plotted box plots of citation distributions for each topic, using 95% confidence intervals, as shown in Figure 6(c). This analysis reveals that while most metaverse articles receive fewer than 60 citations, there are several highly-cited works within Topics 0 through 7. These highly-cited publications notably surpass those from the Web3 community (Topics 8 and 9). This could be attributed to the metaverse's early development that primarily focused on virtual worlds and immersive environments. However, some vital works highlighted the trend of focusing on human factors, like trust and cooperation in metaverse studies directly related to the Web3 features. Therefore, although the Web3 community is relatively new in the metaverse, it warrants the attention of researchers.

2.3 Lessons Learned

This section has provided a comprehensive review of both industrial developments and academic pursuits concerning the metaverse. A significant insight from our analysis is the realization that literature, even those genres as informal as science fiction, is not merely an avenue for entertainment but can offer pivotal blueprints that can forecast potential technological pathways. Our findings underscore the critical role of interdisciplinary collaboration. The flourishing of the metaverse was the culmination of concerted efforts spanning multiple disciplines. Intriguingly, while the metaverse industry benefits from equal contributions of all three communities, the academic sphere saw the immersive convergence and crowd intelligence communities as the mainstream. This dominance can be traced back to the metaverse's nascent stages, which predominantly revolved around creating virtual worlds and immersive experiences. Yet, we observed a nuanced shift with specific scholarly works emphasizing human-centered factors, especially trust and cooperation, that are inherently linked to Web3 features. Hence, even though the Web3 community's footprint in the metaverse is still in its infancy, it undeniably deserves the spotlight in future research.

3 CONSTRUCTING THE WEB3 METAVERSE: DEFINITION AND FRAMEWORK

A notable shift is observed after examining the historical progression of the metaverse in both industrial development and academic research. This shift transitions from a singular, technology-centered paradigm to a more encompassing multidisciplinary and human-centered approach. The metaverse's purpose has evolved from merely constructing virtual environments to promoting social progress. The emergence of the Web3 community confirms this trend. However, a comprehensive definition and description of the Web3 integrated metaverse remain lacking. To address this gap, this section provides a distinct definition and framework for the Web3 metaverse, considering the constituent communities' features, relations, and socio-technical missions.

3.1 Definition of Web3 Metaverse

Previous works tend to define the metaverse by emphasizing its property of virtual enhancement or virtual-physical combination. However, in the existing Internet system, we already learn and work in virtual spaces like Zoom [112], consume and do business in virtual-physical combined markets like Amazon [157], obtain pleasure and intimacy during the immersive experiences of virtual worlds like Fortnite [31], and even shape the political civic forum in virtual worlds like X

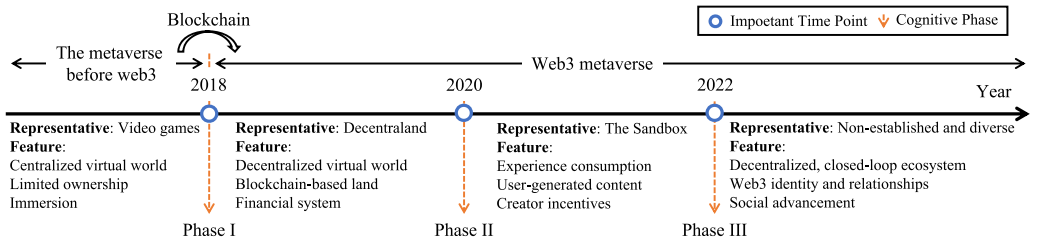


Fig. 7. The brief timeline of cognitions with the metaverse.

(formerly known as Twitter) [171]. Therefore, it may not be possible to distinguish the definition of the metaverse from the Internet only in terms of enriching digital products or multidimensional immersive experiences.

As Figure 7 shows, from the Web3 community perspective, the metaverse was first envisioned as a network of immersive visual experience and blockchain-based shared data [67]. Then, Decentraland described the metaverse as a decentralized virtual world that provides rich and immersive 3D experiences while allowing users to own their virtual land based on blockchain in 2018 [54]. Blockchain-based systems for decentralized digital asset management and trading introduce new dimensions to the virtual world. The cognition differentiates the Web3 metaverse from other virtual worlds and games and has been widely adopted [85, 90, 189]. Around 2020, The Sandbox,[7] which relies on blockchain to transform from a traditional open-world game to a Web3 metaverse, emphasized rewarding creators and disrupting existing virtual worlds, such as Minecraft and Roblox, by enabling users to take ownership of their creations through NFTs [167]. Within The Sandbox, users can leverage UGC tools provided by the project team to create various utility and equipment NFTs and enjoy exclusive UGC-based gaming experiences [166]. Compared with Decentraland, The Sandbox's cognition highlights the creation of digital content and the consumption of digital experiences, inspiring scholars to describe the development of the metaverse in a three-phase manner: (1) Mirroring the real world, (2) Creating native content, and (3) Self-sustaining and surpassing the real world [124, 201]. Around 2022, some studies explored how the metaverse could achieve self-sustainability, pointing out potential paths through PFP, identity, and relationship NFTs [9, 79, 208]. Corresponding industry practices, such as Yuga Labs,[8] develop metaverses based on communities formed around PFP NFT collections. Additionally, a16z,[9] a leading crypto investment fund, asserts that the metaverse transcends the boundaries of virtual gaming. Its essence does not reside in the utilization of VR or AR technologies to "view" the virtual world, but rather in how we communicate, work, and engage within this parallel society, emphasizing a different form of immersion, namely social immersion [97]. However, a clear definition of the closed-loop metaverse is still lacking. Hence, to manifest the social progress potential of the metaverse, we emphasize its decentralized traits introduced by the Web3 technology and define the **Web3 metaverse** as

> *A decentralized, closed-loop society system that utilizes Web3 technologies for distribution and exchange, granting users increased autonomy and control over their digital assets, experiences, and relationships. This system promotes social progress by integrating Web3 technologies with content creation technologies at the production and immersive technologies at the consumption.*

[7] https://www.sandbox.game/
[8] https://www.yuga.com/
[9] https://a16z.com/

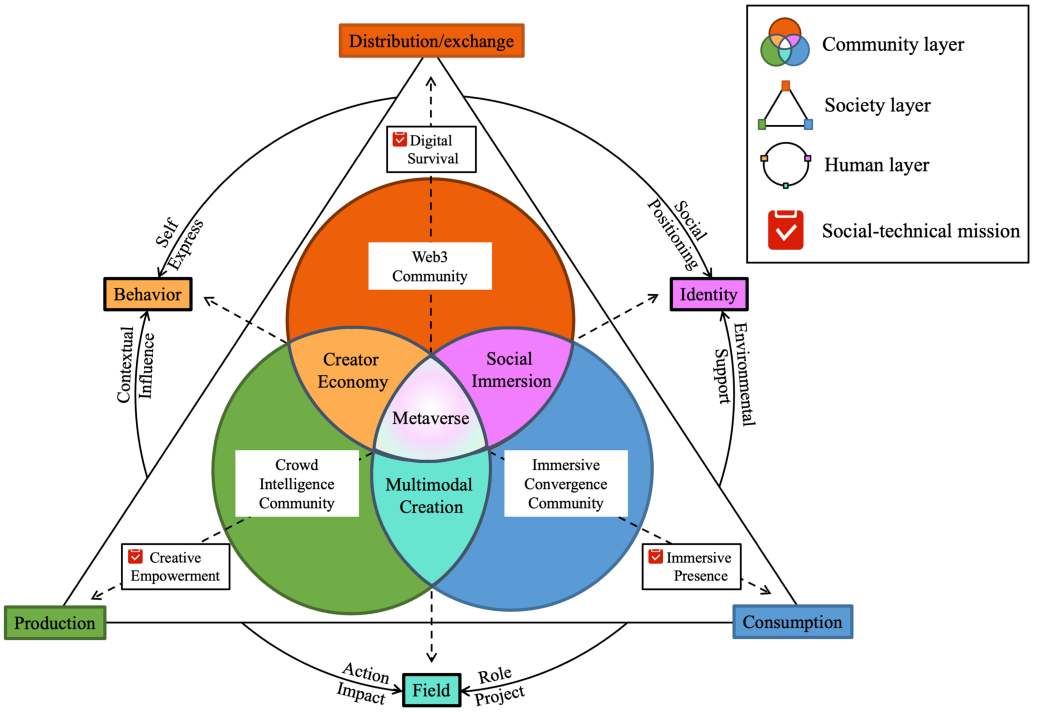


Fig. 8. The framework of Web3 metaverse. Due to the introduction of the Web3 community, the metaverse establishes a multidimensional and closed-loop system, having complete economic and social components.

3.2 Framework of Web3 Metaverse

Our definition treats all three communities as necessary constituents of the metaverse. Figure 8 illustrates the framework of the Web3 metaverse, which introduces the Web3 community and makes the metaverse a multidimensional closed-loop system. Simultaneously, the decentralized socio-technical features of the Web3 community enrich its potential for social progress.

First, in the community layer of the framework, we clarify these three communities and their relations with the metaverse. Understanding these communities and their roles within the Web3 metaverse is crucial in comprehending the system. We define these communities as follows:

— Web3 community: leverages Web3 technologies [10, 118] like blockchain, smart contracts, and NFTs to enable secure, transparent, and trustless distribution and exchange of digital assets, experiences, and relations.
— Crowd intelligence community: harnesses crowdsourcing [22, 128] and AI-driven [126] content creation to revolutionize the production of digital goods, services, and experiences.
— Immersive convergence community: develops and integrates immersive technologies, such as VR, AR, and digital twins [150, 184], to create seamless and highly engaging digital experiences for metaverse content consumption.

The metaverse emerges from integrating three distinct communities, which jointly weave its multi-dimensional structure. Their cooperative interactions amplify the metaverse, nurturing a richer ecosystem. The embodiment of this synthesis is observed in three distinct but intertwined concepts: “social immersion,” “creator economy,” and “multimodal creation.”

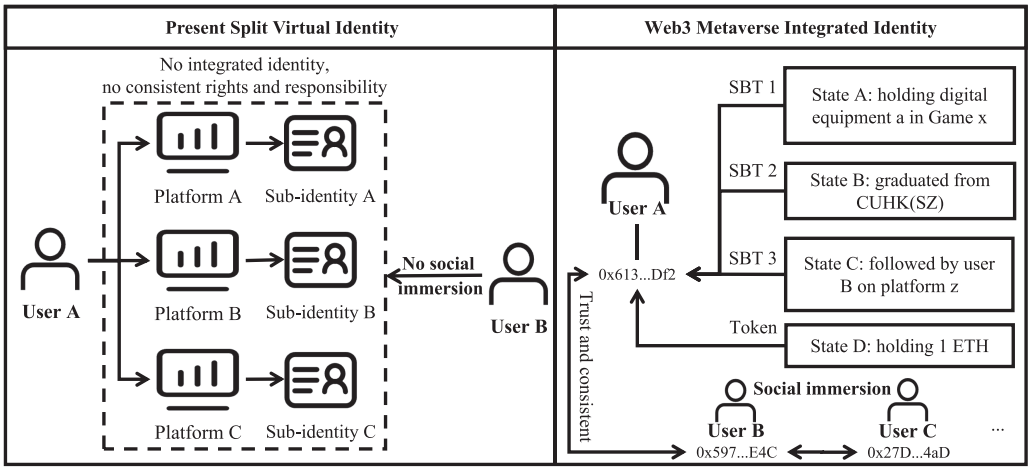


Fig. 9. The comparison of the existing split identity system with the social immersion in the Web3 metaverse.

— Social immersion: Stemming from the union of the Web3 and immersive convergence communities, this concept provides a broader immersion, surpassing the conventional scope of physiologic modalities in traditional virtual worlds [1, 17]. At its heart lies the concept of identity. As Figure 9 depicts, the metaverse underpinned by Web3 technologies introduces a paradigm shift in the identity system. In contrast to the traditional Internet, where platforms exert dominion over user data, yielding fragmented identities, the Web3 metaverse proffers a separating from the centralized platforms but self-cohesive identity. This new approach accentuates decentralized digital identity, grounded in immutable codes [7]. The status of education, social relationships, and asset ownership can be displayed in user A's blockchain address through SBT in a tamper-proof, trusting, and consistent way, which is necessary to maintain a society.
— Creator economy: An amalgamation of the Web3 and crowd intelligence communities, this concept is a revolution of the metaverse's production. By ensuring creators retain formidable control over their work and receive payments directly, it minimizes third-party interferences [141]. Web3's decentralized nature, as illustrated in Figure 10, contrasts sharply with the current centralized Internet system. In the present system, creators publish their works through centralized platforms, and the rewards are often small and not proportional to the value created by creators. In contrast, within the Web3 metaverse, creators can directly publish their works through smart contracts, minting them as NFTs. People consume digital resources by purchasing these NFTs and directly paying the creators via smart contracts.
— Multimodal creation: This concept, stemming from the confluence of crowd intelligence and immersive convergence communities, is further enriched by Web3's foundational role. The decentralization intrinsic to Web3 eliminates the limitations previously imposed by centralized platforms. Liberated from these confines, creators can harness multiple modalities, fostering unparalleled creative expression within the metaverse [122, 197]. As emphasized in Figure 10, creators are subject to various creativity limitations because of the platform's judgment on traffic and trends. While the Web3 metaverse grants creators expansive freedom. Notably, NFT ensures the authorship of creators, so the decentralization attributes of Web3 technologies also pave the way for seamless collaboration between human creators and AI.

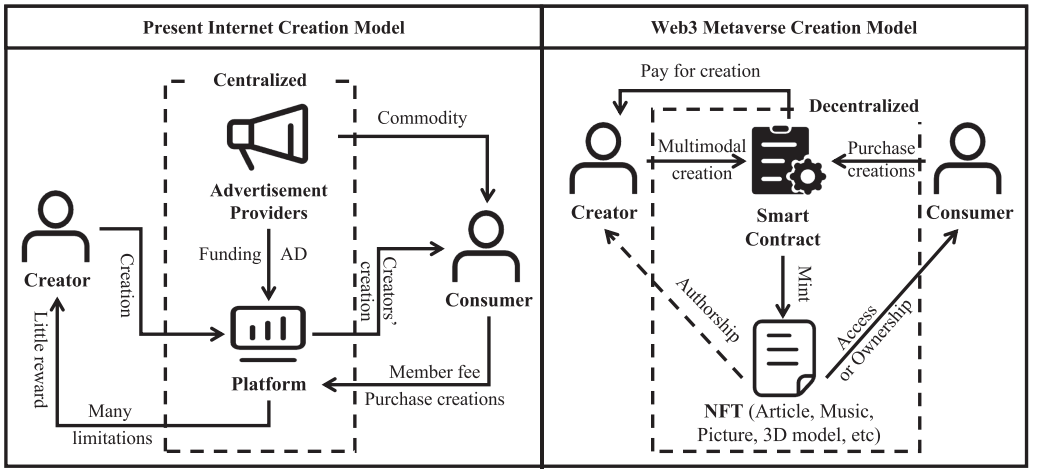


Fig. 10. The comparison of creation models between the present Internet system and the Web3 metaverse.

Let us now have a higher view and examine the society layer. At this layer, we determine the socio-technical missions of each community shaping the metaverse and their roles in social circulation. The Web3 community ensures digital survival, enabling users to control their data, assets, and identities, acting as the distribution/exchange end. The crowd intelligence community caters to the rising demand for varied experiences, symbolizing the production end. Furthermore, immersive convergence ensures an authentic, immersive "presence" in the metaverse, aligning with the transition from possession to experience-based consumption, thus, representing the consumption end [144]. With Web3 integration, the metaverse encapsulates all facets of social circulation [14], laying the groundwork for a self-sustaining ecosystem.

Finally, in the human framework layer, we map social immersion, multimodal creation, and creator economy to identity, field, and behavior. Social immersion underscores user interconnections and aligns with identity. Multimodal creation, emblematic of the field, facilitates innovative and varied immersive experiences in the decentralized Web3 environment. The creator economy reshapes production behaviors, impacting both creators and consumers. Essential interactions include: individuals choosing and molding virtual fields; fields influencing individual actions and behaviors reciprocally molding the field; and identity anchors self-expression and actions, with behaviors reinforcing identity's social position. Collectively, these elements define human existence in the Web3 metaverse, serving as our taxonomy.

3.3 Lessons Learned

Within this section, we inaugurate by mapping the evolution of the metaverse concept, transitioning from a technologically-fueled lens to one rooted in a multi-faceted human-centered purview. We argue that circumscribing the metaverse's essence solely to its abundant digital content or multidimensional immersive experience would be reductionist. Embracing the Web3 community, the mature metaverse heralds societal advancement by championing digital asset ownership, financial systems, and creator incentivesâĂŤsetting it apart from previous perceptions. Therefore, we delineate the Web3 metaverse as a decentralized and close-loop societal system, exalting user sovereignty concerning digital assets and experiences. Stemming from this cognition, we provide the framework of the Web3 metaverse and explain how this three-layer architecture establishes the value circulation by combining the Web3 community's distribution and exchange role with

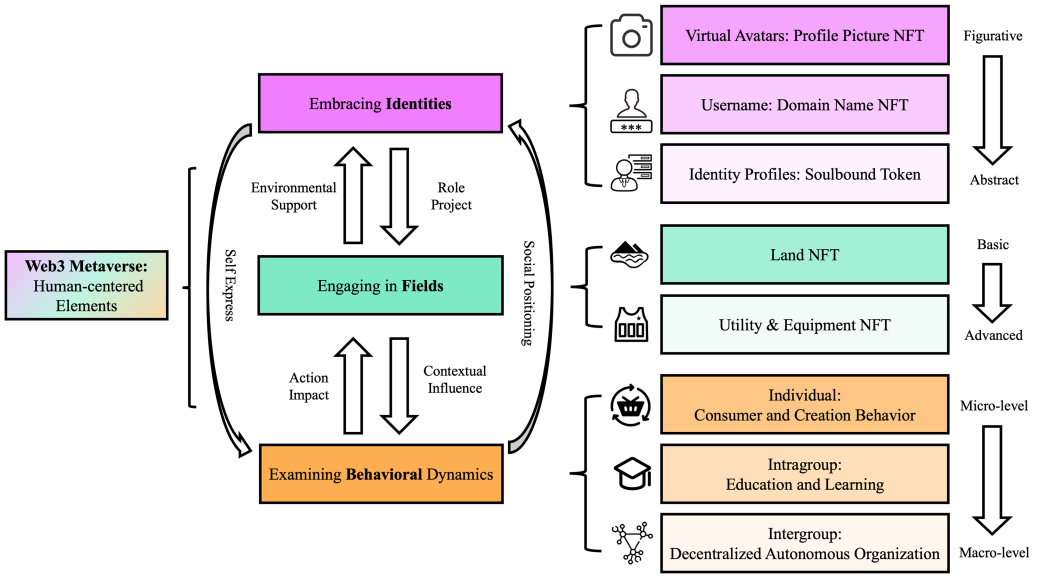


Fig. 11. The structure of our survey and the relations between each aspect.

the crowd intelligence community as creation and immersive convergence community as consumption. The confluences of these components sculpt our conceived Web3 metaverse. Describing the overlapping areas, we introduce notions of "social immersion", "creator economy", and "multimodal creation". Each reveals a distinct socio-technological facet of the Web3 metaverse and is intrinsically linked to identity, field, and behavior elements. Thus, this section sets the stage for ensuing exploration.

4 HUMAN-CENTERED SURVEY: STATE-OF-THE-ART IN THE WEB3 METAVERSE

This section assesses the current state of the Web3 metaverse from a human-centered perspective. By examining identity, field, and behavior, we aim to identify potential issues and areas for improvement. Figure 11 shows the structure of this section and our review logic in each element. Regarding identity, our exploration ranges from the figurative avatar to the more abstract identity profile. Regarding field, we survey from basic land to advanced utility and equipment. For behavior, we review from the micro-level individual to the macro-level intergroup ones.

4.1 Embracing Identities

The identity issue has captivated scholars long before the advent of the metaverse. People construct their identities by disclosing personal information [125]. In the digital world, identity disclosure can be accomplished by setting up avatar pictures and usernames, and constructing identity profiles that reflect relationships and statuses [215]. Security and privacy studies are mainstream in this area [201]. However, within the Web3 metaverse, exploring how individuals construct their identities becomes imperative. Therefore, this section explores the identity construction in the Web3 metaverse from users' avatars, usernames, and identity profile aspects, all based on NFTs.

4.1.1 Virtual Avatars: Profile Picture NFT. The development of NFTs can be traced back to the early concept of Colored Coins, introduced by Yoni Assia in 2012 [164]. The first known minted NFT is "Quantum" (Figure 12(a)), a digital image of a pixelated octagon by digital artist Kevin

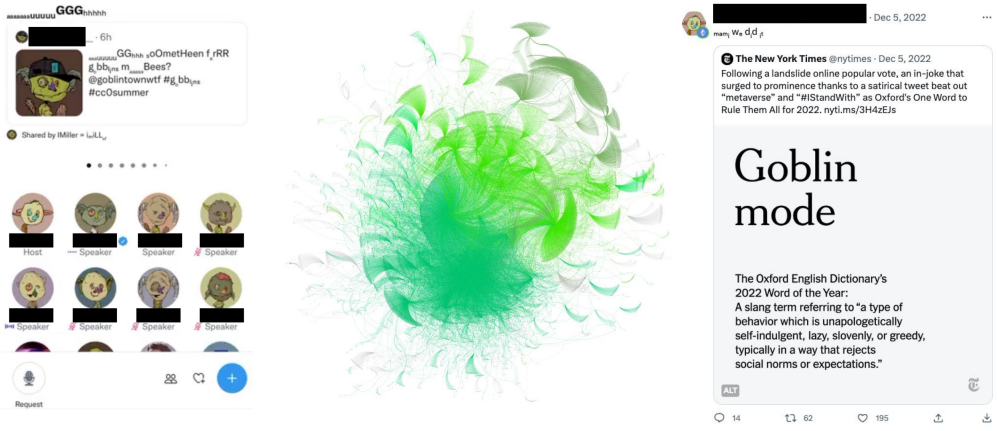
(a) (b) (c)

Fig. 12. (a) The earliest known NFT, Quantum. (b) Use mfers NFT as social media avatar. (c) Use Nouns NFT as social media avatar.

McCoy on 2014 [74]. Then, the Ethereum blockchain and its smart contracts enabled the creation and efficient tokenization of unique digital assets, which led to NFT's first large-scale application, PFP. In 2017, the first NFT collection that entered the public eye was the CryptoPunks[10] by Larva Labs, considered the first official NFT collection. CryptoPunks was launched using the Ethereum ERC-20 token standard, comprised of 10,000 unique, algorithmically generated pixel PFP images that gained significant value over time [168]. CryptoPunks led to the development of the ERC-721 token standard, like CryptoKitties,[11] a virtual pet collection. These pioneers played a crucial role in bringing NFTs to the forefront and paving the way for mass adoption, especially during the NFT boom in 2021 [170]. The current development of PFP NFT is more diverse and decentralized, such as mfers[12] (Figure 12(b)), an NFT collection with no official account and fully operated by the community, and Nouns[13] (Figure 12(c)), a collection that has only one auction per day, and whose community can decide the following PFP characteristics. The auction revenue is in the community treasury, and each Nouns NFT is both PFP and grants the owner voting rights on treasury usage.

The allure of PFP NFT largely lies in its power of identity expression. As scholars delve deeper into the applications of NFT in identity management and digital asset ownership, specific trends emerge. For example, the uniqueness of each Bored Apes NFT, set against a backdrop of thousands of avatars, not only satisfies the property of uniqueness [79] but also serves as a linchpin connecting individuals to communities and places. With the evolution of the Web3 metaverse, PFP NFTs wield an unmistakable influence on social network communities, bringing like-minded individuals under one digital roof. This is evident in how popular PFP NFTs like Bored Apes, Cool Cats, and Doodles act as community magnets. Their fervently active members post thousands of tweets daily, fostering a vibrant discussion around their beloved collections [32]. But what stands out is the Goblintown collection. Its users, despite engaging in seemingly nonsensical gibberish (Figure 13(a)), have amassed a numerous following on X, effectively sculpting a well-structured community (Figure 13(b)). Their exuberance amplified when the term "Goblin mode" was anointed the word of the year for 2022 [93]. To them, this was a nod to their representation of cultural zeitgeist, and they wore their NFT-based identity with unparalleled pride (Figure 13(c)). This phenomenon aligns with discussions around the ripple effect of PFP NFTs in online reputation signaling, where possessing a specific PFP NFT can be equivalent to flaunting wealth [135], affiliating with the notables [203], or signaling membership to a value-sharing community [6].

[10] https://www.larvalabs.com/cryptopunks
[11] https://www.cryptokitties.co/
[12] https://mfers.art/
[13] https://nouns.wtf/



(a) (b) (c)

Fig. 13. PFP NFTs can mirror cultural trends and have the capacity for strong identity inclusion in the post-pandemic era. (a) Twitter users collectively mimic the goblin growl. (b) Visualization of the Goblintown community on Twitter. (c) After the "Goblin" became the annual word of 2022, a slang expression from the NFT community, translating to "Close friends, we did it!" reflects their pride in their NFT-based identity.

The growing interest in NFTs in the art and branding industries contributes to the identity expression based on PFP NFTs [45]. For instance, Vasan et al. [191] quantified NFT-driven networks in the crypto art area, revealing reproducible patterns that allow characterizing the features and mechanisms of individual artists' identity states. NFTs' potential to empower creative industry entrepreneurs has also been explored, with proponents highlighting their revolutionary economic and cultural potential [35]. Investigating stakeholders in the NFT ecosystem reveals a nuanced account of creators, owners, and technologists, as well as the role of investment firms and auction houses as arbiters of knowledge and value [15]. Furthermore, Steiner considers PFP NFTs as a new and important artistic medium to reshape aesthetics, economics, conventions, and cultures [173]. However, the challenges of PFP NFT cannot be ignored. Numerous PFP NFT collections have faced criticism, being likened to Ponzi schemes due to their severe price volatility [114] and the dubious intrinsic value of their images. A prominent example of this is Azuki, one of the most recognized collections in the field. With its new collection, "Azuki Elementals," bearing a striking resemblance to the original and exhibiting a noticeable lack of refinement in quality, the floor price experienced a significant drop of more than 28.16% within 24 hours. Then the team transferred profits from the sale of the new collection into the exchange [186]. Moreover, some PFP NFTs' visual and identity designs fall into the controversy of racism [37]. Using PFP NFT in social networks also might leak the identity behind crypto addresses, making it possible to trace and analyze personal privacy [43]. Furthermore, people participating in PFP NFT communities can be vulnerable to information manipulation due to fanatical identity acknowledgment and suffer significant financial losses [42].

4.1.2 UserName: Domain Name NFT. **Online Social Networks (OSNs)** emerged in the late 1990s, eventually evolving into modern platforms like X and Facebook. Despite their popularity, these centralized platforms restrict communication within the same service, limiting interoperability and the uniformity of user identities [87]. Decentralized OSN, such as XMPP,[14] Matrix,[15]

[14]https://xmpp.org/
[15]https://matrix.org/

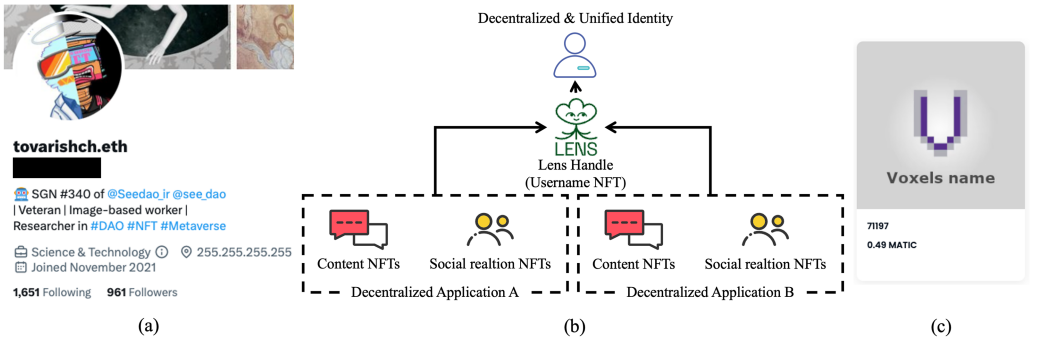


Fig. 14. (a) Using ENS in the social media. (b) Mechanism of Lens Protocol. (c) Username NFT of Voxels.

and Sonic,[16] have been proposed to address these limitations, but their identifiers are not human-readable and are challenging to remember [154]. Human-readable usernames, reflecting personal and cultural information, play a crucial role in virtual social interactions [21, 221]. Although blockchain-based usernames, such as Ethereum's "0x" addresses, provide identity uniformity and interoperability, they fail to overcome Zooko's triangle's tradeoffs between decentralized, security, and human readability [117]. Additionally, the **Domain Name System** (**DNS**), the name system for digital resources, translates human-readable domain names to digital IP addresses. But traditional DNS is vulnerable to attacks and lacks widely adopted security measures. Researchers have attempted to integrate blockchain technology with DNS for enhanced security, as seen in projects like Namecoin, Unstoppable Domains, and EmerDNS [153]. However, their resource-oriented nature constrains their large-scale adoption.

The development of the Web3 metaverse paves the way to form a more inclusive and resilient identity username ecosystem, solving the dilemmas above. One main project in this area is **Ethereum Name Service** (**ENS**).[17] ENS is a decentralized naming service built on Ethereum, offering a complementary solution to DNS by leveraging smart contracts for domain name registration and resolution. The common ENS format is similar to "Alex.eth", which is one kind of NFT, and allows people to map their blockchain wallet address to a human-readable phrase [206]. Based on ENS, people can integrate various types of digital assets (PFP NFT, cryptocurrency holdings, etc.) while expressing their identity orientation (Figure 14(a)). The convenience and identity unification of ENS attracts adoption by many users as their usernames in the Web3 metaverse. Another represented attempt to associate user interactions and digital content with their usernames is the Lens Protocol [104]. The Lens Protocol is a decentralized social graph built on the Polygon chain,[18] characterized by its modular architecture and decentralized approach to personalized social experiences. When users hold one "Lens Handle" (the username in Lens Protocol, which is one kind of NFT), they can integrate their social relations, publications, and conversations as NFTs into their Handle (Figure 14(b)). In this way, users truly own their data through their usernames. They can bring it to any Web3 metaverse application that supports the Lens Protocol and thus have a unified identity. Creators no longer need to worry about losing their previous content and audience due to platform adjustments. In addition, developers have a unified environment that facilitates more efficient development and deployment. Besides, many Web3 metaverse games, such as Voxels, also have their own username NFT (Figure 14(c)) playing similar functions.

[16] http://sonic-project.net/
[17] https://ens.domains/
[18] Polygon is a layer 2 solution of Ethereum, for speedy transactions and low gas fees. https://polygon.technology/

However, challenges remain with user identity management based on username NFT. Xia et al. [207] found that attackers abuse the ENS system, such as domain name robbery, fraudulent address embedment, and malicious website indexing. Jeremy [149] noted that blockchain insufficient performance and high gas fees limit the development of the Lens Protocol. In addition, more research is still lacking in this area.

4.1.3 Identity Profiles: Soulbound Token. User profile in Web3 metaverse aims to establish a decentralized and comprehensive identity system controlled by the owner, ensuring a closed-loop ecosystem and social immersion. Kaneriya et al. [111] surveyed some blockchain-based identity systems and found they have limitations for large-scale applications. In response, SBT, an NFT-based identity profile solution, is evolving rapidly in the industry. The inspiration for SBT is traced back to World of Warcraft, which has some permanent, non-transferable items to signify achievements and personal information [25]. SBT has the same function but is based on blockchain. SBTs can solve scams and theft in **decentralized finance** (**DeFi**) by allowing the Web3 metaverse to verify an individual's trustworthiness [73]. A framework for digital inheritance using SBT has been proposed in the Polkadot and Kusama blockchain networks [34]. Regarding privacy and security, SBT can encode individuals' affiliations, making them more trustworthy. For example, students' credentials regarding their academic achievements and credibility can be stored and verified using SBTs, which provide higher privacy and security compared to centralized systems [183]. Worldcoin[19] develops an SBT-based identity protocol called World ID, which is introduced as a method of "proof of personhood", to allow individuals to distinguish themselves from AI while maintaining anonymity through **zero-knowledge proofs** (**ZKPs**) [205]. Based on SBT, Weyl et al. [202] introduce the concept of "**Decentralized Society**" (**DeSoc**), emphasizing the potential of encoding social relationships of trust using SBTs representing commitments, credentials, and affiliations of "Souls." Notably, there is a tradeoff between identity effectiveness, decentralization, and privacy protection. To ensure the uniqueness and authenticity of the individual's identity profile represented by SBTs, more information needs to be aggregated, which brings privacy leakage risks. Meanwhile, approaches like World ID, which uses specialized hardware (namely, Orbs) to collect people's iris or other biometrics and link them to SBTs by a centralized company, inevitably reduce the robustness of the system's decentralization [26].

A case of large-scale deployment of SBT is SeeDAO.[20] SeeDAO is a decentralized autonomous organization that aims to link global digital nomads and build a network polis in the Web3 metaverse to explore new social and productive relations. SeeDAO members receive a PFP NFT as identification and complete their profiles by obtaining various SBTs. SeeDAO SBTs are released automatically through smart contracts and divided into four categories: role, event, education, and project. Role SBTs are identifiers of SeeDAO members holding public positions in the community or as contributors. They are linked to what tasks a member can undertake or what community proposals a member can initiate. Event SBTs are proof of attendance for events. They play the role of experience certificates. Education SBTs are distributed through SeeDAO's community academy, DeSchool.[21] DeSchool's curriculum is based on community needs and industry developments, and its teachers are experts in their respective fields, and are community members. Community members earn educational SBTs by completing courses, while teachers earn role and event SBTs. Project SBTs are used for task progress management. All SBTs can be displayed as personal on-chain CVs

[19] https://worldcoin.org/
[20] https://seedao.xyz/en
[21] https://deschool.app/en/

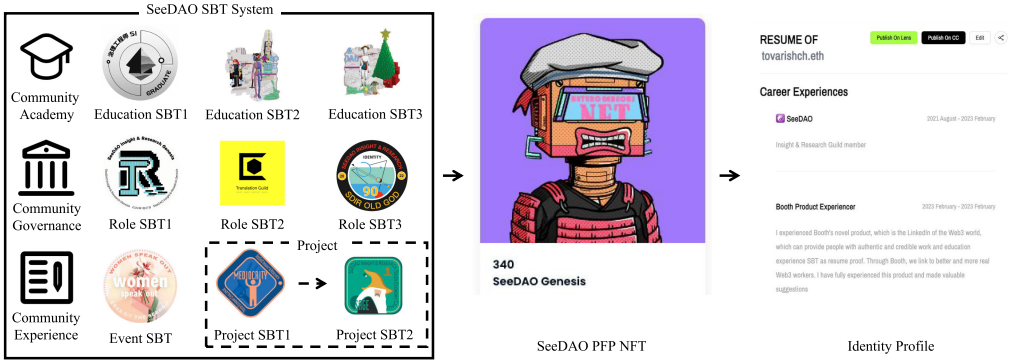


Fig. 15. The SBT-based identity profile system of SeeDAO.

Fig. 16. (a) Otherside. (b) The Sandbox. (c) Decentraland. (d) Worldwide Webb. (e) NFT Worlds.

on SeeDAO's resume page,[22] developed based on the Lens Protocol. SeeDAO has over 10,000 members, issued 15,113 SBTs, and built an SBT-based identity profile system (Figure 15).

4.2 Engaging in Fields

The *field* is the environment and context in the Web3 metaverse, which supports and influences user identity and behavior. Land NFTs are the basic form of the metaverse field, including land, buildings, and other infrastructures, while utility and equipment NFTs are the advanced form. However, existing studies mainly focus on early mature projects such as Decentraland or Voxels while ignoring the latest industrial developments. Meanwhile, they are interested in the economic value aspects (which we survey in the next section) while ignoring other vital aspects.

4.2.1 Land NFT. After the release of Decentraland in 2018 kicked off the Web3 metaverse, the industry has changed significantly over the past years. Based on data[23] of the Land NFT category, the current top 5 projects (Figure 16) are

— Otherside[24] is an MMORPG Web3 metaverse created by Yuga Labs. Yuga might be the most successful Web3 company which holds the IP of first-rate NFTs like CryptoPunks and BAYC,

[22] https://booth.ink/
[23] https://www.nftgo.io/
[24] https://otherside.xyz/

and cooperated with brands like Gucci and Adidas [173]. Otherside aims to establish a Web3 "Disneyland", where up to 10,000 players can simultaneously interact and voice chat.
— The Sandbox allows players to create and purchase digital assets. Land owners can create "worlds" where users can move freely using avatars. It also has various games designed by the team and the community. The platform has attracted celebrities and brands, including Snoop Dogg, Adidas, Paris Hilton, The Walking Dead, and Gucci [98].
— Decentraland is the first Web3 metaverse game to enable users to trade digital assets using blockchain [64]. The creator economy pioneered by Decentraland encourages UGC, such as scenes, artworks, challenges, and buildings, fostering a positive feedback loop within the Web3 metaverse and emulated by later projects.
— Worldwide Webb[25] is a browser-based Web3 metaverse game. It features pixel-style graphics and allows players to use their own NFTs as the avatar providing a unique metaverse experience for Web3 enthusiasts.
— NFT Worlds[26] is initially built on Minecraft. It leverages the world-building abilities of the best-selling video game and its Web3 ecosystem to enable new types of 3D voxel-based, decentralized gaming metaverses.

The diverse development has spawned the exploration of various applications for land NFTs, such as urban planning [101], audit consulting [192], metaverse pharmacy [11], and so on. However, these Web3 metaverse projects have raised many questions over the past year. Because of its centralized development approach and neglect of the community, analysts criticized Otherside as a traditional Internet company in the guise of Web3 [204]. Poor user experiences and lack of feature innovation led to significant user churn in Decentraland and other projects [185].

On the bright side, we still see many explorations of interoperability, which is the most attractive part of the Web3 metaverse. Interoperability [150] means that people in the Web3 metaverse can freely access different systems while ensuring the seamless migration of their identity and assets. To achieve this goal, the Metaverse Standards Forum[27] and the **Open Metaverse Alliances (OMA3)**[28] aim to promote opensource metaverse standards. Several studies have discussed the structure and architecture of the Web3 metaverse [193, 214]. Hong et al. [100], Ryskeldiev et al. [165], and Rodrigo et al. [162] try to tokenize digital assets based on NFT to implement consistency and integrity. On this basis, how people access and migrate the Web3 metaverse is also reassessed [220]. The traditional webpage-liked portal model in most metaverse projects does not meet the need for the metaverse field's multidimensional links. There are some attempts in this area: Openvoxels,[29] is based on Voxels to access metaverse lands on different systems through "doors" in virtual space. Metacat[30] aggregates information (events, traffic, etc.) from different Web3 metaverses into one dashboard. MetaCast attempts to automatically capture hot events [129]. Oncyber,[31] a land NFT building tool, supports multiple blockchains and metaverse projects. Matrix World is a Web3 metaverse that enables users to create digital assets, deploy **decentralized applications (DApp)**, and interact across multiple blockchains, based on its land NFTs [179].

4.2.2 Utility and Equipment NFT. As the advanced form of the Web3 metaverse field, examining utility and equipment NFTs can enhance our understanding of a genuine Web3 metaverse.

[25] https://webb.game/
[26] https://www.nftworlds.com/
[27] https://metaverse-standards.org/
[28] https://www.oma3.org/
[29] https://mirror.xyz/openvoxels.eth/
[30] https://www.metacat.world/
[31] https://oncyber.io/

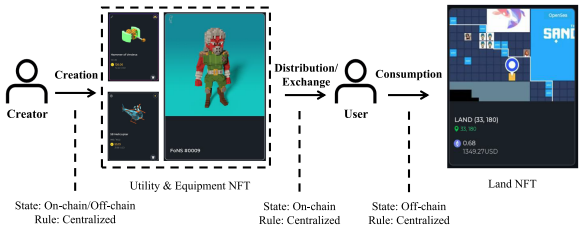


Fig. 17. The circulation in the sandbox.

Table 4. Comparison of Different Metaverses

		Traditional	Semi-Web3	Full-Web3
Creation	States	Off-chain	On-chain/Off-chain	On-Chain
	Rule	Centralized	Centralized	Decentralized
Distribution/ Exchange	States	Off-chain	On-Chian	On-Chain
	Rule	Centralized	Decentralized	Decentralized
Consumption	States	Off-chain	Off-chain	On-Chain
	Rule	Centralized	Centralized	Decentralized

These NFTs are directly related to the game industry, with successful Web3 games like CryptoKitties and Axie Infinity,[32] where players earn cryptocurrency by holding utility and equipment NFTs [62]. A large number of NFT-based games appear and have led to the emergence of **game finance** (**GameFi**) [108, 109]. Additionally, utility and equipment NFTs have broader applications [16, 46, 141]. They can be employed for issuing academic credentials, driver's licenses, passports, medical documents, tickets, and insurance records, streamlining the verification process. Creators of music, books, and patents can also benefit by enabling direct-to-consumer transactions and minimizing intermediaries. Supply chain management can be enhanced by attaching utility NFTs to unique production items, simplifying lengthy processes. DeFi projects have integrated NFTs as loan collateral, enriching the Web3 metaverse's economic system. Hence, utility and equipment NFTs provide a rich contextual field to bridge the identity and behavior of users in the Web3 metaverse.

Despite the rapid development, significant challenges persist in this area. Although NFTs are utilized as intermediaries within various systems, off-chain states record and centralized rule regulation remain in the creation, distribution/exchange, and consumption processes. For instance, The Sandbox (Figure 17) allows creators to develop 3D models using official tools and mint NFTs through interaction with marketplace smart contracts. However, the digital assets' states are not entirely recorded on-chain, and the team centrally controls relevant rules, such as asset categories, functions, and size.[33] Hence, creators may face rule modification risks akin to traditional metaverse lacking Web3 support. In the distribution and exchange phase, users interact with smart contracts to purchase NFTs, with states recorded on-chain and rules embedded in smart contracts. This aspect is often used by projects to emphasize their Web3 attributes. Nevertheless, when users employ their NFTs to access lands and consume game experiences, various user states remain off-chain, and the team controls and monitors in-game rules. Therefore, we call The Sandbox and similar projects semi-Web3 metaverse. As shown in Table 4, although the semi-Web3 metaverse is more decentralized than the traditional one, it does not achieve the on-chain states and rule decentralization in the whole circulation as the full-Web3 metaverse. A recent scandal within the semi-Web3 metaverse involved the Azuki. Confronted by community inquiries regarding the similarity of some images in its new collection, the project team modified the NFT image metadata existing on their centralized servers directly [186]. This action reflects the dark side of current Web3 and has incited broader questions about the decentralization principles of the entire industry.

The current path to the full-Web3 metaverse has two representatives, Dark Forest[34] and Loot.[35] Dark Forest is a decentralized, real-time strategy game fully built on blockchain, where players

[32] https://axieinfinity.com/
[33] https://sandboxgame.gitbook.io/
[34] https://zkga.me/
[35] https://www.lootproject.com/

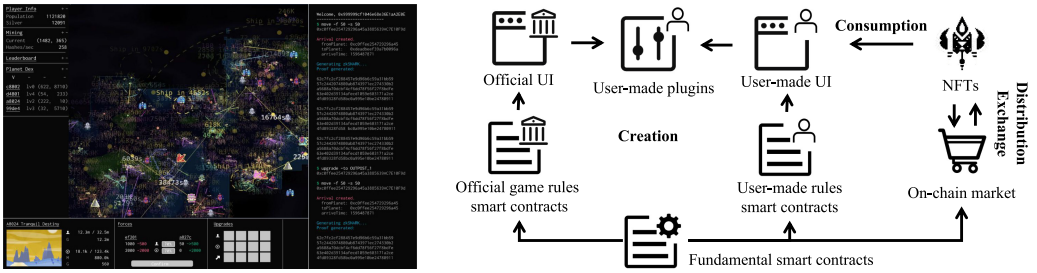


Fig. 18. The Dark Forest and its mechanisms, which provide a full on-chain and decentralized creation, distribution/exchange, and experience consumption phases.

use "spaceship" and "artifact" NFTs to explore and compete in the virtual universe. This game uses zk-SNARKs for ZKPs, allowing players to conceal their moves and adding a layer of strategic depth. Its smart contracts resemble the fundamental rules of the world (like the physical laws of the virtual world), and users can design plug-in or user-made contracts to achieve a fully customized gaming experience (Figure 18). Besides, Loot is a series of NFT collections providing a community-driven game development approach. By releasing text-based NFTs representing in-game figures, equipment, and spaces, Loot empowers people to create games, stories, and experiences using these NFTs as building blocks. Dark Forest [210] and Loot [199] exemplify the potential of fully decentralized, on-chain experiences of creation, distribution/exchange, and consumption, and pave the way for the full-Web3 metaverse.

4.3 Examining Behavioral Dynamics

The Web3 metaverse constructs a closed-loop social system in which people's behaviors reflect who they are and where they position, while these actions will also impact the identity and field. This section reviews the user behaviors in the Web3 metaverse from the micro to the macro level, covering individual, intragroup, and intergroup areas.

4.3.1 Individual: Consumer and Creation Behavior. For the individual level, we focus on people's behavior of consuming and creating various crypto assets, which is the most native feature of the Web3 metaverse and triggered numerous research. Regarding consumer behavior, scholars have analyzed people's motivations for purchasing and holdings of assets in the Web3 metaverse. Compared to traditional ones like stock and gold, these emerging assets are fraught with risk but are perceived to deliver higher returns and innovative distribution [5, 75, 89, 199]. In addition, rumors of possible coin offerings by projects such as BAYC and Azuki enticed people to buy the original assets. This speculative attribute leads to questioning the value of cryptocurrencies [39, 142] and NFTs [35]. In contrast, proponents point to the ability of crypto assets to hedge the risks from traditional financial systems and geopolitical events [198]. In particular, ideological and technical motivations such as building widespread trust based on the blockchain can lead people to hold crypto assets regardless of returns, a phenomenon that increases with the education and blockchain knowledge level of survey respondents [174]. More positive studies emerged with the wide deployment of smart contracts and NFTs that enable people to do creation based on crypto assets. These creations and applications are distributed in various aspects of society, such as art [83], finance [116], business [16], and industry [19], which ensures digital sovereignty, empowers creators, and fosters positive social interactions. We have comprehensively reviewed these in Sections 4.1 and 4.2.

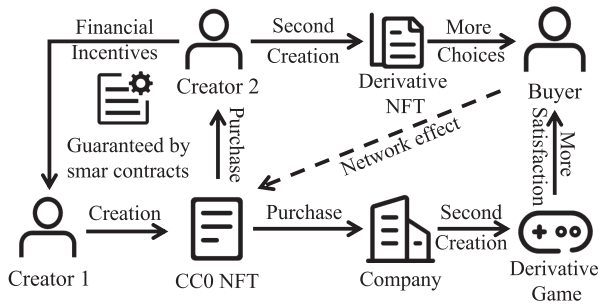


Fig. 19. The creation and business model of CC0 NFTs

Table 5. Top 10 CC0 NFT Collections

Collection	Publish Date	Owners	Derivatives
Blitmap	2021.05	658	107
CryptoDickButts	2021.07	1808	123
Nouns	2021.08	315	190
Loot	2021.08	2552	333
CrypToadz	2021.09	4080	183
Mfers	2021.11	5706	544
Chain Runners	2021.11	3341	123
Tiny Dinos	2022.04	3329	272
Goblintown	2022.05	4691	476
Rekt Guy	2022.05	3978	249

Notably, the judicious distribution of cryptocurrencies or NFTs facilitates sustainable growth for Web3 projects. The mechanism responsible for distributing and exchanging digital assets and value is known as token economics or tokenomics [196]. A well-design tokenomics requires not only deep knowledge but also considerable expertise in the field [84, 136]. Despite its emergence as a relatively new domain, some tools are available to aid in the tokenomics design and enable the evaluation of its performance before deployment. Among these, NetLogo [187] is known for its capacity to simulate complex networks with a multi-agent environment, making it suitable for analyzing the dynamics of token transfers. Nevertheless, the intricacies of its learning and design processes pose a significant challenge for tokenomics designers. SIMBA [20], an education and research simulator designed for business, can be employed for tokenomics design, although its functionalities are relatively limited. Machinations [134], a commercial game numerical design tool, offers certain optimizations for tokenomics design but falls short in supporting floating-point calculations. In contrast, Plutus,[36] a numerical design tool tailored for multi-entity systems, presents a promising solution for tokenomics design and evaluation. As an open-source project, Plutus guarantees the privacy of user data by running locally, while ensuring the accuracy of operation. Furthermore, it offers a rich array of user-defined access points and abstraction modules, thus satisfying the design requirements of tokenomics and benefiting the creation incentive in the Web3 metaverse.

However, behind the rosy vision of the Web3 metaverse's incentive for creation, a non-negligible problem is that while blockchain technologies identify ownership of digital assets, neither authorship nor copyrights are guaranteed. Specifically, due to the accessibility of crypto assets, any other users not owning a certain NFT can download the digital asset (e.g., an artwork) and mint it as a visually identical fake NFT [135]. Additionally, no appropriate law clarifies the copyright issues after purchasing crypto assets. Although some authors have completely opened up the ownership for NFT purchasers as a solution,[37] none of the mature technical or legal means can guarantee the proper transfer of copyright in the resale and production of derivatives [92]. To solve these dilemmas, scholars attempt to introduce AI technologies. For instance, Duan et al. [65, 66] propose a Crypto-dropout that can utilize user on-chain information to control the creation process and ensure the uniqueness of UGC contents. From the legal side, the front-line attempt is introducing the CC0 license. The CC0 license (a.k.a. Creative Commons Zero license) is a public domain dedication that allows creators to relinquish all rights to their work.[38] By doing so, the CC0 license fosters an environment of openness and collaboration, similar to the principles underlying the open-source

[36] https://plutus.games/
[37] https://boredapeyachtclub.com/#/terms
[38] https://creativecommons.org/

movement. Compared with previous open-source licenses, primarily for software, the CC0 applies to various forms and is suitable for the rapidly developing digital era [123].

When combining the CC0 license with Web3 metaverse assets as CC0 NFTs, creators allow unrestricted use, modification, and distribution of their work, encouraging collaboration and innovation in the community. Meanwhile, with the incentives to initial creators ensured by the smart contract and provable ownership and provenance, CC0 NFTs can potentially overcome shortages [48] in the open-source movement. As Figure 19 shows, this approach could lead to the emergence of new business models, creative expressions, and more satisfaction. We counted the top 10 CC0 collections by market value, as shown in Table 5. Taking Mfers for instance, the over 500 derivatives show the immense creation enthusiasm of its decentralized community. CC0 NFT is still in a very early stage, but we believe in its capacity to tackle the issue of copyrights and creation in the Web3 metaverse.

4.3.2 Intragroup: Education and Science. Education and learning behaviors are knowledge transfer based on intragroup collaboration [131]. The advent of the Internet enables knowledge to reach wider audiences through education platforms like Coursera, Open University, and online courses offered by traditional universities. However, the centralized pattern of education presents inequality, high costs, and certification issues [30]. Tokenomics and decentralized identity in the Web3 metaverse offer new avenues to conquer these problems. For educational organizations, tokenomics avoids the drawbacks of bureaucratic distribution models, ensuring token holders maintain control over their organization and distribute assets to real needed issues. The token of a well-performed decentralized educational organization will attract more attention in secondary markets, driving up token prices and incentivizing all token holders. For students, various DeFi tools afford funding at lower costs and are more accessible [46]. In addition, NFT-based skill assessments (e.g., certification SBT), offer a more accurate and private alternative to traditional article and digital certificates. Learners continuously update their knowledge and skill sets and earn micro-certificates SBT for completing tasks or courses, building a comprehensive and detailed skill assessment system [80]. Related industry practices besides the SeeDAO Deschool mentioned in Section 4.1.3 are Open Campus,[39] Bankless Academy,[40] and LearnWeb3.[41]

Similarly to education, scientific research extends the boundaries of knowledge. In the Web3 metaverse, blockchain restructures the foundation and norms of current scientific systems by reshaping collaboration, value systems, and incentive mechanisms. Etzrodt [72] first introduced the concept of **decentralized science** (**DeSci**) by opposing the monopoly of knowledge and the inhibition of innovation by centralized academic publishers and peer review systems. Ding et al. [60] compared DeSci with traditional scientific research from knowledge discovery, management, and automation. They concluded that DeSci is a decentralized paradigm of knowledge exploration built on Web3 technologies. DeSci returns the value and ownership of scientific research to knowledge producers through tokenomics and DAOs. DeSci is in the very early stages, and the only detailed research is an interview-style article with relevant stakeholders of VitaDAO [55].

To have an in-depth understanding of scientific research in the Web3 metaverse, we also use VitaDAO as an example to demonstrate the mechanism of DeSci. VitaDAO[42] is a decentralized autonomous organization challenging the status quo in the longevity industry through tokenomics. Its community comprises VitaDAO token holders, including life scientists, entrepreneurs, individual investors, and venture capitals. Traditional pharmaceutical companies, such as Pfizer, also

[39] https://www.opencampus.xyz/
[40] https://app.banklessacademy.com/
[41] https://learnweb3.io/
[42] https://dao.vitadao.com/

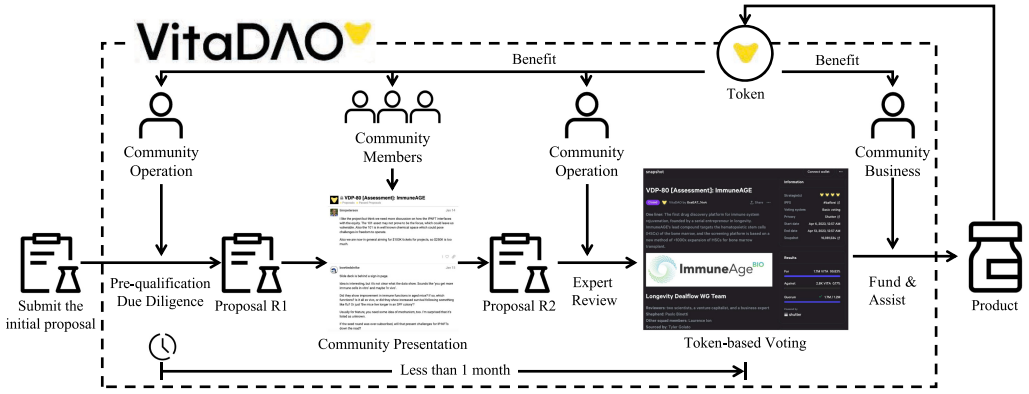


Fig. 20. The decentralized scientific research model of VitaDAO.

invest in VitaDAO. Its community has passed 17 research proposals with over $4 million in grants. Researchers do not need a university or institutional endorsement to submit an initial proposal to VitaDAO. The community operation members will pre-qualify the proposal and help the research to revise. Then the revised proposal will be presented to the community for discussion and reviewed by relevant expert members. After the second round of revision, the proposal will be voted on by community members based on the number of tokens they hold. For approved proposals, VitaDAO business experts will fund and assist researchers in finishing the research and commercializing the product. The revenue from the product will be divided proportionally between the researcher and the VitaDAO treasury. Community members receive tokens to realize profits based on their contributions. Compared to the lengthy approval process of traditional academic funding, VitaDAO's process is within one month. Figure 20 shows the model of VitaDAO. While DeSci is attractive, scholars still have worries, mainly focusing on its emerging organizational form, DAO [55].

4.3.3 Intergroup: Decentralized Autonomous Organization. The concept of DAO was initially proposed in the context of cybernetics to describe intelligent home systems [58]. Buterin [27] later adapted the term to define an organization governed by smart contracts, adhering to the principle of "code is law". Subsequent research has continued to expand and refine the definition of DAOs. Diedrich [57] posits that open-source blockchain platforms, such as Ethereum, enable individuals and organizations to encode operational rules in smart contracts on the blockchain, achieving distributed, automated, and autonomous governance in accordance with predefined rules and without third-party intervention. Jentzsch highlights the significance of tokens and on-chain voting in DAOs [107]. Individuals become stakeholders by holding DAO tokens and exercise their rights through on-chain voting based on their token holdings [77]. DAO members stand to benefit from rising token prices when the DAO interacts with the market or secures funding.

Decentralization appeal spurred the rise of DAO. For instance, The DAO, a pioneering Ethereum-based asset management platform launched in 2016, swiftly raised $150 million [57]. The same year saw the inception of Aragon,[43] providing DAO-building templates using smart contracts. In 2017, Maker DAO[44] introduced DAI, a collateral-based stablecoin, combining the low volatility of fiat with the decentralization of cryptocurrencies, fostering the development of the Web3 metaverse.

[43] https://aragon.org/
[44] https://makerdao.com/

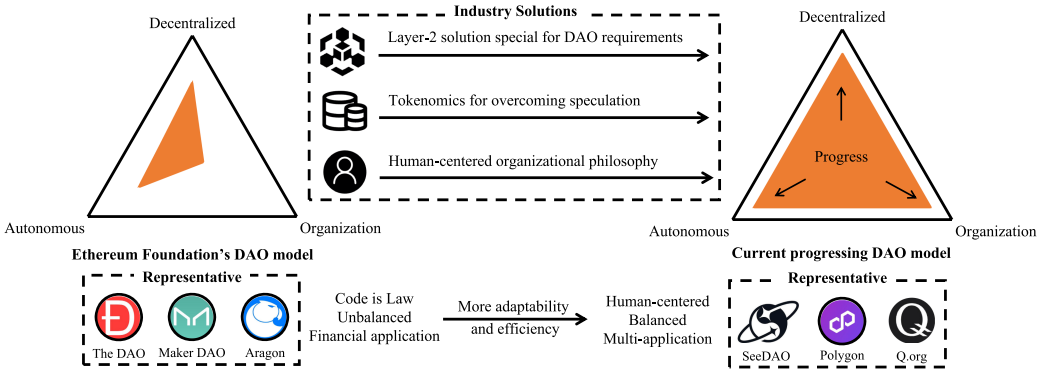


Fig. 21. DAO's dilemmas and current industry solutions.

With the growth of NFT applications, numerous NFT DAOs (particularly PFP NFTs, like Nouns) have emerged. Many research see promise in DAOs. Scholars find that DAO can promote artwork and music creation [102, 156]. In commercial practice, DAO can facilitate project execution and increase revenues [44], since the token-based governance can unify goals between different groups in organizations [133, 145]. DAO was better at relieving intergroup conflicts triggered by wars than centralized autonomous organizations [41]. However, DAO is equally fraught with doubt. The DAO was hacked in the same year of its founding, leading to a hard fork of Ethereum and causing doubt on the centralization of Ethereum Foundation [57]. An empirical analysis of more than 300 Argon-based DAOs found less than 100 monthly active users in these organizations [68]. In addition, the surge in token prices has discouraged participation in governance due to excessive interaction fees [78] and led to DAOs being flooded with speculators. Especially after the Web3 industry entered a winter period, critics are wary of the untested sustainability of DAO [82].

We contend that the challenges DAO practices face stem from unquestioning adherence to the model outlined by the Ethereum Foundation, which inadvertently leads to a kind of centralization. While smart contracts promote decentralization, the current Web3 infrastructure cannot automate numerous high-frequency organizational behaviors. Furthermore, the focus on smart contracts overlooks the essential principle that the metaverse should be human-centered, potentially hindering its adaptability and efficiency[45] [13]. The current changes in the industry support our view (Figure 21). For the insufficient performance of DAO's on-chain operation, projects such as Q.org[46] and Metis[47] develop Layer-2 solutions specifically for the needs of DAOs. For the token price volatility triggering speculation and interfering with autonomy, Giveth,[48] SeeDAO, HashKey,[49] and so on, try to design new kinds of tokenomics, combining token, SBT, and common NFT to split ownership, reputation, and value of a Web3 organization, and inhibit the speculation. In addition, the Polygon Foundation [182] believes that DAO essentially is the organization established by humans, but many DAOs have neglected the community. It proposes that DAO should borrow the idea of game design, taking advantage of the decentralized and automated nature of Web3 technologies

[45] According to Chester Barnard, two criteria are necessary for an organization's survival: effectiveness and efficiency. Effectiveness means accomplishing stated goals. The efficiency of an organization means the ability to satisfy the motives of the members, which is a human-centered metric.
[46] https://q.org/
[47] https://metis.io/
[48] https://giveth.io/
[49] https://www.hashkey.com/

to achieve gamification of traditional companies, i.e., fairer and more reasonable incentives and sustainable individual growth paths, and so on.

4.4 Lessons Learned

This section provides a human-centered survey of the current state of the Web3 metaverse by examining identity, field, and behavior elements. Regarding identity, we explore avatars, usernames, and identity profiles based on NFTs, which is an approach from the figurative to a more abstract aspect related to human identity in the Web3 metaverse. For the field, we review land NFTs as the basic form and utility and equipment NFTs as the advanced. At the behavior level, we analyze individual consumption and creation behaviors, intragroup education and scientific research, and intergroup DAOs.

We found that NFT-based identities enable greater self-expression but face challenges like speculation, privacy leaks, and centralized controls from identity issuers, requiring further innovation. Similarly, the Web3 metaverse is moving toward interoperability and complete decentralization, yet most projects remain semi-decentralized due to the off-chain centralized control of asset creation and consumption. Individual behaviors exhibit the promise of creation incentives, but the copyright dilemma persists, necessitating new technical (e.g., CC0) and legal solutions. Regarding intragroup activities, token-based funding and skill tracking can transform education and scientific research (abbreviated as DeEdu and DeSci) despite concerns around their DAO's form. Finally, DAOs promote decentralization ideas but need greater human-centricity and balance between their different dimensions. The section provides a comprehensive survey of the state-of-art, challenges, and future potential of the Web3 metaverse from multiple lenses. These can be the first bricks for researchers and readers to understand the Web3 metaverse.

5 BEHIND THE SCENES: A TECHNICAL SUPPLEMENT

As a supplement, we provide the technological landscape of the Web3 metaverse. Figure 22 illustrates a brief structure of crucial Web3 technologies, including distributed ledger and consensus mechanism, blockchain virtual machine and smart contract, and tokenization, from bottom to top. Moreover, tokenomics and Web3 identifier are also discussed as the derivative technologies integrated with the crowd intelligence community and immersive convergence community, respectively. Note that this section will only mention some key works to support the Web3 metaverse survey above rather than to conduct a comprehensive introduction of Web3 technologies.

5.1 The Structure of Web3 Technologies

5.1.1 Distributed Ledger and Consensus Mechanism. As illustrated in Figure 22, distributed ledger technology and consensus mechanisms are the fundamentals of the Web3 community. A distributed ledger is the replicated, shared, and synchronized digital data geographically distributed across many sites, countries, or institutions [195]. The term "ledger" denotes data blocks or databases that record time-stamped data and are connected to one another using cryptographic encoding (usually hash encoding [151]), replacing traditional ledgers used to record information [218]. The data structure of a distributed ledger mainly contains linked lists, **directed acyclic graphs** (**DAGs**), or hybrid data structures, and most common blockchains consist of linked lists. More importantly, distributed ledgers need to achieve a global consensus among all distributed nodes, which relies on a **peer-to-peer** (**P2P**) network and a consensus mechanism (a.k.a. consensus algorithm). Since data transmission may be influenced by many network factors (latency, packet loss, malicious attack, etc.), the distributed nodes require a mechanism to verify and synchronize the ledger data. Thus, a consensus mechanism ensures that each distributed node in the P2P network can maintain a consistent copy of the distributed ledger [38, 218]. The most common

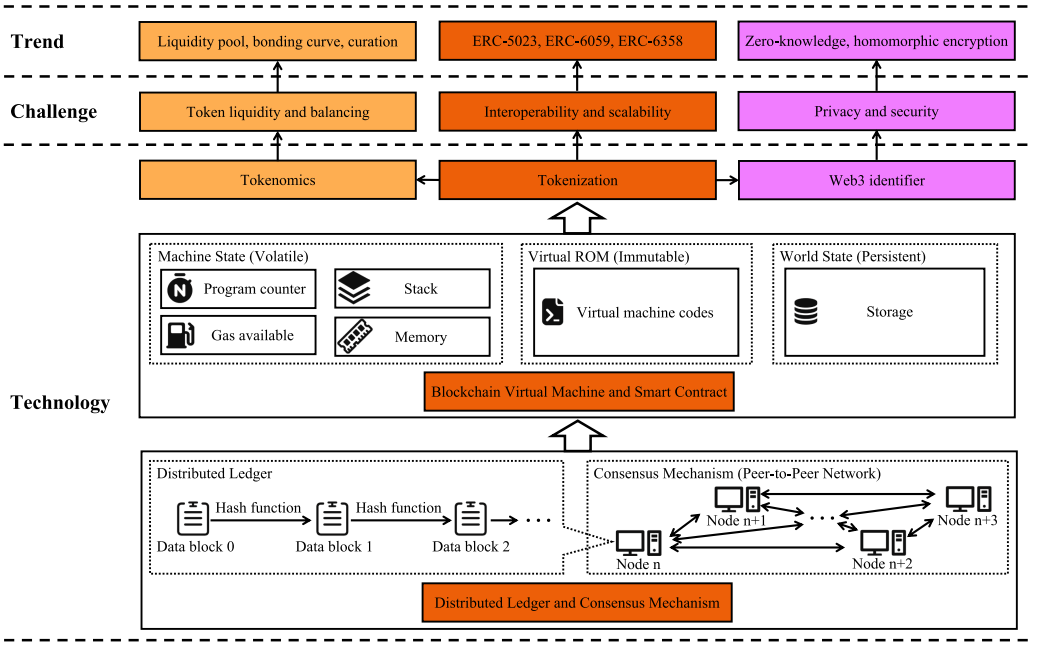


Fig. 22. Technological landscape related to Web3 metaverse.

consensus mechanisms utilized in public blockchains include **proof-of-work** (**PoW**) [105], **proof-of-stake** (**PoS**) [216], **practical Byzantine Fault Tolerance** (**pBFT**) [33], and so on.

5.1.2 Blockchain Virtual Machine and Smart Contract. Based on the distributed ledger and consensus mechanism, the essential functions of a decentralized P2P cryptocurrency system can be realized, named "blockchain 1.0", but the basic form of blockchain cannot satisfy more complex applications. To this end, Ethereum first introduced **Ethereum Virtual Machine** (**EVM**), building on the fundamental distributed ledger and consensus mechanism [27], which is the first prototype of a blockchain virtual machine (called "blockchain 2.0"). Figure 22 shows the brief architecture of a blockchain virtual machine [71], containing machine state, virtual ROM, and world state. As a virtual machine, the volatile machine state includes a program counter, stack, memory, and a special component to record available gas. Another part is immutable virtual ROM (the distributed ledger), which stores blockchain virtual machine code, named smart contract. Implementing a smart contract is usually based on Solidity, an object-oriented programming language with Turing-completeness [110]. Specifically, a smart contract is transparent and open-sourced on the blockchain, which can be automatically executed by all blockchain nodes [64]. Using smart contract technology, thousands of novel DApps are developed on blockchain virtual machines in various areas [28], such as DeFi [116], blockchain games [143], digital art [138], and so on. Running a smart contract needs to cost a certain amount of gas which will be checked by the machine state. Last, the world state will persist like the virtual machine's storage, storing the data of variables defined in smart contracts. All components of the blockchain virtual machine will be supported and validated by all nodes in the blockchain network, achieving a higher abstract layer upon the basic distributed ledger and consensus mechanism.

5.1.3 Tokenization. Generally, a token represents an asset, so tokenization is the process of converting an asset into a token. The concept of tokenization has an extremely long history since

Table 6. Common Non-Fungible Token Protocols Regarding Tokenization

Number	Title	Description
ERC-721 [70]	Non-Fungible Token Standard	A most commonly used standard interface for NFTs, which provides basic functionality to track and transfer NFTs.
ERC-1155 [158]	Multi Token Standard	A standard interface for contracts that manage multiple token types, which allows for each token ID to represent a new configurable token type with its own metadata, supply and other attributes.
ERC-998 [132]	Composable Non-Fungible Token	An extension of the ERC-721 standard to enable ERC-721 tokens to own other ERC-721 tokens and ERC-20 tokens, which is possible to compose lists or trees of ERC-721 and ERC-20 tokens connected by ownership.
ERC-3525 [200]	Semi-Fungible Token	A standard for semi-fungible tokens, which introduces new token transfer models for semi-fungibility, including value transfer between two tokens of the same slot and value transfer from a token to an address.
ERC-5058 [190]	Lockable Non-Fungible Tokens	A standard to extend the ERC-721 standard with a secure locking mechanism, where the NFT owners approve the operator to lock the NFT, and then it cannot be transferred until the end of the locking period.

the emergence of the first currency centuries ago to reduce risk in handling high-value financial instruments by replacing them with surrogate equivalents [163]. In recent years, the blooming of blockchain technologies has raised the tokenization of digital assets [127]. On the one hand, cryptocurrency is a fungible token that plays the role of universal equivalent in value exchange. On the other hand, enabled by smart contracts, other forms of digital assets can be certified as unique and not interchangeable NFTs, which can confirm the ownership of digital assets and support the transferring, trading, and collecting utilities [63]. From a technical perspective, blockchain-based tokenization is achieved on some pre-defined protocols implemented by smart contracts [199]. Using ERC-721 Standard [70] as an example, the tokenization process is to implement a standard **application programming interface** (**API**) of smart contracts using Solidity, including metadata about digital assets and functions like the operation and interaction with a cryptocurrency wallet. The template of the ERC-721 Standard provides basic functionality to track and transfer NFTs, so the users only need to complete the necessary components and deploy the smart contracts on the corresponding blockchain so that the ownership of digital assets can be confirmed and verified by the public. Common NFT protocols can refer to Table 6.

5.2 The Derivative Web3 Technologies Integrated with Other Communities

5.2.1 Tokenomics. Tokenomics (a.k.a token economics) denotes the economic properties based on cryptographic tokens [196]. As discussed in Section 5.1.3, the tokenization process can transform digital assets into tradable tokens. Thus, a series of economic activities are introduced based on the values and flexible features of tokens on the blockchain, such as staking [91], liquidity mining [77], airdrop [76], rental [115], and so on. Due to the limited scope, this subsection mainly discusses the creator economy behavior integrated with the crowd intelligence community. Thanks to tokenization technology, all general creators in the Web3 metaverse can truly obtain ownership of their created digital assets (a.k.a. UGC), like artworks, buildings, documents, videos, and so on. Therefore, the creators' profit from creation activities will not yet depend on the sharing from centralized platforms or firms (attention economy [51]). Instead, they are allowed to apply novel technologies or strategies to optimize their tokenomics [12], thus, guaranteeing tokens' liquidity and boosting community. The liquidity of creators' UGC can directly bloom the creator economy since the fast exchange of tokens can raise considerable creator earnings (similar to royalty fees) for creators, which is automatically shared by pre-defined smart contracts. Similarly, many economic technologies have contributed to the creator economy in token selling, trading, lending, and so on. More detailed information and discussion about tokenomics can be found in [194]. In this article, we also list some representative industrial standards related to tokenomics in Table 7.

Table 7. Representative Industrial Standards Related to Tokenomics

Number	Title	Description
ERC-2981 [23]	NFT Royalty Standard	A standardized way to retrieve royalty payment information for NFTs to enable universal support for royalty payments across all NFT marketplaces and ecosystem participants.
ERC-4907 [4]	Rental NFT	An extension of ERC-721 standard, which proposes an additional role granted to some addresses, who can use the NFT but cannot transfer it or set users, with a time where the role is automatically revoked.
ERC-5507 [69]	Refundable Tokens	A standard adds refund functionality for initial token offerings to ERC-20, ERC-721, and ERC-1155. Funds are held in escrow until a predetermined time before they are claimable. Until that predetermined time passes, users can receive a refund for tokens they have purchased.
ERC-5570 [49]	Digital Receipt NFT	A standard for digital receipts of transactions. Digital Receipt NFTs are issued by a vendor when a customer makes a purchase from their store and contains transaction details necessary for record keeping.
ERC-6997 [81]	ERC-721 with Transaction Validation Step	An extension of ERC-721 standard, which defines new validation functionality to avoid wallet draining: every transfer or approve will be locked waiting for transaction validation.

Table 8. Typical Industrial Standards Related to Web3 Identifier

Number	Title	Description
DIDs v1.0 [160]	Decentralized Identifiers (DIDs) Standard	A technical specification that defines a new type of decentralized digital identifier which provides a foundation for building DID systems and enables interoperability between different systems and implementations, empowering individuals with ownership and control over their DIDs in a secure and privacy-preserving manner.
ERC-4824 [181]	Common Interfaces for DAOs	An API standard for decentralized autonomous organizations (DAOs), focused on relating on-chain and off-chain representations of membership and proposals, which can be regarded as identifiers of DAOs.
ERC-5192 [50]	Minimal Soulbound NFTs	An extension standard of EIP-721, which proposes a minimal interface to make tokens soulbound, where a soulbound token is a non-fungible token bound to a single account.
ERC-5516 [50]	Soulbound Multi-owner Tokens	This standard proposes an interface for non-fungible double signature Soulbound multi-tokens. Previous account-bound token standards face the issue of users losing their account keys or having them rotated, losing their tokens in the process, so this standard provides a solution that allows for the recycling of SBTs.
ERC-6239 [36]	Semantic Soulbound Tokens	A standard extends ERC-721 and ERC-5192 by introducing Resource Description Framework (RDF) triples to SBTs metadata, where RDF is a standard data model of Decentralized Identifiers (DIDs) Standard.

5.2.2 Web3 Identifier. A social identifier is a description or representation of an individual's identity, agency, and information [94]. In the Web3 metaverse, the Web3 identifier is the fundamental element of social immersion integrated with the immersive convergence community. Currently, there exist different methods and protocols of the Web3 identifier, such as the **decentralized identifier** (**DID**), SBT, and ERC-4824 Standard. Firstly, DID is a decentralized, unique, persistent, and verifiable digital identity. The publicly recognized DID standard is DIDs v1.0 Standard [160], published by The **World Wide Web Consortium** (**W3C**).[50] DIDs v1.0 Standard defines the DID as URIs that associate a DID subject with a DID document, allowing trustable interactions. In detail, the standard introduces the architecture, data model, properties, representations, methods, and operations of resolving DIDs to their corresponding resources. Secondly, SBT was proposed by Weyl et al. in 2022 [202], which means non-transferable NFT (known as soul) bounding with a private crypto wallet. Therefore, after obtaining an SBT, it cannot be traded or transferred to an-

[50] https://www.w3.org/

other account, similar to the achievement system in video games for certificates of competence, reputation, education, and so on. The intuition behind SBT is to build a "decentralized society" that supports community wallet recovery, sybil-resistant governance, mechanisms for decentralization, decomposable markets, and shared rights [202]. Thirdly, ERC-4824 Standard [181] provides an API standard for on-chain and off-chain representations of DAO membership and proposals for DAO identifier governance. ERC-4824 Standard considers that all DAOs have at least two primitives: membership and behavior, where membership is a set of addresses and behavior is a set of contract actions. The DAO proposals can be interacted with by members, and the execution of proposals then becomes the behaviors of a DAO. The development of the Web3 identifier is still in an early stage, and different implementations of the Web3 identifier show various features and fit different applications. Specifically, the details of industrial standards related to Web3 identifier can be found in Table 8.

5.3 Challenge and Trend

5.3.1 Tokenization. Tokenization technology effectively introduces novel economic operations and enlarges the application scope of blockchain. The early development of tokenization technologies (ERC-721 [70] and ERC-1155 [158]) in public blockchain introduced the novel concept in 2018. After the real awakening of the NFT market in 2021, the community realized the limitations of existing NFT standards, lacking interoperability and scalability. Therefore, the following technologies or standards are invented to extend the interoperability and scalability of the tokenization process:

- ERC-5023: ERC-5023 Shareable Non-Fungible Token [137] is an interface for creating value-holding tokens shareable by multiple owners. The NFT Sharing is accomplished by minting copies of existing tokens for new recipients, allowing the token owners to build a social relationship with other users.
- ERC-6059: ERC-6059 Parent-Governed Nestable Non-Fungible Tokens [172] is an interface for Nestable Non-Fungible Tokens with an emphasis on the parent token's control over the relationship. This protocol allows an NFT to own another NFT so that the tokens can be composed as a family tree structure with the parent-child relationships.
- ERC-6358: ERC-6358 Cross-Chain Token States Synchronization [217] is a paradigm to synchronize token states over multiple existing public chains. This standard builds an interface for contract-layer consensus-agnostic verifiable cross-chain bridging, which allows the tokenization of multi-chain NFTs.

5.3.2 Tokenomics. Although the tokenomics market has shown a significant increase since 2018 [12], the shortcomings of the current tokenomics system have influenced its development, in which the most intuitive demand is better token liquidity and balancing. Three common applied methods to improve token liquidity and balancing are listed as follows:

- Liquidity pool: The basic component of a liquidity pool is **automated market makers** (**AMMs**), a protocol that allows digital assets to be traded in an automated way, and some traders (called liquidity providers) can contribute digital assets to liquidity pools to obtain profit based on the asset change of supply and demand [209].
- Bonding curve: The bonding curve defines a relationship between price and token supply (usually, a higher amount of tokens in circulation corresponds to a higher price), which can boost the liquidity of tokens and balance the token value and price [2].
- Curation: Curation is to select and filter topics or items (e.g., UGC in creator economy), gather information on the specific topics or items, and then introduce and illustrate them to

the public for greater attention or relationship, thus boosting the liquidity of creator economy [161]. Currently, the Web3 community, especially the digital art-related community, has shown emerging needs and interests in NFT curation [113].

5.3.3 Web3 Identifier. Existing DID solution faces privacy and security problem. For example, Halpin [96] has criticized W3C DIDs Standard [160], saying that storing key material does not compromise user privacy and that storing identifiers may publicly leak valuable data. Sun et al. [178] also claim that the publicly exposed issue of SBT may threaten personal privacy. To improve privacy and security, researchers and engineers are studying two main potential technologies:

— Zero-knowledge: Zero-knowledge mainly refers to ZKP in cryptography, which means a method for one party to prove a statement to another party without conveying any additional information apart from the fact that the statement is true [18]. ZKP can provide a feasible and secure way to verify important properties without leakage of private information.
— Homomorphic encryption: Homomorphic encryption is a form of encryption that allows users to perform specific forms of algebraic operations on encrypted data, and the result will be identical to that performed on unencrypted data [86]. This technology can perform operations on encrypted data rather than requiring decrypting the data first, which reduces the procedure and possibility of exposing secrets.

5.4 Lessons Learned

In this section, we have discussed the cornerstone technologies underpinning the Web3 metaverse to deepen comprehension of its socio-technical architecture. Foundational to this system is the distributed ledger technology, supported by P2P matrices and consensus algorithms, which provides decentralized, shared records of transactions and data. Ascending from this foundation, blockchain virtual machines paired with smart contracts enable the operationalization of intricate protocols and DApp, with the latter executing autonomously within the network and realizing the tokenization process. Tokenization means transmuting digital assets into fungible tokens (commonly dubbed as cryptocurrencies) or their NFT within the blockchain. This tokenization process subsequently paved the way for the burgeoning field of tokenomics, spawning novel economic paradigms encompassing valuation, commerces, and incentive mechanisms. Concurrently, decentralized identification mechanisms are incorporated to guarantee the regular operation of tokenomics. Despite the swift technical advancements characterizing this domain, challenges of interoperability, scalability, privacy, and security. As a response, new standards, cryptographic techniques like ZKPs, and architectures for cross-chain coordination are developing as the solution. Overall, the synergistic combination of these Web3 technologies holds immense potential to galvanize the expansion and enrichment of the Web3 metaverse.

6 LOOKING FORWARD: CHALLENGES AND PROMISING DIRECTIONS

Based on the work above, this section presents our insights into three full of challenges but promising research directions in developing the Web3 metaverse, namely, integrating social and technical disciplines, leveraging and going beyond "code is law", and countering the monopoly of technology companies and capital:

6.1 Integrating Social and Technical Disciplines

There is no doubt that the Web3 metaverse is a significantly complex socio-technical system, which is reflected in the proposed Web3 metaverse framework (Figure 8), so the issues arising in the Web3 metaverse require interdisciplinary solutions [64]. This article provides a survey of the state-of-the-

art interdisciplinary collaborations and paradigms, but the integration of socio-technical studies is still not enough to support the construction of a virtual society. To this end, many research topics need to be explored from a socio-technical perspective, such as better platforms of interdisciplinary collaboration, efficient interdisciplinary discussion and communication, and sufficient funds for interdisciplinary research and development.

6.2 Beyond "Code is Law"

Code has progressively established itself as the predominant way to regulate the behavior of Internet users. Specifically, with the advent of blockchain technology and associated smart contracts, code assumes an even stronger role in regulating people's behavior, representing the phenomenon of "Code is law" [53]. However, "Code is law" is insufficient to support a complex society of the Web3 metaverse [212]. Various reasons prove the weakness of only "Code is law", e.g., it may repeat the same mistakes of the pre-modern contracting era and fail to incorporate principles of equity into dispute resolution [130], and can not solve the various speculation and centralization, the "dark side" of the current Web3 metaverse, mentioned in our survey. Truthfully, the reality is that laws are only the baseline of a real society, while constructing culture and morality in the Web3 metaverse is a real difficult and promising task. Balancing social regulations and laws in the Web3 metaverse is another imperative question that needs to be tackled.

6.3 Countering the Monopoly of Big Tech Firms

An essential question to build the Web3 metaverse is: "Who is the builder?" From the ordinary people's perspective, building a Web3 metaverse involves multiple technologies, like communication, coding, and modeling, so constructing the Web3 metaverse can only rely on technology companies and capital. For example, the current development of AIGC technologies brings promising and convenient tools that facilitate the fast construction of a complex virtual world via the quick generation of various digital assets, but which are all developed by big technology companies with sufficient capital and technical resources [152, 159]. Indeed, the neural network model size and computational cost of these AIGC technologies have shown a sharp increase that ordinary people cannot afford, de facto introducing a monopoly barrier. Although blockchain technologies are considered an anti-monopoly solution [3], basic consensus mechanisms of notable blockchains (BitCoin and Ethereum), rather profit tech organizations with important financial resources. In particular, PoW [146] requires huge computational power provided by **application-specific integrated circuit** (**ASIC**) miners, while PoS introduces a weaker decentralization feature and the Matthew Effect [140], both mostly benefit big technology firms with significant financial assets. Therefore, the development of the Web3 metaverse needs to counter the potential monopoly of technology firms and capital, and corresponding regulations and policies should be deployed before the wider application of the Web3 metaverse.

7 CONCLUSION

Metaverse is a rapidly evolving socio-technical landscape that presents numerous opportunities for creation and collaboration. By leveraging Web3 technologies such as blockchain, smart contracts, and NFTs, the metaverse is set to revolutionize various social areas. Therefore, the Web3 metaverse is the convergence of advanced multimedia technologies, which has shown a promising future for the industry and academia, especially in multimedia. However, existing studies overlook the importance of Web3 and fail to analyze the development of the metaverse from a human-centered perspective. This survey systematically overviews the metaverse development over three decades, defines the Web3 metaverse as a decentralized, closed-loop social system, and provides a multi-dimensional analytical framework covering complete economic and social components. Based on

interdisciplinary theories, we survey the current developments and challenges of the Web3 metaverse in terms of identity, field, and behavior aspects, aiming to promote the development of the Web3 metaverse further. This work also provides a supplementary review of relevant technologies to support our insights. For future work, we suggest integrating social and technical disciplines, leveraging and going beyond "code is law", and tackling the monopoly issue.

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