# Web3 Multimedia Applications: Under the Impact of Decentralization

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In the Web3 ecosystem, multimedia applications exhibit significant potential by leveraging decentralization, regarded as the core spirit of Web3. This survey aims to provide a comprehensive overview of the potential of decentralization in shaping multimedia applications in the Web3 ecosystem. Through a systematic review of the academic research conducted over the past decade on Web3 decentralization, we identify the two key distinctive decentralization characteristics (decentralized assets and decentralized participation). Subsequently, we comprehensively analyse Web3 applications from both technology and application dimensions. Building upon this, we focus on multimedia-related aspects and propose an architecture for Web3 multimedia applications. In contrast to the broader scope of Web3 applications, the unique aspects of Web3 multimedia applications reside in their core application components (non-fungible tokens and smart contract-based rules) and core application domains (art, games, and social media). Based on this architecture, we provide a precise definition of Web3 multimedia applications. Lastly, through the lens of the two identified distinctive decentralization characteristics, we investigate the advantages, development, and limitations of Web3 multimedia applications within the three core application domains, namely crypto art, blockchain games, and blockchain on social media (BOSM). Furthermore, we share our insights into several promising yet challenging directions, covering the interoperability and potential of increasingly valuable multimedia content, as well as the delicate balance between centralization and decentralization.

CCS Concepts: • **General and reference** → **Surveys and overviews**; • **Human-centered computing** → *Human computer interaction (HCI)*; *Collaborative and social computing theory, concepts and paradigms*; • **Applied computing** → *Arts and humanities.*

Additional Key Words and Phrases: Multimedia applications, Web3, decentralization, survey

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## 1 Introduction

With the advent of Web3 (sometimes referred to as Web 3.0), the Internet is clearly undergoing a paradigm shift. In the current mainstream read-write Web2 ecosystem, users assume the dual role of content consumers and creators [96]. However, Web2 is typically characterized by centralized platforms that integrate user data and services, and are governed by a handful of tech giants that maintain significant control over user data [186]. Indeed, the identity and content produced by users on Web2 belong to the enterprises who own the platforms rather than the users themselves [61]. The adverse consequences of users losing ownership of (and control over) their personal data have appeared numerous times. For instance, in January 2023, Blizzard shut down its services in China, causing millions of players to lose their game accounts that they had striven to create and enrich for over 20 years [195]. Moreover, the centralized power structure of Web2 has also resulted in a number of issues, such as inherent vulnerability to attacks, data monopolization, privacy-violation through user data collection, censorship, and interest-oriented user activity and behavior exploitation and monetization [6, 106].

To address the negative impacts brought about by the centralized nature of Web2 platforms, researchers and practitioners have proposed Web3 as a new Internet model. As a disruptive read-write-own ecosystem, Web3 aims to leverage the decentralized characteristics of blockchain technology, thus enabling users to regain ownership and complete control over their personal data and information [6, 10, 134]. As such, decentralization has become the core objective of the Web3 community [212]. According to Partha Pratim Ray's comprehensive survey on the current state of the Web3 ecosystem, as Web3 gradually develops, the concept of decentralization is no longer limited to the data layer, but has expanded to broader application domains [160]. Nevertheless, compared with the mature Web2 ecosystem, Web3 remains in its early stages and faces challenges in attracting users.

Traditional multimedia applications employ a combination of a variety of media elements, such as text, graphics, images, audio, animation, and video, to enhance information expression and user experience [52, 147]. As such, Web3 multimedia applications can play a crucial role in the Web3 ecosystem by providing an attractive and user-friendly online space. Indeed, the utilization of Web3 multimedia applications in various application domains, such as art, games, and social media, demonstrates unique innovation potential and attracts a significant number of active users transitioning from Web2 [59, 69, 128]. Although researchers have recognized the advantages of the blockchain technology for multimedia management [154], the focus has mainly been on features such as security, privacy, and copyright protection, while overlooking the full potential of the decentralized nature of Web3 and its impact on multimedia applications.

Existing surveys covering decentralization and Web3 applications primarily investigate these topics from three perspectives: **(1) The implementation of Web3 application components:** Web3 has given rise to some innovative application components based on blockchain technology and embodying decentralized attributes, which did not exist prior to the advent of Web3. Researchers have conducted surveys on their implementation methods, such as the technical foundations and standards of Non-Fungible Tokens (NFTs) [200], the smart contract implementation methods and models of Decentralized Autonomous Organizations (DAOs) [182, 204], and the technical implementation of Tokens and their role in DAO governance [199]. **(2) The impact of Web3 application components on application domains:** These application components have introduced decentralization attributes to different application domains, leading to far-reaching consequences. For instance, researchers have explored the impact of NFTs on multiple domains including art and game [162], the influence of DAOs on education and research domains [55], and the effect of Tokens on the business domain [108, 199]. **(3) The impact of Web3 application**

**components on higher-level complex systems:** Built upon Web3, the Web3 metaverse, as a decentralized societal system that goes beyond the concept of applications, has been valued by many researchers [34] who have investigated the impact of Web3 application components on this societal system in various aspects, such as human factors [34], asset and data management [196], and marketing [19].

In light of the above, studies on decentralization and Web3 applications are clearly dispersed across Web3 application components, application domains, and higher-level complex systems, which leads to a fragmented understanding of decentralization. As such, existing surveys lack a holistic perspective on Web3 decentralization, and fail to offer a thorough examination and clear understanding of how decentralization impacts the development of Web3 applications in general, and Web3 multimedia applications in particular.

Indeed, Web3 multimedia applications integrate various Web3 application components to achieve decentralization and are utilized across multiple application domains. While existing studies have covered these components and domains separately, they have not consolidated these factors into a comprehensive understanding, from which new insights on Web3 multimedia applications can emerge.

Table 1. Comparison with Previous Surveys.

| **Survey** | [108] | [204] | [182] | [128] | [199] | [53] |
|---|---|---|---|---|---|---|
| Year | 2019 | 2019 | 2019 | 2019 | 2020 | 2020 |
| Decentralization | AD | AC | AC | AD | AC-AD | AC |
| Web3 multimedia applications | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate |
| **Survey** | [200] | [33] | [41] | [19] | [225] | [60] |
| Year | 2021 | 2022 | 2022 | 2022 | 2022 | 2022 |
| Decentralization | AC | AC-AD | AC | HLCS | HLCS | HLCS |
| Web3 multimedia applications | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate |
| **Survey** | [201] | [171] | [55] | [48] | [222] | [146] |
| Year | 2022 | 2022 | 2022 | 2022 | 2023 | 2023 |
| Decentralization | AC-AD | AC | AD | AD | AC | AD |
| Web3 multimedia applications | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate |
| **Survey** | [34] | [196] | [134] | [81] | [160] | **ours** |
| Year | 2023 | 2023 | 2023 | 2023 | 2023 | **2024** |
| Decentralization | HLCS | HLCS | AD | AD | AD | **Comprehensive** |
| Web3 multimedia applications | Moderate | Moderate | Moderate | Moderate | Moderate | **Comprehensive** |

AC: Application Components, AD: Application Domains, HLCS: Higher-Level Complex Systems.

Compared with previous surveys (as shown in Table 1), this paper takes a holistic approach to investigate how Web3 decentralization exactly impacts the development of Web3 multimedia applications.

Towards this end, a thorough understanding of Web3 decentralization is first needed. Following a bibliometric approach, we survey the development and evolution of Web3 decentralization in the academic field over a 10-year period, categorizing decentralization characteristics into decentralized assets and decentralized participation. Subsequently, we investigate the impact of decentralization on the development of Web3 multimedia applications. As Web3 multimedia applications are intermingled within a diverse range of Web3 applications without a holistic review or a focus on their specific multimedia content, a comprehensive understanding and a precise definition of these applications are lacking. To bridge this gap, we build upon the existing literature to investigate

Web3 applications from both technology and application perspectives. By focusing on the portions of the composition that specifically involve Web3 multimedia applications, we summarize their architecture and propose a precise definition that clearly captures the integration of both decentralization and multimedia applications. Following our holistic exploration of Web3 decentralization and Web3 multimedia applications, we draw upon existing academic literature and industry projects to investigate the influence of the two previously identified decentralization characteristics on Web3 multimedia applications across different application domains. We then capitalize on this exploration work and present our insights into three challenging but promising research directions in developing Web3 multimedia applications: exploring the potential of increasingly valuable multimedia content, integrating content from diverse Web3 multimedia applications, and striking a balance between decentralization and centralization.

The organization of our work is as follows: Section 2 introduces Web3 Decentralization including its evolution in the academic field and two decentralization characteristics: decentralized asset and decentralized participation. Section 3 presents the architecture and definition of Web3 multimedia applications. Section 4 investigates the impact of decentralized assets on the development of Web3 multimedia applications, while section 5 focuses on the impact of decentralized participation. Section 6 summarizes the current state of Web3 multimedia applications, proposes potential directions, and discusses existing challenges. Finally, conclusions are drawn in section 7.

## 2 Web3 Decentralization in Academic Research

Based on blockchain technology and pursuing decentralization, Web3 was first proposed by Gavin Wood in his blog post "Dapps: What Web 3.0 Looks Like", published in April 2014 [215]. As the Web3 ecosystem gradually develops, decentralization has been emphasized as its soul [212]. However, existing Web3 surveys have not investigated decentralization as an independent object. Decentralization is typically scattered among surveys of Web3 application components, application domains, and higher-level complex systems [34, 48, 200], lacking a holistic perspective. This section uses bibliometrics to depict the academic trajectory from 2014 to 2024, analyzing the evolution of decentralization triggered by Web3. Through examining the role of decentralization in Web3, two main types of Web3 decentralization characteristics are identified: decentralized assets and decentralized participation. This analysis and classification set the stage for understanding the impact of Web3 decentralization on Web3 multimedia applications.

### 2.1 The Evolution of Web3 Decentralization in Academic Research

To understand the evolution of Web3 decentralization in academia, we used the Publish or Perish tool[1] to collect data from Google Scholar, a database with comprehensive coverage of academic articles. The search keywords were ("Web3" OR "Web 3.0") AND ("decentralization" OR "decentralized"). The data included article titles, abstracts, and publication citation counts spanning April 2014 to May 2024. After de-duplication, a total of 10,060 relevant works were obtained. We then used CiteSpace[2] for further analysis and visualization. By mapping the co-occurrence network based on title and abstract information of the articles, we generated the timeline shown in Fig 1(A) (Q=0.669, S=0.912). It consists of horizontal axes representing research topics, which are clustered and labeled using the Latent Semantic Indexing algorithm. Among the articles related to Web3 decentralization, we identified 10 major research topics, with corresponding descriptions listed on the right side of each horizontal axis. CiteSpace extracts "noun" phrases from the titles and abstracts of articles using natural language processing techniques. The phrases with high centrality are represented by the

[1]https://harzing.com/resources/publish-or-perish
[2]https://citespace.podia.com/

nodes on the horizontal axis. The position of each node represents the time when the corresponding phrase first appeared. The size of each node correlates with the number of publications containing that phrase, while the lines connecting nodes indicate the co-occurrence relationships of phrases within the titles and abstracts of relevant articles. The visualization provides insights into the evolution of various research topics involved in Web3 decentralization.

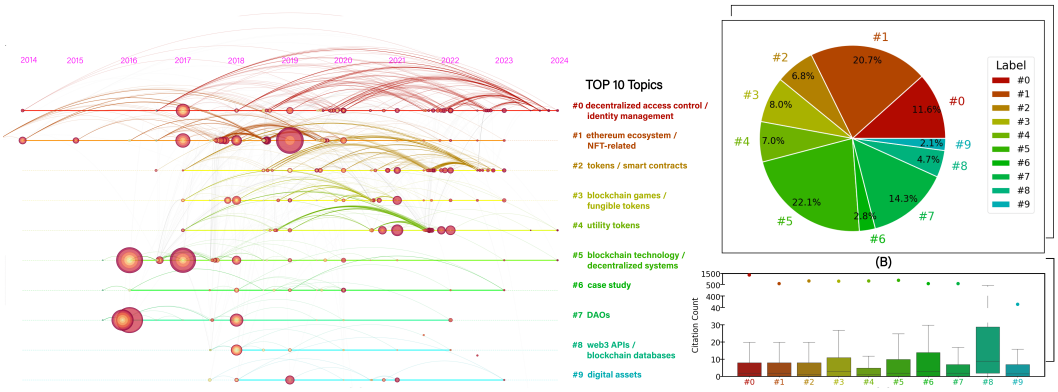


Fig. 1. (A) The timeline of academic research on Web3 decentralization. (B) The distribution of articles across different academic topics. (C) The distribution of citations of different academic topics.

As shown in Fig 1(A), the concept of Web3 decentralization in academia was initially introduced through the exploration of the Ethereum ecosystem (Topic 1). Before Gavin Wood proposed the concept of Web3 [215], the Ethereum team had already published a whitepaper for building a decentralized ecosystem [24]. Then Ethereum was officially launched in 2015, providing a practical environment for the development of research related to Web3 decentralization. Ethereum has continuously driven innovation throughout its development, such as proposing the standards of NFTs [200], thereby expanding the scope of academic research centered around Ethereum. As of January 2024, Ethereum remains one of the most active ecosystems in Web3 [131], and exploration of Web3 decentralization surrounding Ethereum is still ongoing. In the early stages of research on Web3 decentralization, researchers also explored the implementation and impact of decentralized access control and identity management (Topic 0) [3, 168], which directly responds to the original motivation behind the proposal of Web3: empowering users with control over their data and information. Subsequently, the research topics in this field began to expand in three directions: 1. The construction of fundamental technology, focusing on blockchain technology/decentralized systems (Topic 5); 2. The emergence of new organizational forms under the influence of decentralization, particularly DAOs (Topic 7); 3. The academic reflections on the rapid development in the industrial world through case studies (Topic 6). These directions provided the technological, organizational, and industrial foundation for further research on decentralization. As the Web3 industry evolves, the growing user base has generated a demand for innovation and consumption [34]. To maintain ecosystem vitality and attract new users, Web3 has witnessed the emergence of diverse applications that directly interact with users. These applications have begun to attract the attention of researchers, including various tokens implemented through smart contracts (Topic 2) [199], blockchain games with financial attributes (Topic 3) [128], and utility tokens with diverse use cases (Topic 4) [71]. These topics have further prompted researchers to consider user-owned digital assets (Topic 9) and application development such as Web3 APIs (Topic 8).

However, it is notable that the distribution of article numbers varies across different research topics, as illustrated in Fig 1 (B). In the research related to Web3 decentralization, both Topic 1 (Ethereum Ecosystem/NFT-related) and Topic 5 (Blockchain Technology/Decentralized Systems) account for more than 20% of the research. In comparison, Topic 0 (Decentralized Access Control/Identity Management) and Topic 7 (DAO) account for between 20% and 10%. The remaining topics, which emerged in the middle and late stages of the research, each account for less than 10%. To assess the impact of these research topics, we plotted box plots of citation distributions for each topic, using 95% confidence intervals, as shown in Fig 1 (c). This analysis reveals that while Web3 decentralization is a new research field that has only developed for 10 years, with most articles receiving fewer than 30 citations, there are several articles within Topics 0 to 7 that have garnered exceptionally high citation counts. This could be attributed to the Integration of Web3 with other mature research fields, such as IoT [121] and Metaverse [206]. Furthermore, due to the role of Web3 APIs in providing technical support during the Integration process, the overall citation count for Topic 8 is relatively high.

In conclusion, the academic development of Web3 decentralization exhibits an evolutionary path from infrastructure exploration to application innovation. Although current research involving Web3 decentralization primarily focuses on the Ethereum ecosystem and blockchain technology, related research has begun to address application-oriented topics with the gradual development of the Web3 ecosystem. The combination of decentralization and applications warrants the attention of researchers.

### 2.2 Characteristics of Web3 Decentralization

During the process of generating the co-occurrence network, CiteSpace extracted 692 distinct "noun" phrases from the abstracts and titles of 10,060 articles. Among these phrases, 97 words had an overly broad meaning, such as "21st century," "big upgrade," and "various types." We used the remaining 595 words to construct a framework that illustrates the relationships between the different research efforts on Web3 decentralization within the Web3 ecosystem, and to identify the characteristics of decentralization. As shown in Fig2, the framework is divided into four main parts: enabling technologies for Web3, paradigm shifts brought about by decentralization, applications built on Web3, and humans in Web3.

*2.2.1 Enabling technologies for Web3.* Computer networks represent the technological foundation supporting the development of Web3, with researchers primarily focusing on utilizing Peer-to-Peer (P2P) related technologies to build decentralized networks [39, 101]. These network systems have the ability to impact existing application networks, such as IoT networks [122, 153]. Among the various P2P-related technologies, blockchain has emerged as the core technology of Web3, with researchers extensively exploring its various aspects, including distributed ledgers [16], consensus mechanisms [141, 219], and scalability [37, 144]. Different blockchain protocols define different blockchains [84]. In the process of exploring Web3 topics, some studies have referenced or studied to various degrees these different blockchains, such as Ethereum [38, 159], Bitcoin [7, 156, 199], Polygon [112, 179], Solana [11, 93], and various alliance chains [32]. Among them, Ethereum is currently the most thriving ecosystem on Web3 because it was the first to introduce Ethereum Virtual Machine (EVM), which supports Turing-complete programming languages and can create smart contracts for any type of transaction or application [25, 85]. Therefore, various Web3 technologies related to the Ethereum ecosystem have been explored and utilized by researchers, including smart contracts [145, 228] and oracles [54, 94]. Since the blockchain technology can provide advantages such as privacy, immutability, and consistency for the data layer [143, 193, 221], researchers have also explored innovations in decentralized data management technologies within

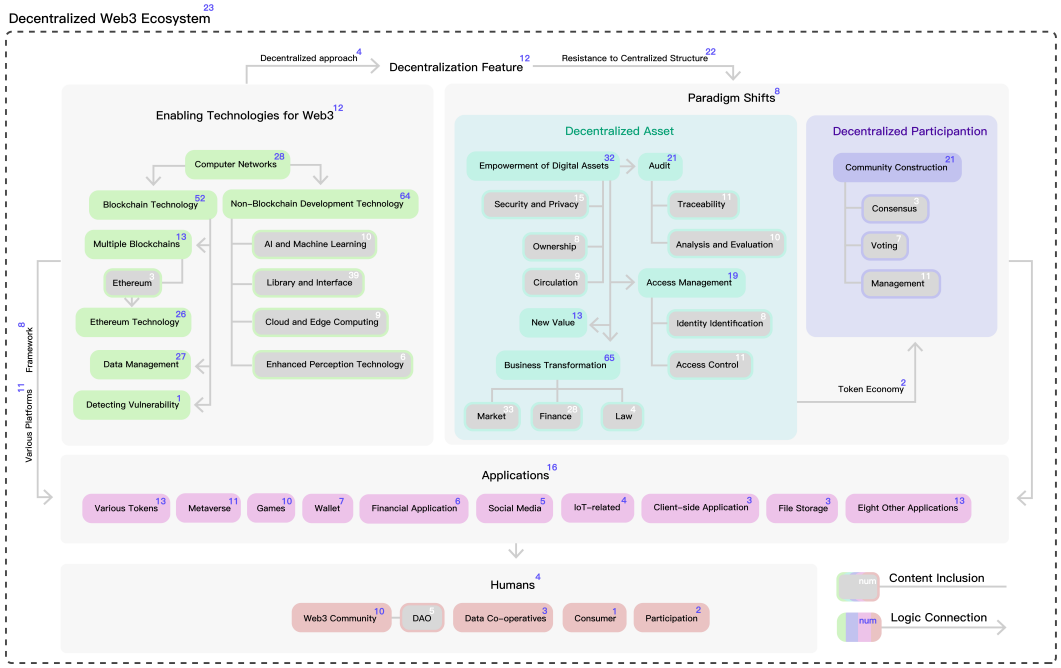


Fig. 2. The Framework of Web3 Decentralization

the Web3 ecosystem [142, 191]. However, the decentralized attribute of blockchain introduces new challenges, as vulnerabilities are difficult to fix through centralized means, prompting researchers to focus on Web3 vulnerability detection techniques [89, 103, 157]. Additionally, many non-blockchain technologies have played a crucial role in supporting Web3. While these technologies do not inherently have decentralized properties, numerous studies have demonstrated that integrating them with blockchain technologies can facilitate and improve the realization of the decentralized Web3 ecosystem. For instance, AI enables intelligent enhancement [28], diverse Web3 libraries and APIs provide the foundation for application implementation [100, 109, 208], edge computing offers high information transmission efficiency [207, 218], and immersive technologies deliver sensory enhancement [102].

*2.2.2 Paradigm shifts brought about by decentralization.* Among the technologies supporting the development of Web3, there are a variety of decentralized technologies that imbue the Web3 ecosystem with native decentralized properties [101, 212]. The rise of the decentralization concept has conflicted with various traditional centralized structures, such as centralized business models [151], centralized financial services [223], and centralized social infrastructures [13], thereby stimulating diverse paradigm shifts. In the process of examining these transformative changes, we find that the shifts brought about by decentralization can be classified into two main categories based on the two key distinctive decentralization characteristics that trigger them: decentralized assets and decentralized participation.

- **Decentralized Assets**. Since online data has already been recognized as a kind of asset in both academia and industry [22, 148], the term "asset" used here encompasses digital goods as well as digital data generated by Web3 users. Compared with digital assets controlled by centralized entities in Web2, decentralized assets realized through Web3

technologies are empowered in multiple aspects: (1) The decentralized blockchain provides a security guarantee of transparency and immutability for the decentralized assets stored on it, through its consensus mechanism, cryptography, validatable transactions, and back-referencing of blocks to establish an order among them [78]. Furthermore, some cryptographic techniques, such as zero-knowledge proofs [80] and secure Multi-Party Computation (MPC) [180], also offer privacy protection for decentralized assets. (2) As the data is immutable, the blockchain can reliably record the association between decentralized assets and their owners' addresses. Owners have direct and trustworthy ownership of decentralized assets without the need for endorsement from centralized institutions, and they can use their assets through their private keys [19, 105]. (3) Although owners possess ownership of decentralized assets, their usage space can be limited if these assets can only be used within a single blockchain or project, leading to data and value silos [1, 92]. To address this issue, existing research has leveraged the openness and interoperability of blockchains, enabling decentralized assets to be used across multiple chains and projects, thus providing greater circulation possibilities [18, 160]. These new attributes of decentralized assets have brought about further influence in several areas. For instance, as decentralized assets have security guarantees and ownership proof, participants can accurately trace the provenance of decentralized assets and conduct analysis, promoting a paradigm shift in audit [63, 76, 187]. Similarly, these attributes allow decentralized assets to serve as the identity carrier for Web3 users and be used as credentials for access control. Combined with automatically executable smart contracts, this makes access management secure and reliable [31, 142, 167]. Moreover, decentralized assets, with their newly empowered security guarantees, ownership proof, and circulation possibilities, overcome the limitations of online assets on the traditional Web2 in terms of difficulty in verifying authenticity, easy duplication, and lack of circulation, endowing assets with new possibilities for value [19], such as NFT avatars [184], cryptocurrency [120] and online luxury goods [137]. Furthermore, the combination of these three attributes has also led to decentralized assets influencing business transformations, including non-agency-centred business models [151], decentralized finance [174], and more. At the same time, it has posed challenges to commercial regulation in the legal domain [217].

- **Decentralized Participation**. In addition to decentralized assets, decentralization has also extended to a human-centric characteristic: decentralized participation. The paradigm shift brought about by decentralized participation primarily stems from individuals engaging with Web3 and each other in a decentralized and autonomous manner, thereby transforming the construction of the Web3 ecosystem as a whole, and of their collectives. In traditional organizational structures, consensus plays a role in reducing conflicts and promoting harmony during the process of group formation [56, 209]. In contrast, consensus assumes a more crucial role in the internal development of Web3 groups [210]. Decentralized participation means that communities need to carry out activities without the coordination of a centralized authority. As a prerequisite, the participants should reach a consensus on views in a decentralized manner to propose action strategies. Leveraging the properties of security guarantees and ownership proofs, decentralized assets can function as participants' identity verification and governance tokens in the form of tokens, facilitating the achievement of decentralized decision-making consensus through voting [199, 227]. The voting process and the subsequent execution of decisions also need to be completed without centralized

control. Smart contracts, which provide transparent and immutable rules along with automatic execution, are regarded as regulators and executors, replacing the traditional centralized control and supporting decentralized cooperation to achieve goals [130]. Moreover, tokens can be automatically and securely distributed to contributors through smart contracts as rewards for task completion [199]. The smart contracts and incentive tokens enable decentralized management within Web3 communities [132].

*2.2.3 Applications built on Web3.* The development of Web3 technologies and the paradigm shift towards decentralization have also given rise to various applications. When examining these applications, relevant studies involve their platforms for deployment or presentation, such as NFT-related platforms [74], video-sharing platforms [86], and social media platforms [230]. In addition, researchers have investigated the frameworks and reference models for the implementation of these applications [48, 160]. Among the diverse applications with decentralized attributes, several categories described using a greater variety of terms include tokens serving different purposes [162, 212], metaverse as a societal system integrating various applications [34], blockchain games [70], Web3 wallets [129], and finance-related applications [38].

*2.2.4 Humans in Web3.* The diverse Web3 applications enable various groups with different identities to participate in the Web3 ecosystem. Existing research on Web3 decentralization primarily focuses on communities directly related to Web3, including groups gathered in the form of DAOs [48], Web3 developers [178], and token holders [200]. Furthermore, research involves groups with different objectives, such as data-driven data co-operatives [27, 169] and consumers with purchasing intentions [172, 225].

In conclusion, based on the "noun" phrases extracted through bibliometric analysis, we propose a framework for Web3 decentralization, including enabling technologies, paradigm shifts, applications, and humans. Fig 2 illustrates the role of decentralization within the Web3 ecosystem. In Web3, decentralization, underpinned by technologies such as blockchain, facilitates a range of paradigm shifts and impacts humans through a variety of applications. Within these paradigm shifts, two types of Web3 decentralization characteristics are identified: decentralized assets and decentralized participation. It should be noted that this framework does not encompass all aspects of Web3. There are two primary limitations to this framework: (1) Since the terms constituting the framework are "noun" phrases extracted from abstracts and titles of 10,060 articles, information in the main text may have been overlooked. (2) The article search was conducted using ("Web3" OR "Web 3.0") AND ("decentralization" OR "decentralized") as the keywords. Some studies that solely examine the impact of blockchain technology without considering them as part of the Web3 ecosystem are not included within the purview of this framework, even though they may involve considerations related to decentralization.

## 3 Architecture and Definition of Web3 Multimedia applications

Web3 multimedia applications on art, games, and social media domains, have attracted numerous active users to Web3 by combining decentralization concepts and multimedia technology, becoming an essential component of the thriving Web3 ecosystem [59, 69, 128]. However, in related surveys, Web3 multimedia applications are currently intermingled within a diverse range of Web3 applications, lacking a comprehensive description of their development and application scope [134, 160]. Although some studies have explored the technical enhancements that blockchain provides for multimedia security and privacy [21, 154], Web3 multimedia applications containing unique characteristics in the decentralized Web3 context have still not been comprehensively defined. To investigate the exact impact of decentralization on Web3 multimedia applications, it is necessary

to fill these gaps. Towards this end, this section provides an architecture and definition of Web3 multimedia applications.

### 3.1 Architecture of Web3 Applications

As Web3 multimedia applications are hidden among diverse Web3 applications, a comprehensive understanding of Web3 applications is essential before focusing on Web3 multimedia applications specifically. This foundational knowledge allows us to effectively elucidate the architecture of Web3 multimedia applications. Existing surveys typically investigate Web3 applications from two distinct perspectives: technology and application, with the former serving as the foundation upon which the latter is built.

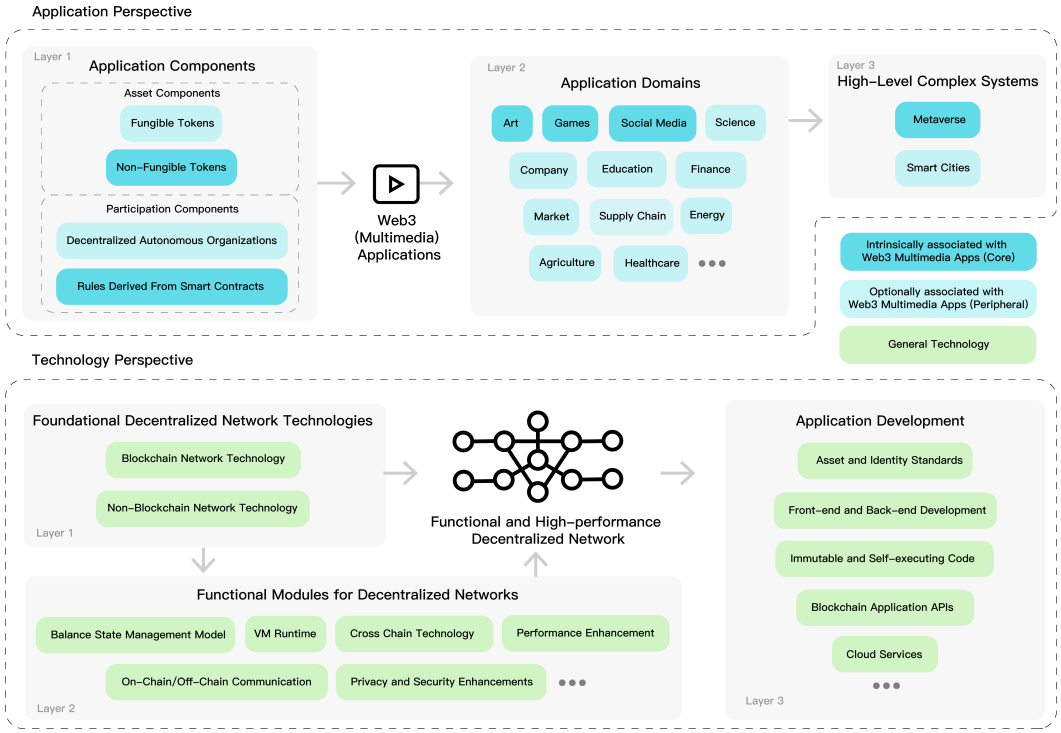


Fig. 3. The Architecture of Web3 (Multimedia) Applications represented from both a technology perspective (green) and an application perspective (blue). Compared with general Web3 applications, the architectural difference and uniqueness of Web3 multimedia applications is observed in their varying degree of association (intrinsic/optional) with application-level aspects of Web3 applications, represented in two different shades of blue (dark/light).

The technologies used to build Web3 applications are organized in three layers, as shown in Fig 3. The bottom layer comprises foundational technologies for building decentralized and distributed networks (layer 1) [101]. The most widely adopted network in Web3 applications is the blockchain network, which employs a series of diverse techniques, including node discovery mechanisms that enable nodes to identify and communicate with each other, data propagation mechanisms that allow newly mined blocks and transaction data to permeate the entire network, consensus mechanisms that facilitate agreement among nodes regarding the state of the blockchain, and cryptographic techniques that safeguard the security and privacy of the blockchain [15, 205]. In addition, Web3

applications also involve non-blockchain P2P networks such as the InterPlanetary File System (IPFS) which offers content-addressed block storage [20] and Secure Scuttlebutt (SSB) which is a specialized social-oriented network [190]. These blockchain and non-blockchain networks collectively provide fundamental decentralization guarantees for Web3 applications.

To improve their practicality, decentralized networks should also provide a variety of functionalities. At the same time, they also face various challenges, such as low throughput, high latency, and privacy issues [51, 189]. As decentralized networks evolve, a diverse range of modules for decentralized networks are being employed to implement practical functionalities and address specific problems (layer 2). These modules mainly encompass: (1) models for balance state management, including the UTXO model used by Bitcoin, which takes transaction outputs as the basic unit, consuming previous unspent outputs and creating new outputs with each transaction [139], and the account model used by Ethereum, which uses accounts as the basic unit to track and manage asset states [24]; (2) virtual machine (VM) runtime for providing program execution environments, such as the EVM for smart contract execution [24], and WebAssembly Virtual Machine (WASM VM), which offers more efficient code execution and enhances smart contract compatibility [183, 226]; (3) technologies for enabling cross-chain interaction, including relays capable of verifying and reading other blockchains, and hash locks that share the same triggers across different chains [23];(4) technologies for enabling data feeds to communicate between on-chain and off-chain, such as oracles that allow blockchains to obtain and utilize external information communication [26]; (5) technologies for enhancing network performance, including sharding, which boosts network throughput [40], and Layer 2 solutions that improve transaction speed and reduce costs by implementing additional processing layers [68]; and (6) technologies for bolstering privacy and security, such as zk-snarks, which prove the authenticity of a statement without revealing specific information [67], and ring signatures, which do not expose specific member signatures [111]. These functional modules are driving the ongoing evolution of decentralized networks, establishing an infrastructure for a diverse range of Web3 applications.

Based on functional and high-performance decentralized networks, the realization of Web3 applications also requires many standards and stacks that directly support application development, including specialized development directly targeting decentralized networks as well as general development migrated from traditional applications (layer 3). These mainly encompass: (1) standards for assets and identities owned by Web3 users, such as ERC-721 [214], BRC-20 [203], and decentralized identifiers (DIDs) [161]; (2) smart contracts, which provide immutable, transparent, and automatically executed code [130]; (3) multifarious blockchain application development APIs, such as Web3.js [109] and Ethers.js [164]; (4) traditional front-end and back-end development, such as React.js [35] and Node.js [14]; and (5) cloud service technologies for developers, such as Application as a Service (AaaS), Blockchain as a Service (BaaS), and AI as a Service (AIaaS) [116]. Through the synergistic effects of foundational decentralized network technologies, functional modules for networks, and application development at three levels, Web3 applications can be brought to fruition.

From a rather application perspective, the various aspects of Web3 applications that are primarily investigated by existing surveys can also be organized in three layers: application components (AC), application domains (AD), and higher-level complex systems (HLCS). At the foundational level are the Web3 application components that embody the decentralized nature of Web3, serving as the concrete manifestations of the decentralized network (layer 1: AC). However, these components alone are insufficient to form a complete and user-facing application. They function as integral parts of applications, carrying out specific Web3 functions and thereby transforming them into Web3 applications. These components can be categorized into two types based on their aims: asset components and participation components. Asset components consist of NFTs and fungible

tokens. Their ownership and associated transaction records are stored on the blockchain, providing guarantees of security and immutability. An NFT typically contains a Uniform Resource Identifier (URI) that points to a metadata file in JSON format. This file includes text describing the essential details of NFT, such as its author, purpose, and name, as well as a specific URI directing users to specific online content such as images, videos, or audio files. Furthermore, each NFT is assigned a unique token identifier (token ID), establishing its distinctiveness [200]. In contrast, fungible tokens are homogeneous and interchangeable tokens, typically without any attached information [199]. They can be further categorized into two types: custom tokens and native tokens. Custom tokens are minted by project teams to create application-specific fungible tokens [17], while native tokens are generated during the blockchain network's genesis and serve as the fundamental unit of value for node incentivization, on-chain transaction fees, and various other functions [134].

Web3 applications employ NFTs and fungible tokens as application components to enable users to acquire decentralized assets. On the other hand, participation components consist of rules generated by smart contracts and decentralized organizational structures, such as DAOs. The properties of smart contracts, such as immutability, transparency, and automatic execution, are inherited by the rules encoded within them [228], ensuring the decentralization and trustworthiness of Web3 applications' operational logic, as exemplified by the implementation of fair and reliable gambling game rules [128]. In addition, DAOs, as decentralized organizational structures, also employ smart contracts to enable autonomous group operation without central control or third-party intervention, which is commonly adopted by Web3 applications to organize users [88, 204]. Web3 applications employ rules encoded in smart contracts and the model of DAOs as participation components to facilitate decentralized user participation. Moreover, there is an interactive relationship between these components. For instance, NFTs and Custom fungible tokens are typically distributed to the users of Web3 applications through the rules encoded within smart contracts [200]. The majority of DAOs utilize custom fungible tokens serving as governance tokens to achieve management [199].

Web3 applications, integrating various application components, are being employed across diverse application domains with transformative impact (layer 2: AD). According to existing surveys, these domains include art, games, social media, scientific research, company management, education, finance, markets, supply chain, energy, agriculture, and healthcare [28, 81, 134, 160]. The influence on these domains is primarily reflected in the following aspects: (1) in the art domain, the authenticity and ownership of digital artworks can be verified without intermediaries, providing artists with new models for creation, trading and community operation [59, 197]; (2) in the games domain, the ownership of video game assets is held by players [128], who can also be given economic incentives under the Play-to-Earn (P2E) model [43]; (3) in the social media domain, users can form a Social-to-Earn model by monetizing their social influence into social tokens, and retain ownership of the content they generate on social media platforms [71, 82]; (4) the scientific research domain has witnessed the emergence of a new scientific architecture and paradigm, namely decentralized science (DeSci), which ensures fairness, freedom, responsibility, and sensitivity in scientific activities (e.g., decentralized funding, peer review, and research incentives) through bottom-up DAO organizational forms [48]; (5) At the same time, the field of company management has also achieved a decentralized governance structure through DAOs, empowering members with decision-making power [160]; (6) in the online education domain, students can obtain certifiable diplomas and certificates without platform constraints, benefit from a learning process that is traceable on the blockchain, and receive additional economic incentives for learning [55, 188]; (7) in the finance sector, a new financial architecture has emerged, namely decentralized finance (DeFi), which possesses the properties of being non-custodial, permissionless, publicly auditable, and composable [211]; (8) the aforementioned art trading in the art domain, Play-to-Earn in the games domain, and Social-to-Earn in the social media domain essentially intersect with the market

domain, enabling markets to give rise to new forms of transactions and value circulation [9, 19]; (9) in the domains of supply chain, energy, agriculture, and healthcare, through rules encoded in smart contracts, data management has become transparent, secure, efficient, and traceable [4, 36, 160, 202].

In addition to their impact on application domains, Web3 applications involve higher-level complex systems (layer 3: HLCS). These systems go beyond the concept of individual applications, focusing on the integration of multiple domains to form complex ecosystems. Among them, the Web3 metaverse is the most frequently discussed within the Web3 community. It is regarded as a decentralized and closed-loop societal system, forging a complete virtual world distinct from the physical world [34]. Furthermore, some studies have explored the integration of smart cities, which are considered comprehensive systems composed of multiple dimensions aiming to optimize urban services [8, 140], with Web3 applications [45, 170]. It is worth noting that although the metaverse and smart cities are frequently mentioned in research related to Web3 applications, many of them essentially still explore the impact of Web3 applications on one or more application domains, merely viewing these domains as parts of a larger system. For instance, researchers have investigated the impact of Web3 applications on the market domain within the metaverse [19], the financial domain within the metaverse [217], and various domains such as healthcare, education, and energy within smart cities [115]. From the application perspective, we argue that the content of these studies falls under the application domain layer, rather than the system layer.

### 3.2 Architecture of Web3 Multimedia Applications

After comprehensively understanding Web3 applications, we focus on the parts that involve multimedia applications to highlight the specific architectural differences of Web3 multimedia applications, as shown in Fig 3. From the technology perspective, Web3 multimedia applications share a similar architecture with Web3 applications. As a subset of Web3 applications, Web3 multimedia applications are also built upon decentralized networks that employ the same foundational technologies and functional modules, and using general Web3-oriented application development.

The architectural differences of Web3 multimedia applications are primarily observed when they are considered from an application perspective, and are expressed in their varying degree of association (intrinsic/optional) with application-level aspects of Web3 applications, which can be accordingly divided into core and periphery. Core aspects are intrinsically associated with Web3 multimedia applications, while peripheral aspects are optionally associated with Web3 multimedia applications, as further detailed below.

Traditional multimedia applications are considered as applications that employ a combination of various media elements to enhance information expression and user experience [52, 147]. As an asset component in the application components layer, NFTs are a common mapping of various media elements, and are thus a core aspect that is intrinsically associated with Web3 multimedia applications. As previously discussed, the metadata associated with NFTs is typically stored in JSON format. The most prevalent approach is utilizing a URI of NFTs to reference this JSON metadata, which contains a specific URI pointing to diverse multimedia contents (e.g., images, videos, and audio), with the actual contents typically stored on other platforms like IPFS. In addition, the encoded media content can be directly written into a JSON file of a NFT in the form of strings (by Base64). If the JSON file is then encoded as a byte array and stored in the smart contract, the multimedia content of the NFT will be actually stored on the blockchain. The utilization of NFT inevitably involves minting and distribution, typically executed on-chain through rules derived from smart contracts to ensure the security, fairness, and transparency of these processes. As a participation component, contract-based rules function as the primary means for managing Web3 multimedia content, thus constituting the core aspect of Web3 multimedia applications. Additionally, when monetization is not emphasized, multimedia contents can directly be mapped or recorded on

the blockchain as string data (e.g., textual descriptions, content hash values, or URIs) via contract-based rules, without necessitating NFTs as intermediary carriers [73]. Contract-based rules can also integrate with traditional multimedia content protection technologies (e.g., digital watermarking, Digital Rights Management (DRM), and encryption), leveraging the trustless, immutable, and secure nature of blockchain to further enhance content protection [21]. In contrast, while other components (DAO and fungible token) can be utilized in Web3 multimedia applications, they primarily serve as general components of Web3 applications to broaden the scope of decentralization, rather than directly engaging in multimedia content-specific operations.

In the application domain layer, we define the core application domains of Web3 multimedia applications as those whose content requires multimedia presentation and that primarily aim at leveraging Web3 technologies to overcome the limitations of traditional multimedia applications. These core domains, which include art, games, and social media, heavily rely on the integrated use of various media forms for content presentation. For instance, the online display of artworks requires a combination of text descriptions, images, videos, audio, and other media; video games are, inherently, applications providing a type of multimedia interactive experience. Similarly, user posts on social media platforms often contain a mix of text, pictures, and videos. The primary motivation for these domains to integrate with Web3 stems from the desire to address the shortcomings of traditional multimedia content, whose ownership and dissemination are controlled by centralized platforms, thereby giving participants control over their own multimedia content [59, 82, 128] By contrast, in the other application domains, although multimedia serves as an optional means to optimize the user experience and enable extended functionalities in Web3, such as in the education domain, where multimedia educational resources can improve the learning experience of students and their creators can obtain better copyright protection by rules derived from smart contracts [73], multimedia is not the core driving force for these domains to embrace Web3. Specifically, the supply chain, energy, agriculture, and healthcare domains aim to improve efficiency, optimize regulation, and ensure safety [36, 160, 202]; the finance and market domains focus on innovations arising from novel Web3 economic paradigms [19, 211]; the education, science, and company management domains concentrate on equitable and trustworthy operational methods [48, 160, 188].

In the high-level complex systems' layer that goes beyond the scope of applications, the above application domains are merely components of the metaverse and smart cities. Despite both systems comprising multiple domains, they have different emphases. The metaverse pursues to construct an online system that resembles the real world in terms of experience and society [34], while smart cities focus more on building a comprehensive system to optimize real urban services [8, 140]. As the core domains of Web3 multimedia applications, such as digital art, video games, and social media, are primarily focused on online culture and entertainment, they align well with the nature of the metaverse. By integrating these domains with Web3, the metaverse also enables ownership of online multimedia content for participants in the virtual world [19, 134, 146]. Conversely, smart cities incorporate more peripheral domains of Web3 multimedia applications, like energy and healthcare, to pursue optimized resource allocation and efficient service provision [140, 181]. Although Web3 multimedia applications can be used in these domains, they are not the core aspects in smart cities.

### 3.3 Definition of Web3 Multimedia Applications

Traditional multimedia applications primarily focus on enhancing information expression and providing users with better experiences through the combination of various media [52, 147]. However, with the emphasis on decentralization in the Web3 era, the focus of some multimedia applications has shifted. As demonstrated by the architecture outlined in Fig 3, these novel multimedia applications, with NFTs and rules derived from smart contracts as core components, are predominantly applied in the domains of art, games, and social media. They go beyond focusing solely

on innovations in information enhancement and user experience by combining decentralized attributes with multimedia content, empowering participants, rather than application developers and managers, to own content. We refer to these transformed multimedia applications as Web3 multimedia applications.

Traditional research fields related to ownership have already pointed out that the possession of an asset inherently grants the owner a wider range of authority [65, 77]. Web3 multimedia applications empower participants by granting them ownership of online multimedia content, which was difficult to achieve in Web2, providing participants with access to a more extensive range of interaction interfaces. For example, participants can freely transact the multimedia content they own without requiring the consent or supervision of application developers. The most prevalent transaction channels are secondary markets, exemplified by Opensea[3], which facilitate the free circulation of multimedia content represented by NFTs [213]; Moreover, participants can utilize the multimedia content they own across different applications, without being restricted by original developers. By leveraging unified asset standards and directly verifiable owner identities, NFTs exhibit interoperability within the same decentralized network[200]. In the case of the Ethereum-based game, Voxels[4], participants can employ NFTs associated with multimedia content created by other applications on the same chain to construct their own virtual land; furthermore, participants can monitor the execution of applications to safeguard their rights and interests. Benefiting from the transparency and openness of contract-based rules, participants have the right to access various on-chain information pertaining to the generation, distribution, and permissions of the multimedia content they own, enabling them to supervise whether applications operate as claimed by project parties[130, 200]. These expanded interaction interfaces essentially delegate to participants the rights that they originally did not possess in traditional multimedia applications. However, a precise definition that captures the integration of decentralization and multimedia applications is still lacking at present. We bridge this gap and define Web3 multimedia applications as follows:

> *Web3 multimedia applications are applications that grant users ownership of assets in various media forms (e.g., text, images, videos) and provide extensive range of interactions (e.g., transaction, cross-application usage, monitoring) through decentralized networks.*

## 4 The Impact of Decentralized Assets on Web3 Multimedia applications

In section 2, we discussed how the decentralization introduced by Web3 in existing research can be divided into two characteristics: decentralized assets and decentralized participation. In section 3, we investigated the architecture and gave a precise definition of Web3 multimedia applications. This provides a solid foundation to examine how decentralization affects Web3 multimedia applications specifically. In this section, starting from decentralized assets, we investigate the performance of Web3 multimedia applications in their three core application domains: art, games, and social media.

### 4.1 Crypto Art

In art, the subdomain that intersects with Web3 is commonly referred to as crypto art [19, 59]. As a carrier that can map or record rich multimedia information on the blockchain and inherit its advantages of immutability, transparency, and security [200], NFTs serve as the on-chain representation of artworks. In crypto art, Web3 multimedia applications are centered around NFTs, and comprise basic functions such as minting, distribution, and trading.

The widespread acceptance of crypto artworks can be largely attributed to the fact that NFTs have generated impact across multiple aspects, which were previously unachievable within the

[3]https://opensea.io/

[4]https://www.voxels.com/

traditional Web2 context. NFTs are typically minted by smart contracts following predefined rules. Each contract possesses a unique address on its deployed blockchain, which serves as an identifier for locating the contract through on-chain searches. Conforming to common NFT standards (such as ERC-721 [214]), each NFT should be assigned a unique token ID within the contract during the minting process. Even if multiple NFTs with identical metadata are minted within the same contract, their token IDs remain distinct. The non-repeatability of contract addresses and token IDs jointly underpins the on-chain uniqueness of each NFT carrying the crypto artwork information [200]. NFTs address the limitations of digital artworks in the traditional Web2 environment, where distinguishing between replicas and originals is challenging, by leveraging the uniqueness of NFTs to clearly identify the on-chain original version [104].

Beyond their uniqueness, the minting and transfer of NFTs, which are recorded on the blockchain, generate an immutable, public, and traceable archive of crypto artworks, further providing authenticity of their original versions [166]. Additionally, the core functionality of NFTs includes proof of ownership, which is achieved by associating the NFT with the wallet address of the user, thereby proving that the NFT belongs to a specific user and granting this address the authority to control the NFT. When an NFT is transferred due to actions such as sales or gifts, the smart contract automatically updates the address information on the NFT [200]. Since blockchain-based smart contracts are immutable, transparent, and self-executing, the association between NFT and user address is securely maintained without intermediaries in a trustworthy manner, which is difficult to achieve in the Web2 context [130].

In crypto art, some researchers argue that the user's ownership of the NFT represents ownership of the underlying artwork [59, 158]. However, other researchers point out that, compared with traditional physical artworks, most owners of crypto art only acquire partial ownership, lacking the freedom to modify the content of the artwork or use it for commercial purposes, as the copyright typically remains with the artist [19]. NFTs provide buyers with ownership of crypto artworks while also being regarded as a means of offering copyright protection for artists [155]. When creating an NFT, artists can record an immutable authorship within the corresponding metadata and smart contracts. Due to the inherent security features of blockchain, the identity of the creators associated with the crypto artworks cannot be altered by any individual. Moreover, by encoding the sales rules of NFTs into smart contracts, artists can potentially receive a royalty from each subsequent sale of their artworks, thereby achieving a form of copyright taxation that has been challenging to implement in both the Web2 and the physical world [136]. These decentralized assets enable crypto artworks to possess uniqueness, archival records, proof of ownership, and copyright protection without the need for centralized institutional authentication, creating a fertile ground for the flourishing development of crypto art. Simultaneously, they have the potential to replace the roles of auction houses and galleries in the traditional art domain, which typically undertake functions such as verifying the authenticity of artworks and providing guarantees of transactions [12]. This has given rise to a sales model for crypto art that allows direct circulation in the secondary market without intermediaries, offering barrier-free access to global buyers [150, 197].

In the early Web3 era, "CryptoPunks"[5], created by Larva Labs and launched on Ethereum in June 2017, is commonly considered one of the first and most famous NFT applications related to crypto art. It consists of 10,000 unique, algorithmically generated pixel Profile Pictures (PFPs). Each profile picture is an NFT. These PFPs are numbered and aggregated into a single image, which is then encrypted to obtain a hash value recorded by its smart contract. As one of the first well-known applications to record ownership through smart contracts and map media information on-chain, "CryptoPunks" inspired the emergence of the universal NFT ERC-721 standard [214].

[5]https://cryptopunks.app/

By standardizing the essential functions and interfaces of NFTs, the ERC-721 standard greatly facilitated the development of NFT-centric applications [29], which in turn sparked the NFT craze in 2021 [9] and led to the significant rise in popularity of the concept of crypto art [58]. Among the diverse types of crypto art, PFP applications are considered a form of generative art due to their unique creation process, in which computer algorithms randomly combine pre-designed visual elements within a standardized template to generate distinctive digital avatars [62]. The value and potential return on investment of a PFP NFT are often positively correlated with the rarity of its constituent elements [107, 126]. Additionally, PFP NFTs are often used as social media avatars. Researchers have further highlighted that PFPs, being decentralized assets designed as avatars with a consistent style within the same collection, possess identity expression capabilities that closely link them to community building and social networking [30, 34]. PFP applications have become the dominant form of crypto art [184] due to their ability to low-cost produce a large number of decentralized assets with varying degrees of rarity and identity expression, leading to higher economic returns, and incentivizing holders to build a community around the project. Notable PFP applications include "Bored Ape Yacht Club"[6], "Cool Cats"[7], and "Doodles"[8]. In addition to generative art represented by PFPs, other common types of crypto art include traditional art minted on the blockchain, and participatory art with engagement from NFT holders (artwork buyers).

In the context of crypto art, traditional art forms (such as paintings, sculptures, and musical compositions,), whether originally created in physical or digital mediums, can be directly minted as NFTs to become on-chain crypto artworks, by using the URI that points to the artwork's metadata. The most well-known and expensive example is "Everydays: The First 5000 Days" by Beeple, which sold for a staggering over $ 69 million. The content of this artwork is essentially a traditional collage of vector-based paintings and animations [163]. In contrast, participatory art in crypto art empowers NFT holders to alter the content of the artwork through rules encoded in smart contracts, free from centralized manipulation, resulting in a collaborative effort between artists and holders. One notable example is "Merge."[9] series by Pak, which attracted over 28,000 participants and achieved a total sales volume exceeding $91 million. "Merge." consists of a large number of sphere-shaped NFTs, where each purchase made by a holder represents a merger of spheres, increasing sphere size. This mechanism ultimately allows holders to control the final content of their acquired NFT based on their purchasing decisions [176].

NFTs are not limited to being used on the most popular Ethereum network through the ERC-721 standard. Similar standards have also been introduced on other blockchains that support smart contracts, such as the BEP-721 on the BNB Smart Chain, the ARC-721 on the Alaya network, and the XRC-721 standard on the XDC Network, among others [203]. However, these NFT standards are primarily developed based on smart contracts. It was not until 2023 that the Bitcoin network introduced a similar NFT technology called Ordinals, making crypto art possible within the Bitcoin ecosystem [110]. During the Bitcoin transaction process, Ordinals achieve the on-chain mapping of multimedia content by recording URI or metadata on the smallest unit of Bitcoin, satoshi (0.00000001 BTC). Although Ordinals bring new opportunities to the Bitcoin ecosystem, researchers have pointed out that issues such as network congestion, increased reliance on centralized tools, and rising fees cannot be overlooked [203].

Moreover, it is worth noting that in the domain of crypto art, Web3 multimedia applications do not only utilize the core asset component, namely NFTs. Fungible tokens represent a peripheral asset component that is incorporated in some applications. The aforementioned "Merge." series

[6]https://boredapeyachtclub.com/
[7]https://coolcats.com/
[8]https://doodles.app/
[9]https://www.niftygateway.com/marketplace/collectible/0xc3f8a0f5841abff777d3eefa5047e8d413a1c9ab/

is a typical example. When a holder merges two smaller ball NFTs into a single larger ball NFT, a predetermined amount of $ASH tokens issued by the Ash community[10] is generated as a compensation for the burning of one NFT during the merging process[123]. Serving as a community fungible token, $ASH tokens attract participants to join the community while participating in artistic creations, and encourage them to take part in subsequent activities by holding these tokens, thereby boosting community engagement. This type of crypto art applications seamlessly integrate art with community development, showcasing its capacity to surpass mere artistic expressions. Additionally, an experimental concept also involves the use of fungible tokens in crypto art, namely fractionalizing NFTs [150]. By splitting an NFT into smaller, easier-to-manage fungible tokens, a wider range of buyers can acquire partial ownership of a crypto artwork with greater ease and affordability, without having to purchase the entire NFT, which can be quite expensive [75].

However, existing decentralized assets have been noted to have limitations that may negatively impact the crypto art domain. For example, under traditional copyright laws, the right of display for owners does not cover digital artworks. This suggests that transmitting digital content from one location to another, such as uploading from personal devices to websites, with the intent to display it to audience in a different location, may constitute copyright infringement if the owner of the digital content does not hold the copyright [135]. Crypto art buyers (NFT holders) who have ownership but not copyright face a fundamental challenge when using their crypto artworks, as it relies on the transmission and display of digital content. This includes showcasing the digital content associated with the NFT on secondary markets or social media platforms, which involves transmitting the content from one location to another on public platforms. These practices may conflict with the interpretation of the right of display under existing copyright laws. Furthermore, despite the prevalent belief within the NFT community that purchasing an NFT represents a transfer of partial ownership for the underlying artwork [59, 104, 149, 150, 200], legal researchers have offered a relatively negative assessment. They argue that owning an NFT does not equate to owning the artwork associated with the NFT, but rather the ownership of a signed receipt [66].

In addition to the incompatibility with current laws, the implementation of decentralized assets has also faced criticism and skepticism [41]. In many crypto art applications, the metadata representing the content of the artwork is stored outside of the blockchain, referenced by the URI of the NFT. This external storage implies that the content is not protected by the blockchain technology. Even if the metadata is stored on the decentralized IPFS, it can still be lost or become inaccessible when no nodes are hosting it. Moreover, if the metadata is hosted on a centralized server, it is susceptible to alterations by the project teams at any time. Notably, researchers have also highlighted that NFT standards allow creators to incorporate the functionality of modifying URIs during smart contract development, which does not align with the expectations of Web3 users. Some malicious creators can exploit this feature to alter the links pointing to the multimedia information associated with the crypto artwork [41, 200].

### 4.2 Blockchain Games

The subdomain that combines games with Web3 is commonly referred to as blockchain games [90, 128]. Compared with the simple applications built around NFT artworks in crypto art, Web3 multimedia applications in this subdomain have a more complex composition, incorporating not only decentralized assets but also gameplay-related functions and content found in traditional video games. Despite this, decentralized assets remain a core component of blockchain games, which is the main distinction between blockchain games and traditional video games [91].

[10]https://burn.art/about

Similarly to the scenario in the crypto art domain, NFTs carrying multimedia information have also brought diverse contributions to blockchain games. In traditional video games, virtual items in a player's account are not the property of the player but rather of the game company. Ubisoft[11], Blizzard[12], Nintendo[13], and other game companies emphatically declare this point in their "End User License Agreements" (EULAs). Game companies can freely freeze, modify, or even revoke the virtual items that players have obtained through time or money investments. However, in blockchain games, these in-game items are typically presented as NFTs, offering the potential to break the limitations imposed on players by traditional video games in the Web2 era.

As previously described, the ownership of NFTs in Web3 is generally attributed to the NFT holders. According to the common NFT standards, the holders, rather than the project creators, possess the rights to transfer and trade the NFTs [200, 214]. This ownership brought by decentralized assets and trading rights that is technologically guaranteed to players, has greatly enhanced the P2E model in blockchain games [43, 152, 198]. In particular, in Web3, NFTs have various secondary markets, such as OpenSea, where players can liquidate their in-game items by converting them to circulating money without being controlled by game companies. Allowing players to genuinely own their in-game assets and profit from selling them has become the common advertising and promotional means used by blockchain games, such as the renowned Axie Infinity[14], to attract and retain players.

It is worth noting that, in addition to the common in-game items dropped by defeating monsters or completing quests, user-generated content (UGC), specifically user-generated game objects such as custom weapons and characters created by players, are also essential sources of NFTs in blockchain games [49]. In traditional video games, UGC plays a crucial role in fostering player engagement and contributing to community prosperity [46, 97]. However, in Web2, although the virtual items created by players contain their creativity, whether they belong to the game company or the players depends on the policy of the company. Unfortunately, in most EULAs declared by game companies, user-generated game objects are not treated differently from other in-game items obtained through direct drops. Players are only granted the right to use them within the game. In contrast, UGC can be minted into NFTs by players in blockchain games. Thus, these items represent not only abstract feelings or enthusiasm for the game but also potential specific values, forming a creator economy ecosystem to expand the scope of P2E, and retaining users' active participation over time. [49, 128].

Additionally, the decentralized assets in P2E are not limited to in-game items represented by NFTs carrying multimedia information. They also widely utilize fungible tokens that serve as in-game currencies. Unlike the currencies in traditional video games, these fungible tokens in blockchain games can be exchanged for real money, further enriching the mechanisms of P2E [5, 43, 152]. While the economic attributes brought about by decentralized assets have been the primary focus, a few researchers have also pointed out that NFTs, typically minted using uniform standards, offer the potential for in-game items to be used across different games [128].

CryptoKitties[15], created by Dapper Labs and launched on Ethereum in November 2017, is widely recognized as the first blockchain game to gain widespread acceptance [90, 118]. Although the universal NFT standard ERC-721 had not been formally approved at that time, CryptoKitties utilized a draft version of the standard in its smart contracts, making it the first game to incorporate decentralized asset NFTs. The core gameplay of CryptoKitties is trading, renting, and breeding

[11]https://legal.ubi.com/eula/en-US
[12]https://www.blizzard.com/en-us/legal/fba4d00f-c7e4-4883-b8b9-1b4500a402ea/blizzard-end-user-license-agreement
[13]https://www.nintendo.com/sg/support/switch/eula/usage_policy.html
[14]https://axieinfinity.com/
[15]https://www.cryptokitties.co/

cats with distinct attributes [175], which are represented as NFTs. Each cat NFT is associated with a set of character attributes, including its generation count, visible traits (displayed and may be inherited by offsprings), and hidden traits (not displayed but have the potential to be passed down to offsprings). Two cats are capable of being paired to breed an offspring. The smart contract-based algorithm determines the attributes of these next-generation cat NFTs, by deciding which traits are inherited from the parents and whether they are dominant or recessive. In CryptoKitties, players primarily aim to breed cat NFTs that exhibit rare visible traits or possess unique attribute combinations. These scarce digital assets can then be directly sold or rented out to other players for breeding, thereby generating profits for their owners. The P2E model employed by CryptoKitties, which focuses on NFTs and leverages scarcity to enhance value creation and user engagement, has profoundly influenced the design of subsequent blockchain games [44]. However, some researchers have highlighted the limitations of excessively relying on scarcity to construct value in blockchain games. For example, as the game progresses, the initially scarce in-game items typically become overly abundant, leading to depreciation; moreover, the value derived from scarcity is heavily reliant on the active player base, meaning that rare items will be worthless in the face of player attrition [175].

After the emergence of CryptoKitties, blockchain games have gradually gained prominence in Web3, leading to a surge of game applications [194]. Among them, Axie Infinity[16], which is a card battle game, is widely regarded as one of the most popular blockchain games [118]. It has refined the P2E model based on the NFT-centric game mechanics of CryptoKitties, becoming a quintessential example of blockchain games [44]. Particularly during the COVID-19 pandemic, Axie Infinity became the primary source of income for many unemployed individuals [42].

To start playing the game, players need to acquire at least three characters, called Axies, which are represented as NFTs. Similarly to CryptoKitties, these Axies possess various character attributes and can be bought, sold, and bred. The difference is that Axies are actively utilized within the game environment, where their unique attributes directly translate to specific combat capabilities. Beyond the economic system and gameplay built around NFTs, Axie Infinity introduces two distinct fungible tokens: Smooth Love Potion (SLP) and Axie Infinity Shards (AXS). SLP serves as the in-game currency, acquired through completing tasks and daily activities within the game. On the other hand, AXS functions as the governance token, obtained by participating in the Player vs. Player mode. Both SLP and AXS are capable of being readily sold on various cryptocurrency exchanges for fiat currency, further enhancing the incentive mechanism and expanding the scope of value creation. As a pioneering representative of blockchain games, Axie Infinity has established a relatively universal P2E model. Numerous subsequent blockchain games have adopted this combined approach of NFTs and fungible tokens as a template for their game mechanism design [5, 152].

It is worth noting that, apart from playing crucial roles in P2E, NFTs in both CryptoKitties and Axie Infinity have achieved cross-game reusability. For instance, cat NFTs act in the capacity of warriors in KotoWars[17], engaging in battles with other players; similarly, Axie NFTs assist players in managing their lands in Axie Infinity: Raylights[18]. In the above P2E model of blockchain games, NFTs have provided players with a broader range of creative possibilities. For instance, players can harness their owned NFT items to generate new NFTs. However, in most blockchain games, UGC is not the primary focus of the gameplay. The roles of Players are more akin to participants within predefined game mechanics rather than content creators.

[16] https://axieinfinity.com/
[17] https://kotowars.com/
[18] https://hub.skymavis.com/games/raylights?from=%2Fgames&name=Browse+Games&filter=partnershipType%253Dsky-mavis

By contrast, some blockchain games aiming to be metaverses, such as the well-known Voxels[19], Decentraland[20], and The Sandbox[21], have demonstrated a strong emphasis on the UGC model, striving to empower players to create and maintain ownership of their in-game items [49, 60]. In the academic realm, Web3 metaverses are considered a higher-level system that transcends the concepts of domains and applications [34]. Nevertheless, some researchers contend that the current metaverse applications, while showing promise, are still in their embryonic stage, with the essence of their experience and presentation remaining that of blockchain games [70, 134]. Voxels exemplifies a metaverse game with a relatively pure mechanism, focusing on UGC and offering high support and reusability for NFT items [79]. In Voxels, players can purchase NFTs representing lands. Each land NFT owner can freely construct buildings on her/his land using the game's editor, resulting in diverse landscapes. Moreover, any player can create and mint NFTs of clothing, furniture, or other items within the game. These items can be freely circulated in the secondary market, providing economic rewards for the creativity of players. In addition, the multimedia content brought from outside the game by universal NFT standards is seamlessly incorporated into Voxels, such that players can showcase crypto artworks or videos that have been minted as NFTs within their virtual land. This core gameplay mechanic, which is based on land NFTs as the foundation for building UGC and allowing players to freely generate game objects in the form of NFTs, has also been employed in Decentraland and The Sandbox [60]. This model enhances player engagement while offering design references for personalized content creation.

While decentralized assets have brought enhancements to blockchain games in various aspects, such as player ownership, P2E, and UGC, they also introduce potential negative impacts. Blockchain technology provides a decentralized, transparent, and immutable security guarantees for in-game assets [200]. However, vulnerabilities in the smart contracts managing these assets or security breaches on players' computers can be exploited by hackers to transfer the assets to their own wallet addresses. In such situations, this decentralized security makes it difficult for both players and game companies to retrieve the stolen assets, leading to irrecoverable losses [127, 175]. Moreover, the user-unfriendly, expensive, and slow on-chain interactions associated with operating decentralized assets have also been criticized by players. Although some games have attempted to address these issues, such as Axie Infinity that was initially deployed on the Ethereum main network but later migrated to the Ronin sidechain to pursue lower gas fees and faster processing speeds [60], the seamless gaming experience of traditional video games has not yet been achieved. Furthermore, a significant amount of criticism is centered on the P2E model introduced by decentralized assets. A major concern is that the primary motivation for many players to engage with blockchain games is not for entertainment but rather for financial gain [91]. Researchers have pointed out the high similarity between the architecture of blockchain games and traditional gambling systems, specifically around their chance-based mechanics and the payment for completion of tasks that underpin these games [173]. This pursuit of profits has led to a phenomenon where blockchain games often have short life cycles, with players quickly abandoning the game once it no longer provides a profitable opportunity [90, 152]. Some traditional games communities even consider blockchain games to be nothing more than Ponzi schemes [87, 185].

### 4.3 Blockchain Online Social Media

Applications in the subdomain that combines Web3 and social media are commonly referred to as Blockchain Online Social Media (BOSM) [69, 71, 82]. Similarly to crypto art and blockchain games,

[19]https://www.voxels.com/
[20]https://decentraland.org/
[21]https://www.sandbox.game/en/

decentralized assets have had a significant impact on this subdomain, and are playing diverse roles in these applications. However, the implementation of social media applications relies heavily on a large number of active users. Given the currently limited user base in the early Web3 ecosystem, BOSM is still in its nascent stage. As of July 2024, compared with the numerous applications related to crypto art (48,627 on SuperRare alone, according to Dune[22]) and blockchain games (4,043 in total, according to Tingbits[23]), there are only 109 BOSM applications according to the statistics of Alchemy[24].

Researchers have identified two primary motivations for the emergence of BOSM [72]: (1) to break the absolute control that companies have over user-related content on traditional Web2 social media applications, empowering users to own their social content; (2) to disrupt the unfair distribution of user-generated content revenue on social media, enabling creators to derive value from the content they produce. Decentralized assets play a pivotal role in both of these motivations. NFTs, characterized by their uniqueness, proof of ownership, and immutability [200], have the potential to function as user accounts in BOSMs, thereby reducing the complete control that companies have over social media accounts [83]. Simultaneously, as mentioned in the crypto art section, NFTs, particularly PFP NFTs, are frequently used as account avatars on social media for identity expression, thus contributing to the development of vibrant communities [30, 34]. In order to decentralize the ownership of user-published information, one viable option is to mint user-generated multimedia content as NFTs. Another common approach is to directly record the URI that links to the metadata of the corresponding content and the relationship between the URI and the creator through smart contracts, ensuring tamper-proof ownership [83]. Furthermore, for applications built on blockchains that do not support smart contracts, a method similar to Ordinals (discussed in section 4.1) can be employed, directly recording the post information in a transaction field to maintain the decentralization of social media content [230]. In contrast, the model in which users can earn income in BOSM is considered a subset of Defi, known as social finance (SocialFi) [82]. By tokenizing information such as likes, comments, and reposts through fungible tokens and NFTs, social influence is given tangible value [71]. This tokenization incentivizes users to create high-quality content and actively engage in social media interactions, enhancing their social influence to obtain higher economic returns.

In the current Web3 ecosystem, the focus of existing social media applications varies. Among them, Lens Protocol[25] built on the Polygon mainnet, is a prominent example of an attempt to construct a comprehensive social media ecosystem. It is an open social network that allows developers to leverage its audience and infrastructure to create a diverse range of social applications with different orientations, such as orb.club[26], which is designed for artists. Lens Protocol employs Profile NFTs as accounts for the entire network. The user-generated content within this network (e.g., posts, quotes, and comments) is stored in metadata, which is referenced in smart contracts via URIs that are associated with Profile NFTs, enabling creators to maintain control over their social media content [83]. By using NFTs as a medium, users seamlessly switch between more than ten existing social applications within the Lens Protocol network. Additionally, Mirror[27] is a notable BOSM that emphasizes the utilization of NFTs to directly represent social media content. It allows content creators to mint their posts into NFTs, thereby transforming readers and fans into collectors. Mirror expects that this approach, which uses NFTs as a medium to allow users

[22]https://dune.com/rchen8/superrare
[23]https://tingbits.com/
[24]https://www.alchemy.com/top/web3-social-dapps?childCategories=Web3+Social+Media+Dapps
[25]https://www.lens.xyz/
[26]https://orb.club/
[27]https://mirror.xyz/

to control and profit from their social media content, would provide sponsorship for creators and form creator-centric, bottom-up communities [138]. Moreover, Steemit[28], a BOSM with the largest user base (over 1 million) and a rich economic system design, is considered a valuable reference for enabling participants to obtain economic benefits in social media [72, 95, 99, 192]. Steemit employs three fungible tokens: Steem, Steem Power (SP), and Steem Dollars (SBD). Steem, the native currency of the blockchain on which this BOSM operates, is tradable for other currencies on external markets and can be converted into SP or SBD; SP, which can only be obtained by converting Steem, functions as a measure of social influence, with higher holdings translating to greater sway within this social media; SBD is a stablecoin designed to maintain a 1:1 peg with the US dollar and is exchangeable with Steem and other currencies. The blockchain used by Steemit mints new Steem tokens with each new block, allocating the majority into a reward pool for the content creators and the curators who upvote content. The remaining tokens are distributed between the SP holders and the witnesses who provide support for the blockchain. Content creators receive a proportional amount of Steem based on the number of upvotes their posts or comments garner. Curators who upvote posts before they gain widespread popularity also earn Steem rewards. The voting weight for upvoters is proportional to their SP holdings. Curators with a higher number of SP tokens have a greater weight in the voting system, enabling them to have a greater influence on content popularity on this BOSM. In addition, to encourage thoughtful content evaluation and discourage hasty voting, Steemit employs a reward mechanism that diminishes the returns for votes cast within the first 5 minutes after a post is created. The earlier a vote is cast within this initial window, the lower the reward.

Although NFTs and fungible tokens have empowered users by granting them greater control over social media content and participation revenues, they also introduce novel challenges. Apart from the common limitations of Web3 applications, such as high fees, scalability issues, and throughput constraints[82], the tokenization of social influence on BOSMs raises concerns about potential economic inequality [72, 230]. As these decentralized assets can typically be bought and sold using other currencies, they create a direct link between real-world wealth and social media influence. Consequently, individuals with greater financial resources may acquire a disproportionate amount of social influence by purchasing more tokens, ultimately concentrating power in the hands of a wealthy few and undermining the decentralization and democratization goals of Web3.

## 5 The Impact of Decentralized Participation on Web3 Multimedia applications

After having examined the performance of decentralized assets in the core domains (art, games, and social media) of Web3 multimedia applications in section 4, this section further investigates transformations in these domains brought about by a human-centric decentralization characteristic: decentralized participation. As discussed in section 2.2.2, decentralized participation enables individuals to engage with Web3 and each other in an autonomous and decentralized manner, without the control of centralized institutions, thereby transforming the construction of the Web3 ecosystem as a whole, and of their collectives.

### 5.1 Crypto Art

Decentralized participation in crypto art can be divided into two categories: decentralized participation by artists and decentralized participation by buyers. As decentralized assets have the ability to replace the functions of traditional auction houses and galleries in terms of art authentication and transaction guarantees, artists can participate in the crypto art market in a decentralized manner without the control of centralized organizations. However, when artists gain independence from

[28]https://steemit.com/

the control of centralized institutions, they also lose the positive effects brought by them, such as increased exposure and assistance in finding potential buyers [57]. Consequently, artists need to take on the responsibilities of promoting their art and connecting directly with the collectors. By investigating, Foundation[29], an open-architecture art-selling platform, researchers have indicated that this decentralized participation creates a direct correlation between the success of crypto artists and the collectors and other artists on the platform [197]. Among them, collectors play the most pivotal role, particularly those who are inclined to repeatedly make substantial purchases of artworks from a select few artists. From the perspective of artists' income, nurturing relationships with these collectors often takes precedence over attracting new ones. It is noteworthy that, in contrast to the traditional art market, in the crypto art domain, the prices of artworks by the same artist can fluctuate significantly due to the absence of centralized operations by galleries. Additionally, artists tend to spontaneously form homogeneous clusters, with members usually possessing similar levels of income and fan bases. To a certain extent, this cluster structure influences the success opportunities of individual artists. In the Web3 context, building communities (often Discord groups) around crypto art has become a widespread phenomenon [98, 177]. This provides artists with a channel to communicate with collectors and potential buyers while creating opportunities for collaboration and mutual promotion among artists. For crypto artists, cultivating robust collector communities and integrating elite artist clusters are pivotal strategies for attaining success under the decentralized participation pattern.

When the attention shifts from the artist to the buyer, a typical decentralized participation occurs in participatory art. In Web2, the servers and websites of online participatory art are set up by artists. Even though participants can contribute to the artistic creation and expression, the entire participatory process is conducted under the central authority of the artists, to ensure that the final artwork aligns with their vision [114]. In contrast, in Web3, by encoding the rules of participation into smart contracts, participatory art can achieve a complete decentralization of partial creative power to include NFT holders. The creativity of artists can be freely unleashed until the rules of participation are determined. Once the rules are uploaded to the blockchain through self-executing and immutable smart contracts, the artists relinquish the rights delegated to the NFT holders within the rules. The contracts assume the supervisory role traditionally held by the artist and provide absolutely objective and strict rule enforcement. Moreover, since contracts are publicly available, NFT buyers can verify whether the rules align with the claims of artists, thereby assessing the credibility of the crypto artwork. Apart from "The Merge" series mentioned above, another typical example is "First Supper[30]", a painting composed of 22 layers [47]. Each layer and the complete painting are represented as NFTs. The holders of the layer NFTs can adjust parameters such as the style, rotation, and position of elements within the layers. The adjusted content is then synchronized with the NFTs of the layers and the complete painting. After setting up the rules in the smart contract for how buyers can modify the layers, the artists lose the power of determining the final appearance of the painting. In addition, this decentralized participation, guaranteed by contracts, gains a level of mechanism sustainability that far surpasses Web2 platforms. "First Supper" also exemplifies this point. Async Art[31], the platform where this crypto artwork was initially released, announced its closure in 2023, thus no longer providing a webpage for NFT buyers to adjust their layer NFTs. Nevertheless, the layer NFT buyers can still participate in the creative process according to the rules defined in the smart contract[32].

[29]https://foundation.app/
[30]https://opensea.io/assets/ethereum/0xb6dae651468e9593e4581705a09c10a76ac1e0c8/0
[31]https://async.art/
[32]https://etherscan.io/address/0xb6dae651468e9593e4581705a09c10a76ac1e0c8

In the crypto art domain, the decentralized participation of buyers is also reflected in investment-oriented institutions that adopt the DAO model. One influential example of such institutions is Flamingo DAO[33], which demonstrates a common process of participation [124, 165]. Buyers gain membership by acquiring the issued fungible tokens of the institution, with the number of tokens representing their voting weight. The approval of each proposal, including decisions on acquiring specific NFT artworks, is determined by a voting mechanism that is rendered fair and secure through the use of smart contracts. If the proposal to purchase is approved and the transaction is completed, the NFT will either be held by the institution or partially allocated to each member proportionally based on their holdings of community tokens. Members have full discretion over the usage of the NFTs. Furthermore, the total revenue generated from the NFTs is distributed proportionally to the members through smart contracts. Through decentralized participation, individual buyers can leverage the power of the collective to engage in the acquisition and management of artworks backed by substantial funds, thus sharing the corresponding profits [50].

The existing research raises concerns about decentralized participation mainly due to the lack of control from centralized institutions, which leads to the unconstrained publishing of crypto artworks. The influx of crypto artworks with varying quality poses the risk of harmful inflation. Buyers struggle to experience, digest, and ultimately purchase artworks amidst their overwhelming quantity, leading to a decrease in average prices and an increased difficulty for emerging artists to achieve success [59, 197].

### 5.2 Blockchain Games

In blockchain games, when rules are encoded on-chain through smart contracts, decentralized participation similar to that observed in participatory art emerges. By delegating the execution of game mechanisms to transparent smart contracts instead of centralized servers controlled by game companies, developers relinquish the ability to arbitrarily alter and obfuscate these mechanics. This decentralized participation in blockchain games, especially in the current context where P2E models are predominant and gradually bearing structural resemblance to gambling mechanisms [173], holds increasing significance. In the traditional Web2 platforms, games with a high degree of economic involvement are often accompanied by the risk of fraud and manipulation perpetrated by developers [64, 133]. Developers can coerce players into increasing their spendings through tactics such as adjusting backend parameters and disseminating misinformation. In contrast, the decentralized participation by players has the potential to provide them with transparency and immutability of game mechanics, safeguarding their experience and offering a channel to demonstrate the credibility of game companies [128].

The current blockchain games can be classified into two categories based on the degree to which they utilize smart contracts: *fully on-chain* games and *partially on-chain* games. Fully on-chain games are those whose core game logic is deployed and executed within smart contracts, allowing players to monitor and verify the execution of the games. These games offer players a higher level of decentralized participation. It is worth noting that fully on-chain games vary in their extent of dependence on smart contracts. Some experimental games, such as BranchClash [216], and games with simple mechanics, like CryptoKitties and various gambling games [128], can implement complete rules, computations, and interactions through smart contracts. In such games, the centralized server is limited to providing a graphical user interface, while the backend is essentially the smart contract. Theoretically, players can interact directly with the contract through a blockchain explorer to play the game, without requiring any additional server. Under these circumstances, blockchain games can achieve high mechanism sustainability, similarly to "First

[33]https://flamingodao.xyz/

Supper" in crypto art. Even if the game company discontinues its services, players can still access and play the game through the contract. Furthermore, some fully on-chain games with complex game mechanics employ a hybrid approach, where only the core logic is executed on-chain, while a substantial amount of the computations takes place off-chain. One of the prominent examples is Dark Forest[34], a real-time strategy game set in a space conquest theme, where players should expand their territories starting from their own planets [113, 220]. Dark Forest utilizes zk-SNARKs[67], a cryptographic method that allows for the verification of a statement's authenticity without revealing specific information. By shifting computational tasks off-chain and generating proofs, which are then verified in the contract to update the on-chain state, the processing efficiency is improved and costs are reduced while ensuring that the contract remains the executor of the core logic. To better benefit from the advantages of blockchain technology, the industry has been pursuing the development of fully on-chain games. Practitioners in the field have created specialized development tools tailored for fully on-chain games, such as mud[35] and dojo[36]. Interestingly, the number of fully on-chain games remains limited. The majority of existing blockchain games are partially on-chain games, where solely the content directly pertaining to NFTs and fungible tokens is encoded within smart contracts. The mechanism and execution of these games are opaque, similarly to traditional video games, making it difficult to provide players with decentralized participation. However, the advantages of convenient development and freedom from blockchain performance limitations make partially on-chain games the primary type of blockchain games.

In blockchain games, decentralized participation can also manifest in the governance aspect of game projects. Some projects transition to a DAO model after their launch, empowering players to engage in the subsequent decision-making processes in a decentralized manner. Decentraland serves as a prime example, where players utilize fungible tokens to vote and reach a consensus, determining the future development of the game [70]. In addition to the decentralized participation brought about by reducing the control of game companies, blockchain games enable players to form DAOs as an alternative to traditional gaming guilds [152]. Through fair participation, players collectively acquire, allocate, and utilize decentralized assets from blockchain games, ultimately profiting from their efforts.

Decentralized participation benefits players by providing them with transparent and secure rules, low risks of deception, and increased management rights, which can foster a sense of trust and ownership in players. However, this comes with some potential restrictions: players may miss out on the rapid version updates or gameplay optimizations delivered by traditional game companies, who have the centralized authority to efficiently determine further directions, modify game content, and allocate resources. Additionally, video games typically require substantial computational and storage resources to support their diverse game mechanics, high-quality multimedia content, and rich narrative elements, thereby creating immersive experiences [2, 125]. The greater reliance of a blockchain game on smart contracts, the higher the costs and the longer the response times associated with on-chain computation and storage, leading to a diminished user experience. Striking an equilibrium between decentralization and centralization poses a significant challenge for current blockchain game developers.

### 5.3 Blockchain Online Social Media

Empowering users to control the social media content they generate and to obtain the potential economic benefits derived from it are the primary pursuits of BOSM [72]. These objectives stand in

[34]https://zkga.me/
[35]https://mud.dev/
[36]https://www.dojoengine.org/

stark contrast to traditional centralized corporate structures, as they transfer the control from the companies to the users. Particularly, social media platforms are primarily driven by user-generated content [119]. Additionally, the core operational logic of BOSM is typically automatically executed on the blockchain [69]. The absence of these control and execution roles further diminishes the need for centralized institutions in BOSM. In fact, the majority of BOSMs are governed through DAOs [117, 224], further enhancing the degree of decentralization in user participation.

Decentralized participation in social media content on BOSMs has led to greatly enhanced user freedom of expression. In the absence of centralized control, users have the ability to freely post any content they desire. However, this also raises a challenge regarding how to handle posts that violate community guidelines, such as fake news, extreme violence, and abusive content. Typically, BOSMs delegate this responsibility of moderation to all users, through upvoting or downvoting social media content [69]. Fewer upvotes or more downvotes are indicative of a post's misalignment with community expectations. BOSMs will subject these posts to remedial actions, such as reduced visibility or complete blockage, in order to ensure a positive user experience. Moreover, some BOSMs provide users with the functionality of unidirectional muting, empowering them to locally filter out any undesirable posts [229]. It is worth noting that for BOSMs that store content on the blockchain, these remedial actions can only be implemented on the web interface. The immutability of the blockchain precludes the deletion or obfuscation of social media content on it. In terms of economic benefits brought by BOSMs, decentralized participation offers users transparency and security guarantees similar to those described in blockchain games. As outlined in section 4.3, BOSMs typically employ fungible tokens and NFTs as vehicles to convert social influence into tangible user gains through various rules. When these rules are implemented on the blockchain, they become publicly accessible and immutable. Consequently, the benefits users acquire through BOSMs cannot be altered or diminished by any centralized actions that violate the established rules.

With decentralization being further expanded to user-oriented decentralized governance, the tokenization of SocialFi in BOSM provides the foundation for the implementation of DAOs [71], through the utilization of various tokens that serve as incentives and a means to quantify the weight of opinion [88, 204]. Taking Steemit as an example, the highly liquid Steem tokens and the stablecoin SBD tokens function as incentives, whereas SP tokens serve as an indicator of social influence, determining the weight of users' opinions [72]. In the DAO of BOSM, SP tokens, which include voting rights and the ability to receive dividends, are considered to assume the role of stocks in traditional companies [117]. A higher number and proportion of tokens with such properties held by users tend to strengthen their sense of belonging to the community, leading them to view themselves as an integral part of the community, and to actively participate in the activities of the BOSM. At the same time, in this decentralized autonomous structure, economic rewards have a positive promoting effect on content creation behavior. Beyond motivating user engagement, the implementation of DAOs for decentralized governance in BOSMs offers cost-reduction benefits, including decreased supervision costs through smart contracts, reduced information asymmetry via transparent management, and diminished managerial self-interest by democratic verification [224].

Despite the numerous benefits of decentralized participation in BOSMs, it also presents challenges due to the high degree of user freedom. In addition to the aforementioned difficulty in handling content that does not meet community expectations, the diverse economic incentive mechanisms introduced by BOSMs may lead users to adopt inappropriate means to pursue personal profit maximization. These behaviors not only run counter to the original intentions of the applications, but are also difficult to effectively control under decentralized participation. For instance, on Steemit, some users engage in practices such as buying upvotes, self-voting, and using bots to enable low-quality content to generate high returns, resulting in the manipulation of the value of social media content [72].

## 6 Trends and Challenges in the Development of Web3 Multimedia applications

This section presents our insights into three challenging but promising research directions in developing Web3 multimedia applications: exploring the potential of increasingly valuable multimedia content, integrating content from diverse Web3 multimedia applications, and striking a balance between decentralization and centralization.

### 6.1 Exploring the Potential of Increasingly Valuable Multimedia Content

NFTs provide a way to prove uniqueness, transaction history, and ownership of multimedia content without intermediaries [200]. In contrast, on traditional Web2 public platforms, the lack of content ownership or provenance records, as well as the fact that digital content can be arbitrarily copied without any distinction between the original and the duplicated versions make it difficult for such content to have a recognized value. The emergence of NFTs provides the possibility to overcome this limitation, enabling a diverse array of multimedia content, including artworks, game assets, and social media posts, to possess value within online ecosystems. However, there are still challenges regarding the relationship between NFTs and their underlying content. Currently, NFTs are essentially just URIs pointing to multimedia content, rather than the content itself [66]. Additionally, if the content referenced by the NFT is not stored on blockchain, it can also be modified, replaced, or deleted [41]. Despite these concerns, the transformations that can be brought about by increasingly valuable multimedia content in Web3 remains a widely explored research direction.

### 6.2 Integrating Content from Diverse Web3 Multimedia Applications

Decentralized assets, including NFTs and fungible tokens, typically adopt standardized formats that are publicly verifiable on the blockchain, with ownership and control rights attributed to the token holders. This imbues them and their underlying tokenized content with the potential for interoperability, undermining the ubiquitous value and data silos in the traditional Web2 ecosystem [160]. However, the realization of such interoperability faces several challenges. Under current legal frameworks, while NFT ownership resides with the token holders, the copyright of the associated multimedia content often belongs to the project creators [19], potentially rendering cross-application usage against copyright laws. Moreover, the Web3 ecosystem is still in the nascent stage, lacking a sufficient number of diverse and mature applications as the foundation to support content integration. Nonetheless, the notion of users utilizing their owned content across different applications and platforms remains an enticing prospect. It expands the applicability of user-owned content and could potentially contribute to the actualization of a closed-loop Web3 metaverse system [34]. As the Web3 ecosystem and its underpinning infrastructure continue to flourish, the combination of Web3 multimedia applications and interoperable content is still a promising direction.

### 6.3 Striking a Balance Between Decentralization and Centralization

Decentralization is the core spirit of Web3 [212] and, as such, it profoundly influences Web3 multimedia applications. By combining different Web3 application components, users can obtain a variety of democratic power in the applications, such as ownership, free trading rights, supervision rights, and even governance rights, which are all guaranteed by blockchain technology and difficult to achieve in Web2 platforms [199, 200]. However, it is to be recognized that these powers granted to users essentially curtail the control of centralized companies. Although such control is often criticized as exploiting users, it also contributes to the efficient operation of applications to a certain extent, such as timely version updates, bug fixes, and content moderation. While striving for the

advantages of decentralization, one should also consider the inefficiency and chaos that may arise from unrestrained user autonomy. How to balance the scope and degree of decentralized power and find an equilibrium between decentralization and centralization remains an area that warrants further exploration.

## 7 Conclusion

Web3, the new generation of the Internet ecosystem built on blockchain technology, is rapidly evolving with decentralization as its core pursuit. In Web3, multimedia applications are widely adopted to attract active users and foster ecosystem prosperity due to their capacity to deliver rich information and enhance user experience. Web3 multimedia applications have been influenced by the decentralization brought about by Web3, exhibiting novel attributes and potential. However, existing research lacks a comprehensive understanding of decentralization, and how it exactly influences the development of Web3 applications in general, and Web3 multimedia applications in particular. This study systematically reviews the evolution of Web3 decentralization over the past decade, identifying two key decentralization characteristics: decentralized assets and decentralized participation. Drawing upon the technology and application of Web3 applications and focusing on multimedia, we delineate the architecture of Web3 multimedia applications. Furthermore, we highlight that such applications grant users ownership of assets in various media forms and provide interfaces for an extensive range of interactions. We then investigate the development of Web3 multimedia applications in their core application domains from the perspectives of the two identified decentralization characteristics. From this investigation, three key trends and challenges emerge as important research directions: exploring the potential of increasingly valuable multimedia content, integrating content from diverse Web3 multimedia applications, and striking a balance between decentralization and centralization.

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