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Non-Fungible Tokens (NFTs)—Survey of Current Applications, Evolution, and Future Directions

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ABSTRACT Non-fungible tokens (NFTs) have become an exciting technology that provides a fresh perspective on asset ownership, provenance, and value exchange. NFTs, a blockchain-based technology, are distinct and indivisible cryptographic tokens used to confirm and record the ownership of digital and physical assets in an immutable and transparent way. The fundamental block of NFT is a smart contract built on a blockchain network. This contract contains specific information about the asset it represents, such as its unique identifier, metadata, and ownership details. The information is kept private and tamper-proof due to the decentralized and distributed structure of the blockchain, boosting faith in the token's authenticity. The NFT is gaining popularity, but it is still in the developing stage. There is a need for a comprehensive survey to guide future research and development in NFTs. Thus, this paper presents the technical components of NFTs, their features, and the minting process. Further, this survey paper describes different token standards for NFTs. It presents various applications of NFTs in healthcare, supply chain, gaming, identity verification, agriculture, intellectual property, smart cities, charity and donation, and education. The article also emphasizes the significant difficulties faced currently in implementing NFT technology from the viewpoints of ownership, governance, and property rights, as well as security, privacy, and environmental effects. This work also elucidates the future directions to overcome the challenges in adopting NFTs in various applications.

INDEX TERMS Non-fungible tokens, NFT, blockchain, smart contract, cryptography, metadata, distributed ledger.

I. INTRODUCTION

NON-FUNGIBLE tokens (NFTs) are digital assets with distinct characteristics, setting them apart from other digital assets like cryptocurrencies or traditional financial instruments. Unlike cryptocurrencies, NFTs are not interchangeable with one another, and each NFT is unique, representing a specific item or asset. On the other hand, fungible items are interchangeable because their value determines their identity rather than any distinct characteristics they may possess [1]. For instance, currencies such as ETH (Ethereum) and dollars are fungible since one unit of ETH can be exchanged for another unit of a dollar, or vice versa, without any difference in their value [2]. As a result, NFTs are an excellent means of establishing ownership of digital content like music, artwork, or artifacts. By utilizing blockchain technology, NFTs establish a digital record of ownership and transfer, guaranteeing that every transaction is documented and validated through a decentralized network. This incorporation of blockchain technology ensures the authenticity and exclusivity of each NFT, preventing any possibility of replication or duplication and offering a dependable and transparent approach to demonstrate ownership of digital assets [3]. Non-fungible tokens (NFTs) have gained significant traction recently

as they use blockchain technology. Such usage provides verifiable proof of ownership for the item NFT is associated with.

In 2014, Kevin McCoy and Anil Dash created the first NFT and named it "Quantum" [4]. But it wasn't until the success of the online game called CryptoKitties in 2017 that the public became aware of NFTs [5]. The NFT market witnessed a tremendous surge in value in 2020, with its worth increasing threefold to approximately $250 million. Furthermore, during the first quarter of 2021, an additional $200 million was spent on NFTs [6], indicating the continued growth of this market. The idea of safeguarding digital content ownership has been around for some time, but it is now becoming more tangible with the use of NFTs [7]. NFTs have already gained popularity in gaming and art, but their potential applications extend to numerous other fields, including healthcare, real estate, identity management, certifications, and agriculture. By utilizing NFTs, these industries could address some of their existing challenges and unlock new opportunities for innovation and growth. Recently, NFTs have garnered a lot of attention from both the scientific and industrial communities. According to statistics, the NFT market has an average 24-hour trading volume of $4.5 billion compared to the whole cryptocurrency market's $3.4 billion. In only five months, the liquidity of NFT-related goods took up 1.3% of the entire Bitcoin market [1].

NFTs offer many benefits, with one of their most notable advantages being their capacity to ensure a secure and transparent method for verifying the legitimacy and ownership of digital assets [12]. In fields like art, NFTs provide a means of demonstrating ownership and reducing the risks associated with counterfeit items. Moreover, NFTs introduce fresh avenues for creators to monetize their digital content by selling unique digital collectibles or licensing their creations. NFT ownership is determined by a unique identification code and accompanying metadata that any other token cannot replicate. Smart contracts are utilized to create and manage the transferability of NFTs. Creating or minting an NFT involves executing code stored within smart contracts that adhere to specific standards, such as ERC-721 [13]. This data is then stored on the blockchain, a ledger for managing the NFT. At a high level, the minting process follows a series of steps, including creating a new block, validating information, and recording the data onto the blockchain.

A. MOTIVATION

The increasing popularity of NFTs in recent years has attracted widespread attention, making it a highly relevant and topical subject for research. NFTs are unique digital assets that cannot be replicated, making them highly valuable in digital art, collectibles, and other industries [14], [15]. The emergence of NFTs has disrupted traditional models of asset ownership, creating a new paradigm that can have far-reaching implications. Understanding the mechanics of NFTs and their potential impact can be highly valuable for businesses, investors, and policymakers. A survey paper on NFTs can provide insights into the possible impacts of NFTs on various industries, their implications for intellectual property rights, and how they could shape the future of asset ownership. NFTs are built on blockchain technology, Thus understanding the mechanics of NFTs can help researchers gain a deeper understanding of blockchain technology and its possible uses beyond cryptocurrency.

Musicians are considering adopting NFTs to commercialize their work since digital artworks are now selling for millions [16]. Understanding how NFTs work, their value proposition, and their potential uses in various industries are crucial for businesses, investors, and policymakers who need to assess the potential impact of this new technology on the economy and society. NFTs are still a relatively new concept, and many unanswered questions about their long-term viability, security, and scalability exist. For example, as NFTs become more popular, there is a risk that they could become a target for hackers, who may try to exploit vulnerabilities in the underlying blockchain technology to steal or manipulate NFTs [17]. In conclusion, researching NFTs in a research paper can provide many opportunities to gain insights into this exciting new technology, its potential benefits, risks, challenges, and broader societal implications. By exploring this topic in-depth, researchers can contribute to a better understanding of NFTs and their potential to transform how digital content is created, owned, and valued.

B. LIMITATION OF EXISTING WORKS

There are only a handful of publications on NFTs, their evolution, applications, and challenges as research in NFTs is in the nascent stages. A comparison of the existing literature with this paper is summarized in Table 1. The authors in [3] have mentioned the working and applications of NFTs, including a few challenges such as volatility, security, and interoperability which inhibit wide-scale adoption of NFTs. The discussion on the current challenges and open issues in [3] is brief and does not have a comprehensive account of the challenges in NFTs in various domains. It also does not present the future directions to solve the current issues in NFTs. Khati et al. [8] present a mapping review of academic research conducted on NFTs applications, discussing a few popular domains such as digital Art, education, supply Chain and assets Control, and ongoing research topics in NFT literature. The author in [9] provides a perspective on NFTs as a substitute for ownership of scholarly publications and manuscripts. But this paper does not discuss different token standards required for NFT creation and does not discuss the future direction to overcome different issues in NFTs. Rehman et al. [10] presents an overview of NFTs' applications in different market areas and concerns associated with NFT-based ownership rights. This paper does not present the future scope of NFTs and different token standards. The authors in [11] highlight the historical rise of blockchain technology with the emergence of NFTs, including current and future NFT use cases, but in a

TABLE 1. Related surveys on NFTs and its applications.

Reference	Token Standards	Transaction Workflow	Applications/ Use-Cases	Challenges/ Open-Issues	Future Directions
Hammi *et al.* [3]	✘	✘	Very limited	✓	✘
Khati *et al.* [8]	✘	✘	✓	✓	✘
Zanjanb *et al.* [9]	✘	✘	Very limited	Very limited	✘
Rehman *et al.* [10]	✘	✘	✓	✓	✘
Park *et al.* [11]	✘	✘	✓	✘	Very limited
H.Taherdoost [12]	✘	✘	✘	✓	Limited
This Survey paper	✓	✓	✓	✓	✓

very limited way. They also do not discuss different token standards and challenges faced in the wide-scale usage of NFTs. The author in [12] discusses the current state and development trends of NFTs, highlighting unsolved challenges and potential future research directions but not comprehensively. Also, he does not discuss the various applications of NFTs and their related token standards.

C. OUR CONTRIBUTION

The contribution of this survey paper is as follows:

1) Compared to other survey papers, this survey gives a detailed account of the evolution of token standards and its transaction workflow.
2) It also discusses elaborately various applications and use cases of NFTs in various domains like healthcare, supply chain, identity verification, supply chain, gaming, agriculture, intellectual property, smart cities, charity and donation, and education that were missing in other related papers in this domain.
3) Further, it also gives a comprehensive account of current challenges and open issues in NFTs and future directions that can be adopted for wide-scale usage of NFTs.

D. ORGANIZATION

The rest of the paper is organized as follows: Section II provides background knowledge on Blockchain, Smart Contracts, and NFTs. Section III discusses the different token standards. Different applications of NFTs that can be adopted in the real world are presented in Section IV. Sections V and VI describes existing challenges/open issues in using NFTs in different applications and presents some future research directions, respectively. Finally, Section VII summarizes lessons learned and concludes the paper. The organizational overview of this survey is also shown in Fig. 1.

II. BACKGROUND

Blockchain, smart contracts, and NFTs are related technologies that have revolutionized various industries. By cutting out the middleman, blockchain facilitates openness and reliability as a distributed, unchangeable record. This technology may automate transactions using smart contracts, and agreements can be represented as self-executable code. NFTs, based on blockchain technology, are digital assets that are both unique and whose ownership can be verified. Smart contracts and NFTs work together in amazing ways. Conditions, such as royalties on future sales, may be attached to NFTs by their developers via smart contracts. In addition, they make it easier to set up decentralized markets that link producers with consumers. However, NFTs improve smart contracts by introducing digital assets that are both unique and verifiably genuine. This convergence has disrupted traditional systems of ownership, provenance, and transactions. It has empowered creators, reshaped industries such as art, gaming, and real estate, and holds the potential to transform various sectors like supply chain and finance. Integrating blockchain, smart contracts, and NFTs paves the way for innovation and a futuristic technology for the distributed ledger. The following section gives a brief account of blockchain and smart contracts, which are the underlying technology of NFTs. Section III-C describes NFTs, its related features, main components, workflow, and minting process. This section briefly details Blockchain, Smart Contracts, and NFTs.

A. BLOCKCHAIN

Blockchain is a decentralized distributed database of immutable records in which a robust cryptographic algorithm protects the transactions. In blockchain before storing them in a new block, every new record is validated across the distributed network. Nakamoto originally proposed it in his whitepaper [18] on Bitcoin. Blockchain is gaining popularity quickly in finance [19], UAVs [20], [21], [22], [23], IoT [24], [25], [26], [27], smart cities [28], [29], supply chain management [30], VANETs [31], [32], etc. Blockchain has gained immense popularity considering features such as transparency, decentralization, security, speed, and many more [33], [34], [35]. Blockchain is based on the following principal notions:

1) *Blocks:* The blockchain is a database of records that are stored in the form of blocks. These blocks are

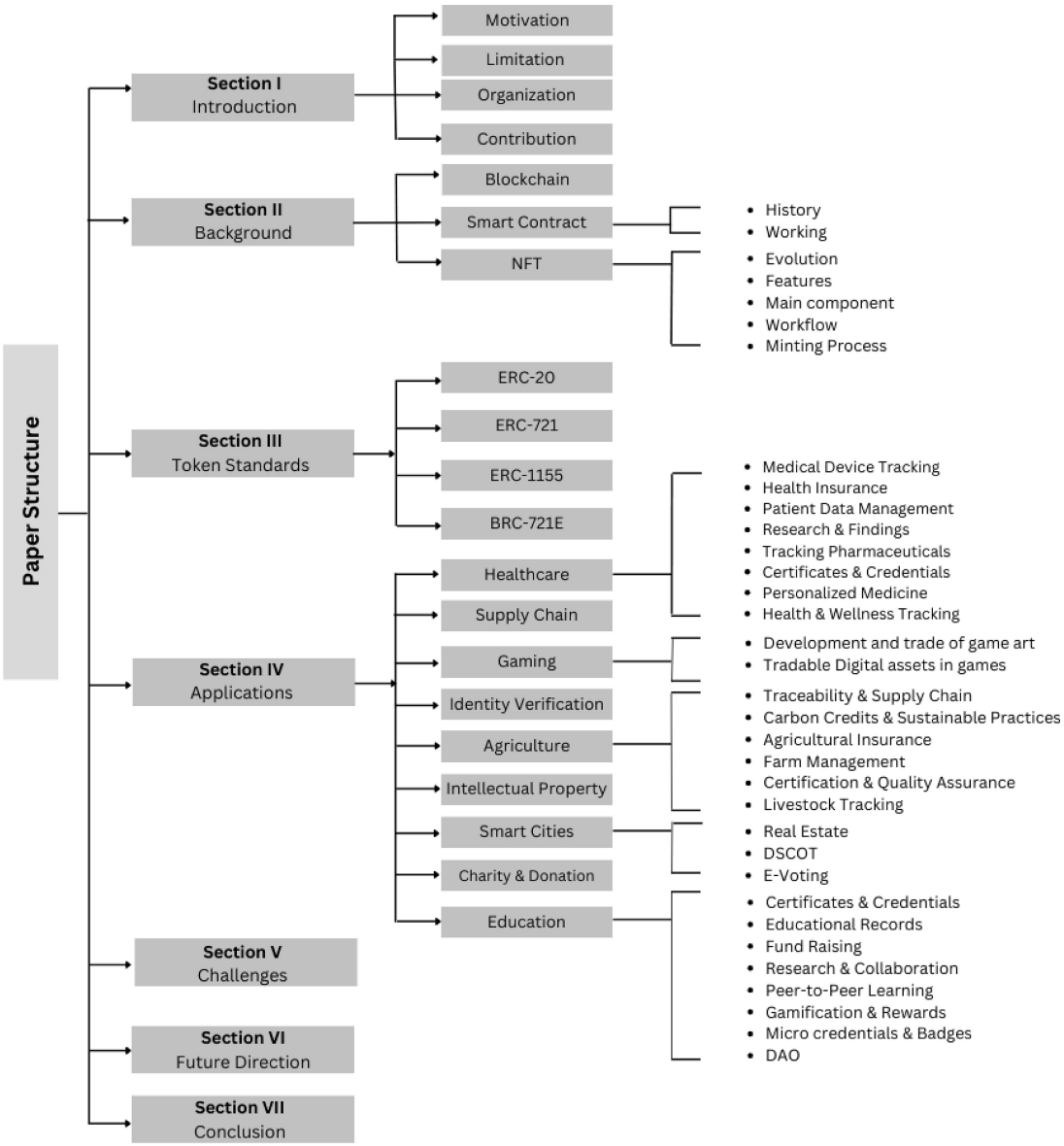

FIGURE 1. Survey Overview.

connected to one another to form a chain known as the blockchain. Every block in this ledger contains a hash pointer that links to the block that came before it. Once data is written in a block, it cannot be changed because a powerful cryptographic algorithm secures it, and any changes to any records will cause the hash of those records to change. The block header contains several pieces of information, including the Merkle tree root, the timestamp, the block version, and the hash of the block preceding it. Since every block in the blockchain is connected to the preceding block's hash, these recorded hash values make the transaction immutable. The header hash of all preceding blocks will be tampered with if any block is removed from the network.

2) *Hashing:* Hashing uses a specific algorithm to convert and generate input data of any length into a string of a predetermined length. The Secure Hashing that is SHA-256 is the hash algorithm Bitcoin uses.
3) *Consensus Algorithm:* A consensus algorithm is a procedure through which different nodes in the blockchain network reach a common agreement. Through the use of consensus algorithms, one can achieve reliability and trust between unknown peers in a distributed computing environment. The blockchain consensus protocol ensures every node's participation in the consensus process to reach an agreement. It also ensures each node is provided equal rights. Thus a consensus algorithm works to find a common agreement among all the nodes.

There are mainly three types of blockchain- public, private, and consortium:

1) *Public:* This is an open blockchain that anyone can join. Anyone wanting to become part of the public network must download the software and start running the node independently. There is no need to take anyone's permission which makes the network permissionless. Examples of public blockchain are Ethereum and Bitcoin.
2) *Private:* All permission are kept centralized. Everyone on the Internet is often permitted to view transactions on this blockchain, but only certain organization members are authorized to verify and contribute transactions to the block. Example of a private blockchain is Hyperledger.
3) *Consortium:* This is also a private blockchain managed by a group of individuals or a consortium of members. Only predefined sets of nodes have access to write data or a block. An example of this type of blockchain is Web Foundation.

B. SMART CONTRACTS

A smart contract is a computerized transaction protocol that executes the terms of a contract. By automating the conditions of an agreement between the participants, they promote confidence and transparency in a decentralized system. Smart contracts are designed to automatically carry out when specific criteria are satisfied, eliminating the need for middlemen and lowering the danger of fraud. This makes them the perfect option for various applications, including supply chain management and financial services. Blockchain technology makes smart contracts tamper-proof, secure, and immutable. They can completely alter how business is done and connect with one another by bringing a new standard of accountability and efficiency. Recent blockchain designs such as Ethereum [36], Hyperledger [37], and several other frameworks support the deployment of smart contracts in their ecosystem.

1) HISTORY

The concept of smart contracts dates back to 1994 when computer scientist Nick Szabo first introduced the idea of using digital code to execute contract terms. In his paper [38], Szabo proposed the execution of such contracts for synthetic assets, such as derivatives and bonds. These complex payment structures could then be built into standardized contracts and traded at low transaction costs. However, it was not until the emergence of blockchain technology in 2008 that smart contracts became a practical reality. The first blockchain-based smart contract platform was Ethereum, launched in 2015. This platform enabled the creation and execution of smart contracts using a programming language called *Solidity*. Since then, smart contracts have gained widespread recognition as a powerful tool for automating transactions and reducing the need for intermediaries in various industries. Today, smart contracts are a core component of the blockchain ecosystem and drive the development of decentralized applications and services.

2) WORKING

The functioning of a blockchain-based smart contract is briefly discussed in [39]. The steps involved in the working of smart contracts can be summarized as follows:

1) *Agreement:* The first step required to create a smart contract is for all parties involved to reach a consensus on the terms of the contract.
2) *Coding:* Once the contract terms are agreed upon, the next step is to encode them into the smart contract using a programming language such as Solidity.
3) *Deployment:* The smart contract is then deployed to the blockchain network. This step involves paying the network a fee, known as gas, to execute the contract.
4) *Execution:* The smart contract is now live on the blockchain and can execute automatically when certain conditions are met. These conditions are programmed into the contract and are triggered by specific actions or events.
5) *Verification:* As the smart contract executes, each step is verified by the nodes on the blockchain network. This ensures the contract is executed correctly and the terms are upheld.
6) *Completion:* Once the smart contract conditions are met, the contract automatically executes, and the outcome is recorded on the blockchain. This outcome can be anything from the transfer of funds to the delivery of goods.

C. NON-FUNGIBLE TOKENS (NFTS)

Non-fungible is an economic term describing things like songs, educational certificates, art, etc. These things cannot be exchanged with other items because of their unique properties. On the other hand, fungible items can be traded because their values define them rather than their unique properties. NFTs are built on blockchain technology, a distributed, immutable ledger that stores data in peer-to-peer network of decentralized nodes. The nodes that upkeep the ledger, examine fresh transactions, and create new blocks are called *miners*. Each NFT contains a unique identifier stored on the blockchain, verifying its authenticity and ownership. NFTs have been quite popular recently, and they may serve as digital certificates to demonstrate asset ownership [40]. Transferring ownership of a physical or digital thing into a digital token is known as *asset tokenization*. Additionally, NFT owners may easily trade their tokens by transferring ownership from their accounts to the buyer's. A token is often an item that symbolizes something and may represent a wide range of physical and digital assets. Examples include certificates, artwork, digital collectibles, and factual representations. ERC-20, ERC-721, and ERC-1155 define the rules for creating and maintaining Ethereum NFTs.

Digital collectibles are the most well-known and prominent NFT applications. The authors in [41] discuss creating

a digital collectible for wildlife using NFTs. The objective is to sell NFTs to tourists in return for money to support animal conservation initiatives. However, there are other use cases for NFTs than digital collectibles. For example, NFTs can also be used in Real estate, which may aid in accelerating the real estate transaction and promoting transparency in real estate auctions since all bidders may see every bid against a property. In December 2020, Jack Dorsey, CEO of Twitter, created an NFT from his first-ever Twitter post that sold for $2.9 million. The prominent auction house Christie's sold a digital collage named "Every Day - the First 5,000 Days" for $69 million [6], [42], [43]. The rise of NFTs has been driven partly by their innovative potential for creators to earn money from their digital works. Another factor contributing to its increased acceptance is its ability to provide a safer and more transparent method of storing and transferring ownership of digital items.

1) EVOLUTION OF NFTS

NFTs were incorporated into blockchain technology to address the challenge of creating and managing unique digital assets.

Before the advent of NFTs, digital assets such as art, music, and videos were difficult to prove ownership and value of. NFTs allow the creation of unique digital assets, whose ownership and authenticity can be easily verifiable through blockchain technology. This opens up a whole new world of possibilities for creators and collectors, enabling them to monetize digital assets in ways that were not previously possible. NFTs have also introduced new blockchain applications beyond just currency and have sparked a new wave of interest in the technology. The evolution of blockchain technology from RFID to NFTs is fascinating and spans over a decade of innovation and experimentation. The following is a brief overview of how this evolution took place:

RFID (Radio Frequency Identification) technology was first developed in the 1980s to track inventory and assets using radio waves. The technology became popular in the early 2000s, and businesses began using RFID tags to track their products and assets [44]. In 2009, a new technology called Bitcoin was developed, which used blockchain technology to create a decentralized digital currency. Blockchain is a distributed ledger technology that makes it possible to record and trace transactions safely, transparently, and immutably. In 2014, Ethereum, a blockchain-based platform, was developed, introducing the notion of smart contracts that execute themselves and have the conditions of the agreement written in code. This allowed developers to build decentralized applications (Dapps) on top of the Ethereum blockchain, enabling a whole new range of use cases for blockchain technology beyond just currency. One of the early use cases for blockchain technology was to create digital tokens that could represent assets such as stocks, commodities, and even real estate. These tokens could be traded on blockchain-based marketplaces, allowing for greater liquidity and accessibility to these assets.

In January 2018, a new type of token called an ERC-721 token was introduced on the Ethereum blockchain. Unlike traditional interchangeable cryptocurrencies, these tokens, also known as non-fungible tokens (NFTs), were unique and indivisible. NFTs allowed for creating and trading unique digital assets, such as artwork, music, and other forms of media. In the later half of 2018, the ERC-1155 token standard was introduced which addressed the limitations of previous token standards like ERC-721 and ERC-20. Its ability to support multiple token types and multiple assets within a single smart contract reduced the complexity and costs associated with deploying multiple contracts. Since then, NFTs have become a major trend in blockchain, with high-profile digital art sales and other unique items fetching millions of dollars. NFTs have opened up a whole new world of possibilities for creators and collectors alike, enabling the ownership and monetization of digital assets in ways that were not possible before. Timeline of some key events in the development of NFT technology is shown in Fig. 2. The distinctive features NFTs possess that set them apart in the realm of digital assets are discussed below.

2) FEATURES OF NFTS

NFTs possess distinct characteristics that set them apart from other types of digital assets and grant them versatility for various purposes. NFTs possess various features as shown in Fig. 3.

1) *Unique:* Each NFT is unique and cannot be replaced or replicated. This allows for creation of one-of-a-kind digital assets that can be verified and tracked.
2) *Ownership:* NFTs use blockchain technology to record and track ownership, which allows for the token's ownership transfer in a secure and verifiable way.
3) *Interoperability:* NFTs are created using blockchain technology, making it possible for them to be easily integrated with other blockchain-based platforms and applications, making them more versatile and useful.
4) *Decentralized:* NFTs are built on decentralized blockchain technology, which ensures that they are not controlled by any central authority, making them more secure, transparent, and resistant to censorship.
5) *Immutable:* All NFT transactions and ownership information are stored on an immutable blockchain ledger, which cannot be altered or deleted.
6) *Programmable:* NFTs can be programmed to include rules and restrictions that govern how the asset can be used or transferred, giving creators more control over their digital assets.
7) *Verifiability:* Minting, transferring, or burning NFTs are all transactions permanently stored on the blockchain; therefore, the full history of an NFT can be verified.

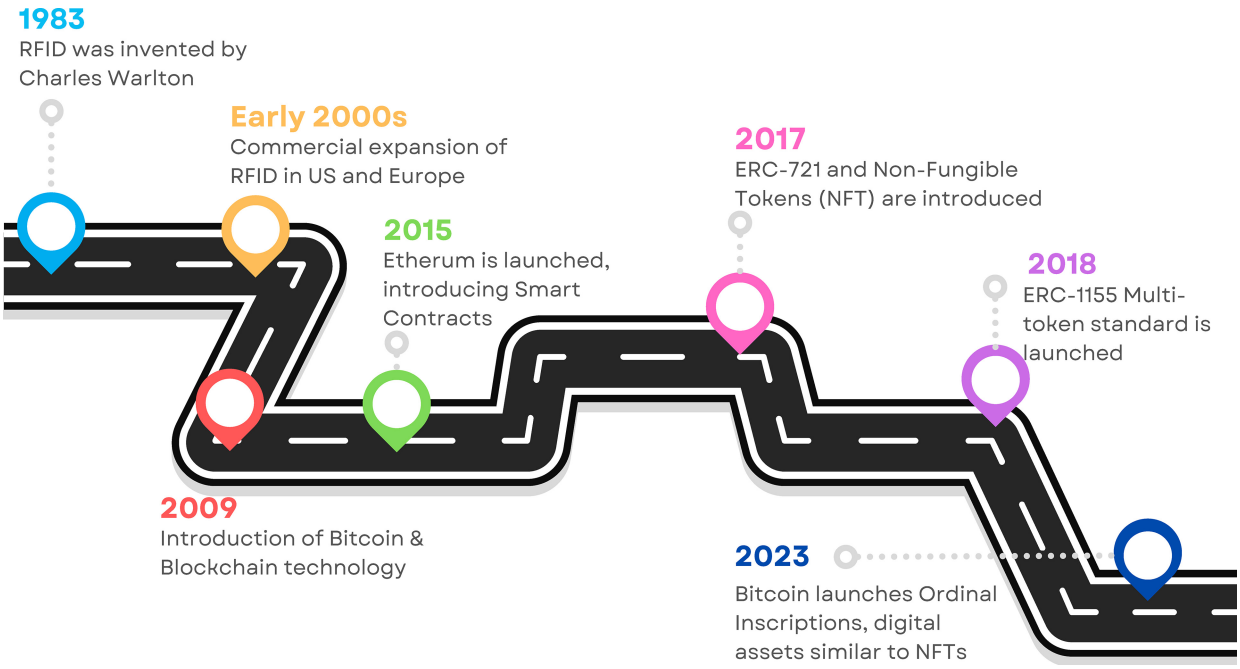

FIGURE 2. Timeline of some key events in the development of NFT technology.

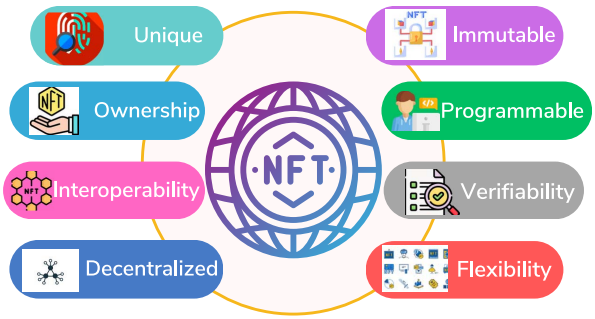

FIGURE 3. Features of NFTs.

8) *Flexibility:* A wide variety of digital assets, such as virtual real estate, music, films, and art, may be represented by NFTs.

NFTs possess various characteristics that make them highly beneficial for facilitating digital ownership, authentication, and financial gain. As a result, they hold the potential to significantly transform various industries and enhance people's perceptions of ownership and value in the digital realm. NFTs consist of various components that are briefly discussed below.

3) MAIN COMPONENT OF NFTS

NFTs are digital assets that utilize blockchain technology, particularly the Ethereum blockchain, to ensure uniqueness, verification, and immutability. The typical framework of NFTs includes various components.

1) *Token ID:* Each NFT has a unique token ID that serves as a digital fingerprint and allows for identifying the specific token.
2) *Metadata:* NFTs typically include metadata that provides information about the token, such as a description, image, or other relevant details.
3) *Smart Contract:* When specific criteria are satisfied, a smart contract will automatically run and carry out its intended function. Digital contracts regulate token ownership and exchanges in NFTs. This smart contract encodes the rules and guidelines that define the token and its specific properties.
4) *Ownership:* NFTs use blockchain technology to record and track token ownership. After creating an NFT, it is assigned to an initial owner, and the ownership can be transferred to other parties through a process called minting.
5) *Token Standard:* NFTs use token standards like ERC-721 and ERC-1155 to define their structure and behavior. These standards specify the required functions and events for the smart contract. These standards also provide a common interface for interacting with the token.
6) *Gas fee:* Each transaction on the Ethereum blockchain requires a small fee called gas. This fee incentivizes miners to process the transaction and is required for minting, transferring, and interacting with NFTs.

NFTs are unique digital assets representing anything from digital art, collectibles, virtual real estate, and more. The structure of NFTs allows for the creation of a digital asset that can be easily verified, tracked, and transferable, making

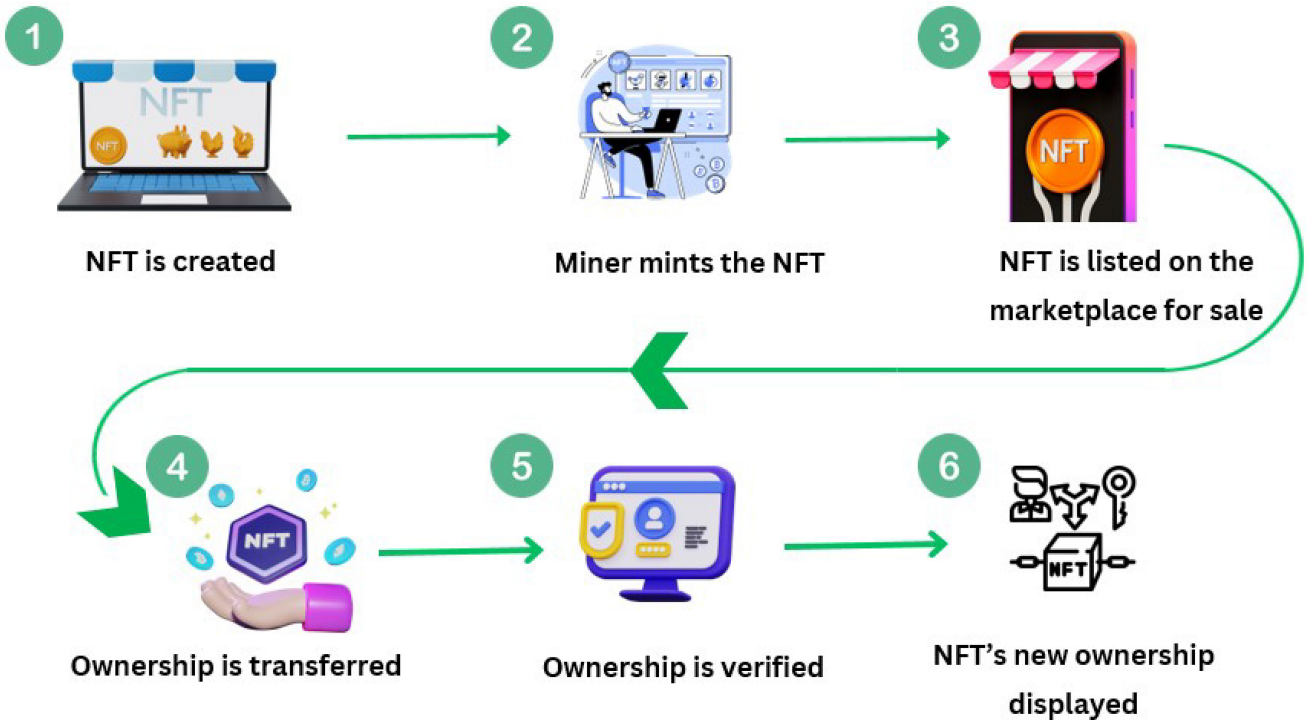

FIGURE 4. Workflow of NFTs.

it a valuable tool for digital ownership, verification, and monetization.

4) WORKFLOW OF NFTS

The workflow for creating and using NFTs typically involves the following steps as shown in Fig. 4:

1) *Creation:* An individual or organization creates a unique digital asset, such as a piece of artwork or a collectible, and adds metadata to it, such as a description and a unique identifier.
2) *Minting:* The creator mints the NFT on a blockchain by adding the digital asset and its metadata to the blockchain and issues a unique digital token representing ownership of the asset.
3) *Sale or trade:* The NFT can be bought, sold, or traded on a marketplace supporting NFTs. These marketplaces are typically built on top of a blockchain, such as Ethereum.
4) *Transfer of ownership:* When the NFT is sold, the ownership of the digital token is transferred to the buyer from the seller on the blockchain.
5) *Verification of ownership:* The ownership of the NFT can be easily verified by viewing the digital token on the blockchain and checking its transaction history.
6) *Use or display:* The new owner can use or display the NFT as they see fit, subject to the creator's restrictions.

5) MINTING PROCESS OF AN NFT

Minting an NFT is the process of writing a digital item to the blockchain. This proves its unchangeable record of ownership and legitimacy. The digital token is stored in a decentralized database or distributed ledger that cannot be changed, altered, or removed. The steps involved in the minting process are as follows:

1) The user initiates the NFT minting process from the client application by requesting to create an NFT.
2) The miner validates the request.
3) If the request is valid, the minting service utilizes the blockchain to generate the NFT token.
4) The blockchain confirms the generation of the NFT token and sends a response to the miner.
5) The miner then generates the NFT metadata by interacting with the metadata services.
6) The metadata service confirms the generation of the NFT metadata and sends a response to the miner.
7) The miner stores the NFT metadata on the blockchain.
8) The blockchain confirms the storage of the NFT metadata and sends a response to the miner.
9) The miner notifies the client application about the successful minting of the NFT, or if the request is invalid, it notifies the client application about the failure.
10) The creator requests to list the minted NFT on the NFT marketplace.
11) The NFT marketplace confirms the listing of that NFT.

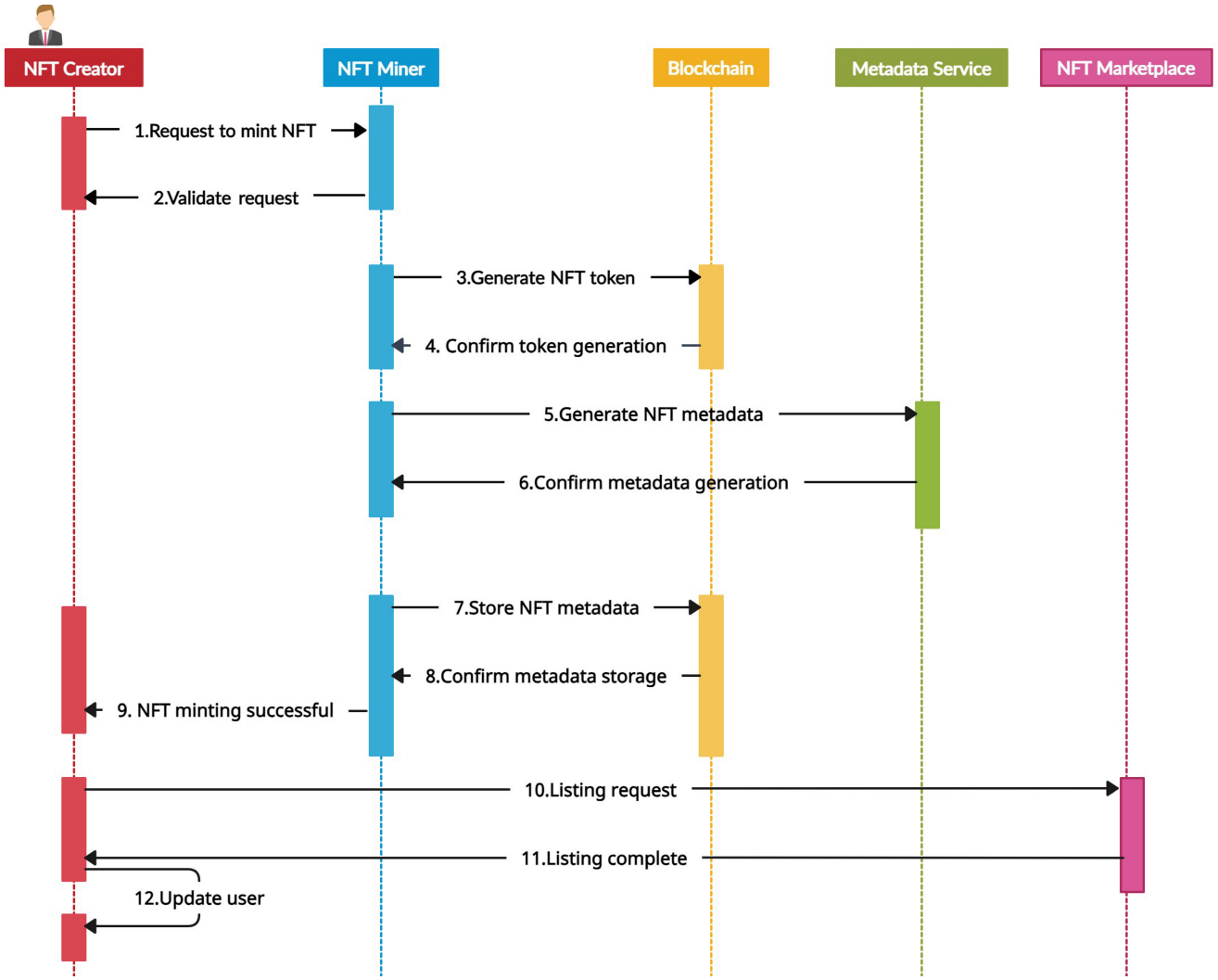

FIGURE 5. Minting process of an NFT.

12) Finally, the creator gets notified about the successful listing of NFT. The NFT minting process is explained in Fig. 5.

III. TOKEN STANDARDS FOR ETHEREUM BLOCKCHAIN

Token standards refer to a set of rules and specifications that define how a particular type of token, such as a non-fungible token (NFT), should be created, stored, and transferred on a blockchain network.

In the context of NFTs, several token standards have been developed to ensure interoperability and compatibility between different NFT platforms and applications. The most popular NFT token standards include ERC-721, ERC-1155, TRC-721 (TRON Blockchain), and BEP-721 (Binance Smart Chain). The comparison of ERC-20, ERC-721, and ERC-1155 is shown in Table 2. These token standards provide a common framework for developers and users to create, manage, and exchange NFTs across different blockchain networks. By adhering to these standards, NFTs can be easily transferred and traded without the need for complex customization or modifications. The following subsection gives a brief account of the different token standards that are used for NFT creation.

A. ERC-20

A technical standard called ERC-20 [45] is applied to smart contracts on the Ethereum network. The majority of tokens on the Ethereum network comply with ERC-20, making it one of the most extensively utilized token specifications. ERC-20 defines a set of rules that must be followed by any token that uses the standard to ensure compatibility with other Ethereum-based applications and services. Some of the key features of the ERC-20 token standard are:

1) *Basic functionality:* ERC-20 tokens must implement a basic set of functions, including the ability to transfer tokens from one address to another, get the current token balance of an address, and approve another address to spend tokens on behalf of the token owner.
2) *Token supply:* The total supply of an ERC-20 token must be fixed and predetermined. This means that no

TABLE 2. Comparison of ERC-20, ERC-721 and ERC-1155 token standards, adapted from [48].

Criteria	ERC-20	ERC-721	ERC-1155
Ease of Use	Individual transactions and a common smart contract are required.	Individual transactions and smart contracts are required for each token type.	A single smart contract can support multiple functions.
Batch Transfers	Allows batch transfers	No support for batch transfers.	Allows use of a single smart contract for batch transfers.
Support for Semi-Fungible Tokens	Only supports creation of fungible tokens.	Only supports creation of non-fungible tokens.	Supports the conversion of fungible tokens to NFTs and vice-versa.
Security of Assets	Does not have an inbuilt transaction verification system.	Impossible to revert transactions after transferring assets to the wrong address.	Safe transfer function enables verification of transaction validity and allows reversal of transactions.
Know Your Customer (KYC) Verification	No KYC required	In-built KYC and Anti-Money Laundering system	In-built KYC and Anti-Money Laundering system
BME(burn-and-mint) Model	Not Available	Available	Available

more tokens can be minted or burned once the tokens are created.

3) *Token division:* ERC-20 tokens can be divided into smaller units, commonly called "decimals." This allows for greater flexibility in the value of the tokens and makes them easier to use in everyday transactions.
4) *Token ownership:* ERC-20 tokens are owned by Ethereum addresses, which are controlled by private keys. These private keys must be kept secure to prevent unauthorized token access.
5) *Token transfers:* ERC-20 tokens are transferred between addresses using the transfer function, which takes the recipient's address and the number of tokens being transferred as inputs. The transfer function must check that the sender has enough tokens to make the transfer and then update the balances of both the sender and recipient accordingly.
6) *Token approvals:* ERC-20 tokens can be approved for spending by another address using the approve function. This is commonly used in applications such as decentralized exchanges, where users must give permission for the exchange to spend their tokens on their behalf.
7) *Events:* ERC-20 tokens can emit events when specific actions occur, such as a transfer or approval. These events can be used by other smart contracts to trigger additional actions.

By following the ERC-20 standard, tokens can be easily traded and used in a wide range of Ethereum-based applications and services. This has helped to create a vibrant ecosystem of decentralized finance (DeFi) applications, where users can trade and lend tokens in a trustless and decentralized manner. The drawback of ERC-20 standards is that they can only be used to represent fungible tokens. It means no special ownership functions can be allocated. This led to the development of another token standard, i.e., ERC-721, which is non-fungible.

B. ERC-721

ERC-721 [46] is a non-fungible token standard on the Ethereum blockchain that enables the creation of unique digital assets that are easily verifiable, provably scarce, and indivisible. This standard defines a set of rules and interfaces that NFTs must follow to be compatible with other applications and platforms. The ERC-721 provides a standard API for NFT smart contracts and publicizes mandatory and optional interfaces [47].

The ERC-721 standard is designed to enable the creation and management of these assets in a secure and standardized way. Some key features of the ERC-721 standard include:

1) *Ownership:* Each NFT is owned by a specific Ethereum address and can only be transferred to another address through a specific transfer function.
2) *Non-Fungibility:* NFTs are unique and cannot be exchanged one-to-one like fungible tokens.
3) *Metadata:* Each NFT can have associated metadata, such as a name, description, image, or other data that describes the asset.
4) *Indivisibility:* NFTs cannot be divided into smaller units like fungible tokens.
5) *Immutable:* After an NFT is created, its properties cannot be altered, ensuring its authenticity and scarcity.
6) *Interoperability:* NFTs can be used in various applications and platforms that support the ERC-721 standard, enabling seamless integration and transferability of assets.

The ERC-721 standard has been widely adopted by various platforms and applications, including art marketplaces, gaming platforms, and virtual real estate platforms. It has enabled the creation and transfer of unique digital assets in a secure, standardized, and interoperable manner, paving the way for new use cases and innovations in the blockchain ecosystem.

C. ERC-1155

On the Ethereum blockchain, a multi-token standard called ERC-1155 was released in 2018 [49]. This is an extension to the ERC-721 non-fungible token (NFT) standard which allows the creation of both fungible and non-fungible tokens on the same contract.

In contrast to the ERC-721 standard, where each token is unique and has its own smart contract, the ERC-1155 standard allows for the creation of a single smart contract that can hold an unlimited number of tokens, both fungible and non-fungible. This makes it more efficient and cost-effective to create and manage multiple tokens on the Ethereum blockchain.

The ERC-1155 standard defines a set of functions that must be implemented by the smart contract to ensure compatibility and interoperability with other contracts and applications on the Ethereum network. These functions include:

1) *balanceOf:* This function returns the balance of a particular token owned by a specific account.
2) *balanceOfBatch:* This function returns the balance of multiple tokens owned by a specific account.
3) *setApprovalForAll:* This function allows an account to give permission to another account to transfer all of its tokens on its behalf.
4) *isApprovedForAll:* This function returns whether an account has been granted permission to transfer all tokens on behalf of another account.
5) *safeTransferFrom:* This function allows for the safe transfer of tokens from one account to another, preventing the loss or theft of tokens.
6) *safeBatchTransferFrom:* This function allows for the safe transfer of multiple tokens from one account to another.

The ERC-1155 standard also includes additional features such as batch transfers, which allow for the transfer of multiple tokens at once, reducing transaction costs and increasing efficiency.

Overall, the ERC-1155 standard provides a more flexible and efficient way to create and manage tokens on the Ethereum blockchain, making it an attractive option for developers and users who require a more complex token ecosystem.

D. BRC-721E

The BRC-721E token standard is a new token standard that allows users to transfer non-fungible tokens (NFTs) based on Ethereum to NFTs based on the Bitcoin network. It is meant to connect the Ethereum and Bitcoin networks by letting clients change ERC-721 NFTs to BRC-721E tokens on Bitcoin. This token standard is based on the Bitcoin ordinals protocol, which is comparable to the BRC-20 token, and was designed specifically for NFTs in which BRC-20 standards could not be adopted. Using Bitcoin ordinals, the BRC-721E token standard acts as a bridge between the Ethereum and Bitcoin blockchain networks. Although it is still in its early phases of development, its use is projected to boost the popularity and adoption rate of Bitcoin ordinals. It enables Ethereum-based NFT holders to burn their tokens and inscribe them on the Bitcoin network.

IV. APPLICATIONS OF NFTS AND MARKET OPPORTUNITIES

NFTs have exploded in popularity in recent years. NFTs market size was valued at $16 billion and is poised to grow from $21.39 billion in 2022 to $212 billion by 2030, growing at a compound annual growth rate (CAGR) of 33.7% in the forecast period (2023-2030). The market opportunities in NFTs are vast and varied, with a growing number of industries exploring the potential applications of this technology. The various real-world sectors where NFT technology can be adopted are discussed in the following section.

A. IDENTITY VERIFICATION

In [50], the authors propose using NFTs to verify identity. Each individual would be assigned a unique NFT, which could be used to verify their identity in various contexts, such as accessing government services or opening a bank account. This could significantly improve privacy and security for individuals and create a more efficient means of identity verification.

B. SMART CITIES AND GOVERNANCE

In [51], the authors explore the use of NFTs in smart cities and governance systems. By creating unique NFTs for each citizen, blockchain-based voting systems can provide greater security and transparency in the voting process. NFTs can also represent ownership of governance tokens, allowing stakeholders to participate in decision-making processes for decentralized organizations. Blockchain, which is transparent, immutable, and secure, is used to store unique NFTs of citizens and assets in the proposed smart economy systems. Therefore, participants can examine the history and authenticity of the listed NFTs. NFTs can potentially resolve the security and trust issues in existing peer-to-peer economic systems due to these inherited features from blockchain technology. This section discusses the different applications of smart cities that can benefit from NFTs' adoption.

1) REAL ESTATE

NFTs are also used to create unique virtual real estate, such as virtual land or buildings, which can be bought and sold

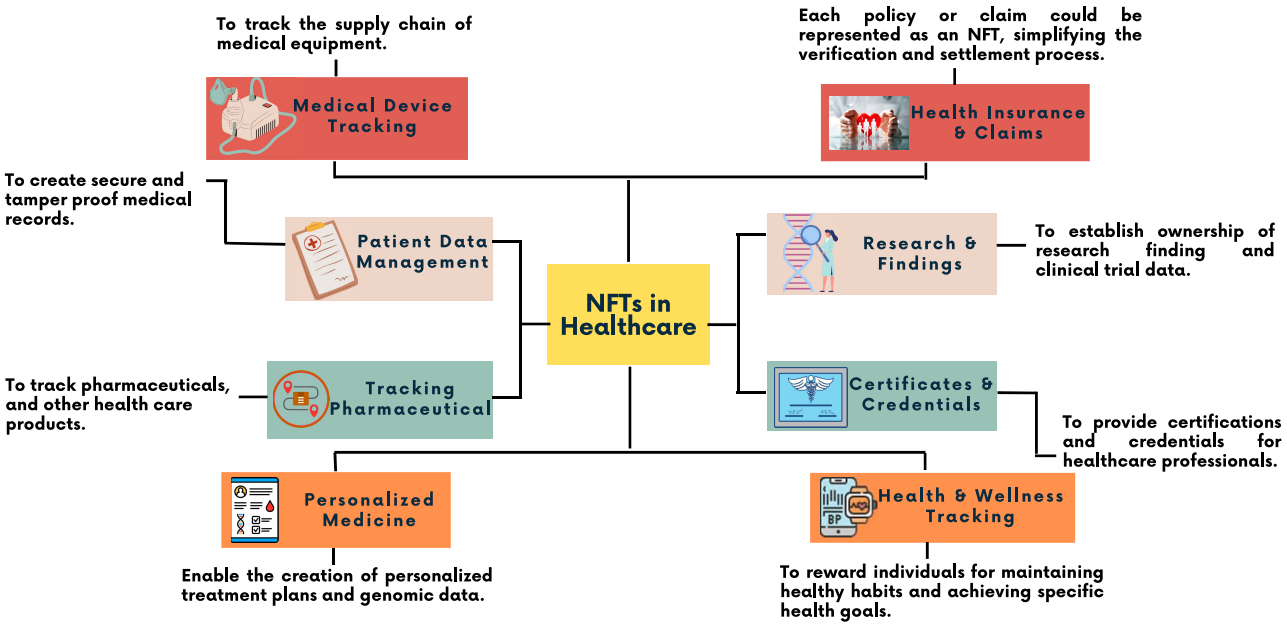

FIGURE 6. NFTs opportunities in healthcare.

like physical real estate. The author in [52] explores using NFTs to represent ownership of real estate assets. Asset finality is established by tokenizing real estate assets and encrypting data, and a digital proof of ownership is created. The NFT registers real estate static and dynamic information for trading in the data marketplace among various consumers and stakeholders, including investors, occupants, insurers, and property managers. The information recorded in the NFT includes real estate deeds, transactions, and mutable parameters.

2) DSCOT

Decentralized Smart City of Things (DSCoT) [53] is a private blockchain architecture that uses blockchain tokenization, i.e., NFTs, to identify and validate user and IoT assets uniquely. The suggested architecture guarantees unique asset representation by using smart contracts for IoT assets and user authentication. The suggested functions and components have performed well when evaluated regarding time complexity and gas usage. The proposed change is efficient regarding time complexity and gas price since the new set of functions to query the smart contract for the status of assets in the NFT registry does not incur any transaction fees. This architecture uses Blockchain and SHA-III encryption mechanisms to provide a safe and effective smart city solution with robust security features.

3) E-VOTING

Yavuz et al. [54] explore the possibility of developing a trustworthy electronic voting system by using blockchain technology and, more significantly, Ethereum. With its distributed and secure nature, blockchain technology can address many issues associated with traditional e-voting systems. They propose using smart contracts on the Ethereum platform to develop a trustworthy Electronic Voting System. Traditional paper-to-box voting systems have many problems, including a lack of transparency and the potential for corruption. E-voting systems have been studied extensively, but few implementations are reliable enough for official elections. The authors in [54] developed a prototype e-voting app using Ethereum wallets and Solidity programming language. The Ethereum blockchain stores ballots and votes after an election. Users can submit their ballots from an Android device or Ethereum wallet. Every node on the blockchain uses consensus protocols to process these transaction requests. This paper presents a compelling argument for using blockchain technology to create a secure and transparent e-voting system.

C. HEALTHCARE

NFTs have been proposed as a potential tool for various healthcare applications as shown in Fig. 6. The use cases of NFTs in Healthcare from recent literature are as follows:

1) PATIENT DATA MANAGEMENT

Bharath et al. [55] discusses the issues with the conventional system of patient-data management, which stores stored as unstructured physical records on paper prescriptions, files, and other traditional forms of storage, which are prone to redundancy, degradation, and loss of record. The authors propose using blockchain technology to manage patient data into a single record owned by the patient. This would allow for better transparency and ownership of sensitive data, thereby promoting and transforming the healthcare industry.

Conventionally, centralization of information meant that every healthcare provider and the hospital has to maintain all information about the patient records on their premise, that is, the locally maintained storage and databases. The authors conclude that electronic health records (EHR) using blockchain is a revolution in the medical industry that can significantly minimize the time and effort expended in managing patient data with effective and efficient results. They argue that it solves most challenges today because of trust in the medical sector. It provides a reliable patient data exchange platform and a faster and more flexible system. By assigning a unique NFT to each patient, healthcare providers and researchers could track the ownership, usage, and history of patient data while ensuring patient privacy and security.

2) MEDICAL DEVICE TRACKING

Data integrity, finality, traceability, and transparency are some of the challenges associated with the data of medical devices used in healthcare supply chains. As they pose a substantial threat to the safety of their consumers, counterfeit devices are a significant challenge that the healthcare industry is attempting to eliminate. Existing systems adhere to a centralized architecture which is prone to total failure or outage of the systems and eliminates transparency and verifiability. The proposed solution relies on non-fungible tokens (NFTs), smart contracts, tokenization protocols, and a decentralized storage system to ensure reliable and effective medical device traceability. In this system, NFTs represent the medical device's digital counterpart. This digital twin collects important information about a medical device throughout its entire life cycle, from production to distribution, current usage, and ownership. This NFT-based solution provides a dependable and efficient method for tracking and managing the ownership of medical devices throughout their life cycle. This system addresses the difficulties associated with data integrity, provenance, traceability, and transparency in healthcare supply chains through smart contracts and a decentralized storage system.

3) TRACEABILITY OF PHARMACEUTICAL SUPPLY CHAIN

Chiacchio et al. [56] proposes the NFT track and trace prototype solution's design and implementation, which consists of a progressive Web Dapp (decentralized application), a blockchain server integrated with the serialization manager for inventory and an NFT smart contract deployed on the VeChain Thor blockchain. The unique benefits of this approach are:

- Transparency: The NFTs provide a digital twin of the serialized products, allowing for the tracking and tracing of their history and status along the distribution network from the manufacturer to the final client.
- Quality control: Traceability offered by NFTs can contribute to the quality and safety of pharmaceutical products by enabling the identification and prevention of issues such as tampering, contamination, counterfeiting, and fraud.
- Regulatory compliance: The traceability provided by the NFTs can help to comply with regulatory requirements for serialization and track-and-trace in the pharmaceutical sector, such as the EU directive 2011/62/EU.
- Recall management: The traceability provided by the NFTs can facilitate the recall management process by allowing for identifying and retrieving specific batches or units of products that may be affected by a quality or safety issue.

4) PERSONALISED MEDICINE

NFTs, which enable the safe and regulated exchange of patient genomic data, have the potential to revolutionize personalized treatment. NFTs guarantee the validity and ownership of genomic data while reducing worries about data integrity and trust by tokenizing genomic information as distinct digital assets. With NFTs, patients may use smart contracts to govern precisely who has access to their data, improving privacy and consent administration. By encouraging cooperation between healthcare professionals and researchers, this restricted sharing method using blockchain technology accelerates the identification of diseases and personalized treatment approaches [57]. Healthcare professionals may use the tokenized genomic data of patients to create personalized treatment plans, choose the best medications, and reduce unpleasant responses. Large-scale genomic investigations may be fueled by the collection and anonymous exchange of tokenized genomic data, which might promote precision medicine and better disease diagnoses.

5) HEALTH INSURANCE AND CLAIMS

Processes related to health insurance and claims, including several parties, documentation, and verification requirements, may take time and effort. By tokenizing insurance plans and claims, NFTs can accelerate these procedures, benefiting patients, healthcare professionals, and insurers. The specific conditions of an insurance policy may be safely saved and quickly verified on a blockchain by representing them as NFTs [58]. As a result, manual verification procedures are no longer necessary, and administrative costs for insurers are decreased. Using the NFT linked to the patient's policy, a healthcare professional may swiftly confirm his insurance coverage when the patient visits him. The practitioner and the patient benefited by saving time and increasing the productivity of this simplified verification procedure. Payment of insurance claims may be made simpler by tokenizing them as NFTs. A patient's claim may be tokenized as an NFT that includes relevant data like the specifics of the therapy, the cost, and any necessary supporting materials. The insurer may securely receive the NFT and use the data included in the token to speed up the verification and decision-making processes for the claim. With less manual paperwork and back-and-forth communication needed in the claims process, healthcare providers may be paid more quickly, and patients' financial burdens may be reduced.

Transparency and immutability are also brought through using NFTs in health insurance and claims procedures. Because blockchain is decentralized, it guarantees that the data held in NFTs cannot be changed or tampered with, giving a trustworthy and auditable record of policies and claims. This maintains the integrity of the whole process and aids in preventing fraud.

6) RESEARCH AND FINDING

Establishing ownership, provenance, and monetization of research discoveries, intellectual property (IP), and clinical trial data is made possible by NFTs. Researchers may build a verifiable record of their work and open up new opportunities for rewarding and commercializing their discoveries by tokenizing discoveries, research papers, and other scientific contributions as NFTs. Research results and intellectual property may be tokenized as NFTs to provide a distinct and unchangeable record of ownership. Each NFT is a unique research output or intellectual property asset safely stored on a blockchain. By doing so, open and immutable evidence of ownership is established, prohibiting misuse or unauthorized use of the work [58]. Researchers' capacity to safeguard and defend their intellectual property is improved by their ability to assert their ownership rights and provide a trustworthy digital record of their contributions. NFTs also make it possible to trace the origin of research and intellectual property. Blockchain technology's decentralized structure ensures that an NFT's complete history, including its creation, ownership changes, and related information, is openly recorded. In areas where trust and repeatability are crucial, like scientific research and academic publication, this enables researchers to show the provenance and legitimacy of their work.

7) CERTIFICATES AND CREDENTIALS

NFTs are a viable approach for delivering safe and verified certificates and credentials. Healthcare professionals may have a digital record of their continuous education and training by tokenizing their credentials and credits as NFTs. This will simplify sharing and confirming their credentials with employers, regulatory organizations, and other essential stakeholders. The validity and integrity of data are guaranteed by tokenizing credentials as NFTs. Each NFT is a tamper-proof and verifiable record of a healthcare professional's educational credentials [59]. NFTs may lower the danger of falsified or fraudulent credentials, improving the verifier's ability to rely on them. Healthcare workers may readily share their credentials with employers, licensing bodies, and other parties safely+ that need verification by storing their NFT-based certificates in a digital wallet. This simplifies the qualification verification and review process, saving time and effort for all the participants in the verification process.

8) HEALTH AND WELLNESS TRACKING

NFTs provide an exciting way to encourage and reward people for developing, maintaining, and accomplishing healthy behaviors and objectives. A verifiable and transferable record of an individual's accomplishments may be created by tokenizing health and wellness data as NFTs and collecting it through wearable technology or health applications. These NFTs may then be exchanged or redeemed for other prizes, encouraging people to adopt healthy lifestyle practices. Creating a digital record certifying a person's efforts and development is possible by tokenizing health and wellness data as NFTs. For instance, wearable or health-tracking software may gather information on exercise habits, sleep patterns, diet, or other health parameters. This information may transform into distinctive NFTs that signify specific successes or milestones. The NFTs act as a digital badge, giving verifiable proof of the person's commitment to his wellness and health objectives. These NFTs provide concrete incentives encouraging people to engage in healthy behaviors actively. The benefits range from exclusive access to health-related activities or experiences to savings on medical services, exercise gear, or wellness items. The possibility of exchanging or redeeming these NFTs for worthwhile prizes offers a gamified experience that encourages people to continue with their journey towards wellness and health [60].

D. SUPPLY CHAIN MANAGEMENT

The paper [61] showcases the use of smart contracts in facilitating e-commerce transactions, including order placement and shipment tracking between suppliers and consumers. This is extended in paper [62], in which the authors propose using NFTs to track products and their ingredients throughout their life cycle in the supply chains. Each product is assigned a unique NFT, which records its origin, transportation, and other relevant details. This enables greater transparency and accountability in the supply chain and helps to prevent counterfeiting and other fraudulent activities. As explained in the previous section, this can be used as a supply chain of pharmaceutical drugs and medical equipment [56]. This can also be extended to the supply chain of agricultural goods to track the journey of agricultural products throughout the supply chain, as explained in the upcoming section.

E. GAMING

NFTs are used in the gaming industry to create unique in-game and virtual real estate items. Players can purchase NFTs for particular items, such as weapons or clothing, which can be used in the game or traded on secondary markets. NFTs can enhance the gaming experience by allowing players to own and trade virtual assets outside the game environment. This would create a secondary marketplace for in-game items and could provide players with a new source of income. Some of the applications of NFTs in the gaming industry are listed.

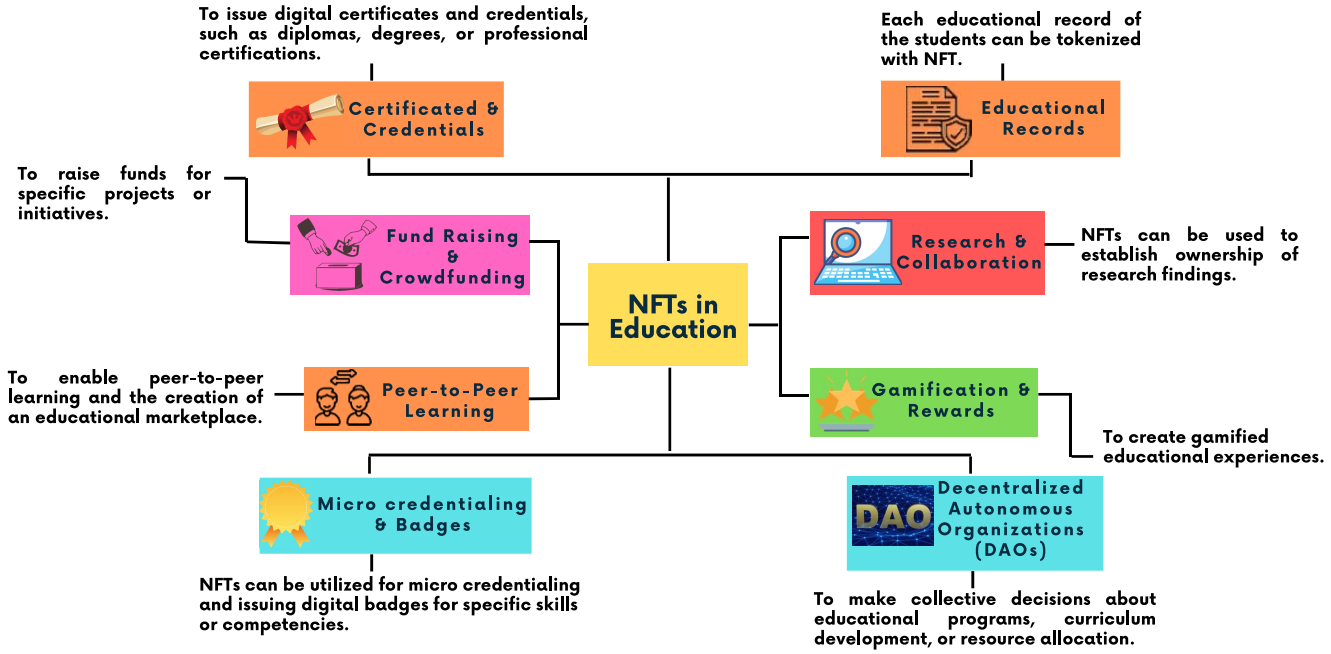

FIGURE 7. NFTs opportunities in education.

1) DEVELOPMENT AND TRADE OF GAME ART

Development and trade of game art as NFTs have been discussed in [63]. NFTs represent considerable opportunities for game developers and the potential for incentivizing game developers and content creators. Using NFTs in games enables players and investors to buy and sell in-game content, creating considerable revenue and interest. NFTs also enable the collection and trading of unique game objects, such as in-game artworks or collectible items. Additionally, NFTs can be used to integrate unique rewards for players or groups.

2) TRADABLE DIGITAL ASSETS IN GAMES

The InterPlanetary File System (IPFS) and NFTs enabled by Distributed Ledger Technologies (DLTs) are used in the paper [64] to create a flexible and decentralized system for exchanging game assets. The proposed solution creates an entirely decentralized system in which novel revenue streams are enabled, as the evolvable game assets can be priced and resold according to their scarcity, and the digital artist can be compensated for the same without needing a trusted third party. The system guarantees that assets will always be accessible on the blockchain without any single point of failure, so users don't risk losing control of their items or value even if the game's developer loses interest or declares bankruptcy.

F. EDUCATION

One key application of NFTs in education is creating and distributing digital certificates and credentials. Traditional paper-based certificates can be easily lost, forged, or damaged, leading to potential issues in verifying one's educational achievements. NFTs can revolutionize how educational content is created, distributed, and monetized. Educators and content creators can tokenize their educational materials, such as e-books, lesson plans, or online courses, as NFTs. These NFTs can be a form of attribution, recognition, and collaboration, fostering a culture of trusted and safe knowledge sharing and innovation within educational communities. NFTs have immense potential to enhance the various aspects of the education industry shown in Fig. 7 and discussed in the following section.

1) EDUCATIONAL RECORDS AS NFTS

The candidates' authenticity about their credentials and knowledge is susceptible to numerous defects, like establishing their credibility. Degree and certificate forgery is one such example. This also affects hiring decisions, as companies cannot validate a candidate's competency. The authors in [65] propose a decentralized education model that utilizes blockchain technology. Students' educational credentials are cryptographically hashed and stored as NFTs, uniquely identifying each educational record on the blockchain. It is proposed to use IPFS (Interplanetary File System) to store original data and return a unique Content Identifier (CID), which can be used to access educational records.

2) CERTIFICATES AND CREDENTIALS

The authors in [59] present a solution for the problem of certificate packaging by using blockchain, smart contracts, and NFTs. Several colleges are using NFTs for certification and working in remote learning environments. Duke University is one such instance that has accepted NFTs as proof of education for its Master of Engineering in Financial

Technology program [66]. The solution aims to preserve the authenticity of certificates and prevent counterfeits from being affiliated with them. The solution works by converting certificates into e-certificates created as NFTs, which can be used as a transaction method between recipients of the certificates and issuing organizations. Creating a soft copy of certificates can aid in mitigating the issue of certificates getting damaged. The e-certificate can be constructed using a PDF as its document format. The proposed solution uses smart contracts to store e-certificate data on a blockchain network effectively. The blockchain solution developed with *Solana* [67] is ideal for the proposed system as it offers a wide range of smart contract applications and consistency.

3) FUND RAISING AND CROWDFUNDING

NFTs can revolutionize fundraising and crowdfunding in the education industry. Educational institutions like schools and universities can leverage NFTs to raise funds and engage their communities. Institutions may delight and cherish their supporters by issuing limited-edition NFTs that symbolize rare opportunities, access to prestigious events, or extraordinary experiences [68]. These NFTs may be auctioned, enabling anyone to place bids and buy highly desired physical items or digital assets. Institutions may also provide limited-edition digital items like music or artwork as NFTs, giving fans one-of-a-kind digital collectibles. Alumni engagement can be fostered by recognizing and appreciating donors through NFTs, showcasing their contributions to the institution. Through NFTs, collaborative fundraising initiatives involving students and faculty may also be supported, strengthening community connections. In addition to collecting funds, NFT-based fundraising fosters a feeling of belonging and participation among supporters, demonstrating the institution's dedication to innovation and community involvement.

4) PEER-TO-PEER LEARNING

NFTs have the potential to enhance peer-to-peer learning experiences by providing unique benefits and incentives. Learners may use NFTs to trade knowledge with their peers by producing tokens that signify their proficiency in specific fields or abilities. These NFTs help learners become respected experts in the peer-to-peer learning community by establishing their credibility and recognition. NFTs may also operate as rewards for teamwork, with students receiving tokens for contributing actively, offering feedback, or helping a fellow student [69]. These collectible tokens may be exchanged for other items or used to open up new learning opportunities, increasing incentive and engagement.

5) MICRO-CREDENTIALING AND BADGES

Micro-credentialing and badges are additional ways that NFTs are used in education to provide creative methods to identify and highlight specific abilities and accomplishments. NFTs may produce distinctive digital badges that signify attaining specific tasks, abilities, or achievements [69]. These badges connected to particular skills may be kept in wallets and readily sent to companies, educational institutions, or Internet platforms. NFTs also function as verifiable evidence of a person's talents, validating the associated badge's legitimacy and validity by encoding pertinent information inside the token.

6) RESEARCH AND COLLABORATION

NFTs can completely change how people collaborate and are rewarded for contributing to Research and Development (R&D) initiatives. Researchers may establish ownership and fairly compensate contributors by minting NFTs for research results, datasets, or software code. Researchers have historically had trouble claiming ownership and getting credit for their contributions to joint initiatives. Researchers may tokenize their work using NFTs and provide distinct digital tokens for specific research outcomes [70]. A research paper, for instance, might be tokenized as an NFT with the author as the original owner. This ownership may be extended to other coworkers, ensuring each contributor is acknowledged and credited for their contributions.

7) GAMIFICATION AND REWARDS

NFTs provide an effective method for gamifying the educational process and inspiring students with rewards and recognition. Institutions may build a fun, dynamic atmosphere that appeals to students' innate desire for competitiveness and success by incorporating NFT-based incentives into educational platforms or ecosystems [71]. Educational institutions may display virtual badges, trophies, or other digital artifacts that reflect specific accomplishments or milestones using NFTs. For instance, finishing a tough assignment, understanding a complex idea, or getting a good grade on a test might give students unique NFT tokens connected to their achievements.

8) DECENTRALIZED AUTONOMOUS ORGANIZATIONS (DAOS)

Integrating NFTs into educational DAOs, also known as decentralized autonomous organizations, provides numerous valuable educational applications. When DAO and NFT come together, it creates a new form of decentralized avenue and investment source in the market. The DAO in NFT platform development ensures transparency through a distributed decision-making system. It will automate the governance of the NFT marketplaces, where users will take part in deciding the future of the marketplace. By minting these tokens as NFTs, anyone, including students, teachers, and administrators, may engage in decision-making processes and influence educational policy. These tokens serve as ownership and voting rights inside the DAO. NFTs may be utilized in educational DAOs, where participants come together to decide on educational initiatives, curriculum design, or resource distribution [66].

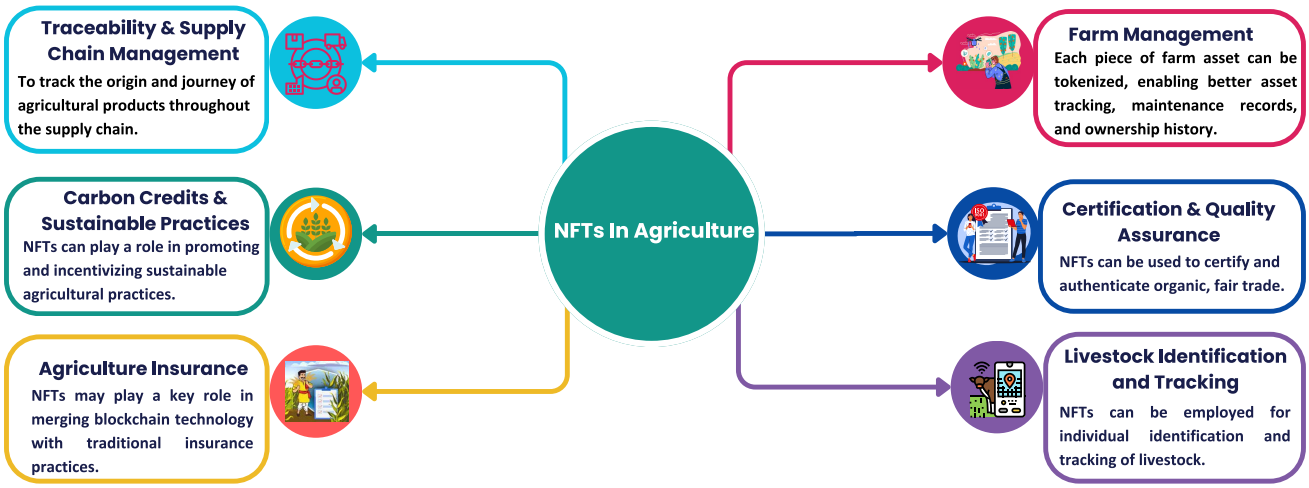

FIGURE 8. NFTs opportunities in agriculture.

G. INTELLECTUAL PROPERTY

1) DIGITAL SOFTWARE LICENSING

Madine et al. [72] explores the use of NFTs to protect the intellectual property rights of software. By creating unique NFTs for each software license, developers can prove ownership and control the distribution of their licenses. This would help developers prevent unauthorized piracy and ensure they are adequately compensated for their work.

2) PATENTS

The authors in [73] explore the development of an NFT-based patent protection system. The system depends on generating an NFT for each patent using a hashing algorithm and storing the hash on a blockchain network with a digital timestamp. The blockchain network can verify the patent's existence and its origin, linking it to its original owner and thereby preserving the organization's contribution. The authors propose using the above system to protect patents as it provides confidentiality and trust in data collection, reporting, and review processes during patent registration.

H. CHARITY AND DONATIONS

NFTs can also be used for charitable purposes. By creating NFTs for charitable donations, donors can track the impact of their contributions and see how their donations are being used. This would create greater transparency and accountability in the charitable sector, helping to build trust between donors and organizations. Fundraising to support various philanthropic causes, such as animal protection, child rights protection, gender equality, and education, is a recent trend involving NFTs. Shaquille O'Neal, a former professional basketball player from the United States, recently raised $2 million for his philanthropic foundation, which assists underprivileged youth through selling his NFTs. Animal enthusiasts can purchase NFTs of their favorite animals while supporting conservation efforts. WildEarth created NFTs for 25 animals in Djuma Game Reserve, South Africa. About 40% of NFT sales go to habitat care, and 8% of trades go to caretakers. The Patchwork Kingdoms is a collection of 1,000 data-driven NFTs introduced in January 2022 by UNICEF, the biggest organization in the world for aiding children with humanitarian and developmental needs. The revenue from the main sale of these NFTs will go towards funding projects like Giga [74].

I. AGRICULTURE

Some of the potential applications of NFTs in agriculture include the following as shown in Fig. 8:

1) TRACEABILITY AND SUPPLY CHAIN MANAGEMENT

Tracking the origin and movement of food products is a common use case for NFTs shown in Fig. 9. This ensures transparency and trust in the supply chain. This could be particularly useful in food-borne illness outbreaks or verifying organic or non-genetically modified (GM) claims [75]. NFTs can represent ownership of unique assets in the food supply chain. The tracking of ownership of food products is done through digital certification, while smart contracts enable seamless trading. In the case of food products, composable NFTs are utilized, representing complementary items like raw materials and packaged products in a hierarchical structure of parent-child relationships. This results in added value within NFTs, mainly when subsets of NFTs are necessary. NFTs can be integrated into supply chains to enable warehouses, manufacturers, and consumers to understand better and refine the product journey. By creating a secure and verifiable supply chain, the utilization of NFTs leads to decreased food waste, improved food safety, and augmented profit margins. It provides consumers with complete transparency and confidence in the food they purchase.

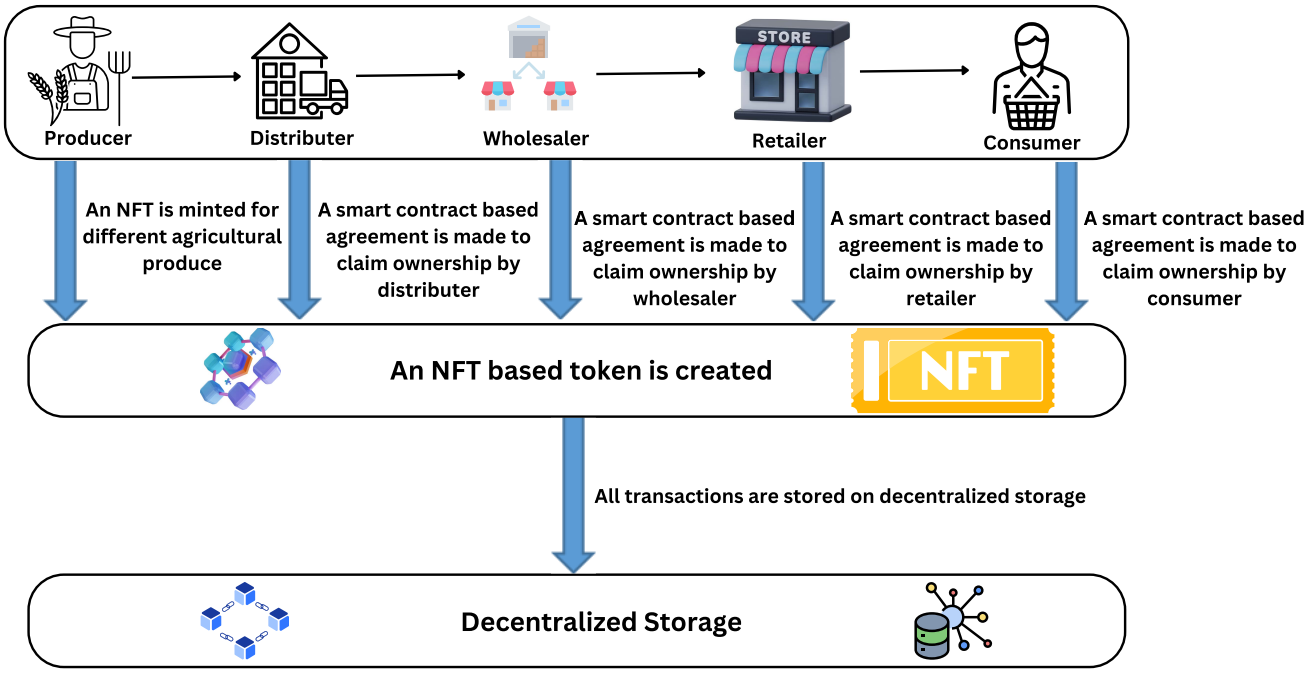

FIGURE 9. NFTs in the agricultural supply chain.

2) CARBON CREDITS AND SUSTAINABLE PRACTICES

NFTs are crucial in promoting and offering incentives for sustainable agricultural practices in the context of carbon credits and environmental sustainability. Renewable energy sources or carbon sequestration techniques are examples of climate-friendly agricultural practices that may be tokenized as NFTs [76]. NFTs representing carbon credits may be purchased, sold, or exchanged on specific platforms or marketplaces. As a result, interested buyers may support sustainable agricultural methods. The acquisition of these NFTs offers financial assistance to the farmers and encourages the adoption of sustainable practices more generally.

3) AGRICULTURE INSURANCE

Agriculture insurance using NFTs is a groundbreaking concept merging blockchain technology with traditional insurance practices. Each farm or agricultural asset is represented by a unique NFT containing crucial data, enabling smart contracts to automate claims based on predefined conditions, such as adverse weather events [77]. Real-time data sources, like IoT devices and satellite imagery, inform these contracts, and premiums are determined by risk assessment models. The transparent, secure nature of blockchain reduces fraud, and secondary markets allow farmers to trade their coverage NFTs. Decentralized insurance pools can spread risk, but regulatory compliance and education are key to widespread adoption, ultimately enhancing efficiency and risk management in agriculture insurance.

4) FARM MANAGEMENT

NFTs can represent farmland ownership, ensuring transparent and fraud-resistant land documentation [78]. Farmers can track and manage crops by associating each cycle or batch with an NFT that contains relevant data such as planting and harvesting dates, fertilizers used, and certifications achieved. NFTs can streamline farm equipment and asset management by storing maintenance history, usage statistics, and ownership records. Integrating NFTs into farm management applications can improve transparency, traceability, and efficiency across various aspects of agriculture, revolutionizing the industry and benefiting farmers, investors, and consumers.

5) CERTIFICATION AND QUALITY ASSURANCE

NFTs may greatly aid the certification of agricultural product quality and authenticity. For example, organic farmers can create NFTs that represent their organic produce. These tokens may include details regarding the farm's organic certification, the procedures followed, and any audits carried out by other parties. Consumers may confirm a product is organic and believe the farmer's claims by scanning the NFT attached. This boosts customer trust and rewards farmers for maintaining high-quality standards [79].

6) LIVESTOCK TRACKING

The application of NFTs in livestock tracking has the potential to revolutionize agriculture by providing secure and transparent digital records. Farmers may easily monitor and manage livestock throughout their lifespan by assigning distinctive NFTs to each animal [80]. These NFTs enable the traceability and provenance of the animals by including crucial data like breed, age, medical history, and ownership information. Farmers may assure transparency and accountability in the management and transportation of animals by

establishing an unalterable audit trail using NFTs. NFTs help livestock transactions go smoothly by facilitating ownership transfers, which lowers the chance of fraudulent or disputed deals.

V. CHALLENGES

Even while NFT has made significant progress in recent years, it still faces several significant obstacles to overcome before it can be widely used. Some of the challenges in the wide-scale adoption of NFTs are:

A. USABILITY CHALLENGES

In the context of NFT, usability challenges relate to the problems that users face while attempting to utilize NFTs. These problems may affect the user experience and prevent NFTs from being widely used. The following are some widespread usability problems with NFTs:

1) LACK OF STANDARDIZATION

Currently, there is a lack of standardization in NFT creation and management, which presents several challenges within the NFT ecosystem. Different platforms and marketplaces have their specifications and standards for creating and managing NFTs. These specifications can vary regarding file formats, metadata, royalties, and smart contract functionality. As a result, NFTs created on one platform may not be compatible or easily transferable to another platform. This lack of standardization can create confusion and limit the liquidity of NFTs [81]. Due to the absence of standardized protocols, verifying the ownership and provenance of an NFT can be challenging. It becomes difficult to determine whether an NFT is an original or a copy and whether the creator or current owner has the legitimate rights to sell or transfer it. This lack of transparency can undermine trust and lead to disputes over ownership, potentially devaluing the NFT. Furthermore, the fragmented nature of the marketplaces makes it challenging for users to compare assets and navigate through various platforms. Each marketplace may have different user interfaces, features, and payment options, creating a fragmented experience. This fragmentation also makes comparing prices and discovering NFTs across different platforms harder. Non-standardized NFT specifications limit cross-platform functionality and hinder the potential utility and value of NFTs [17]. For example, certain platforms may have unique features, such as interactive or gamified NFTs, which may not be supported or accessible on other platforms. This restricts the potential use cases and value propositions of NFTs, preventing them from reaching their full potential. Additionally, the absence of standardization can lead to confusion and a steep learning curve for NFT users. Each platform may have different procedures, requirements, and terminology, making it difficult for newcomers to understand and navigate the ecosystem. This lack of user-friendly standards can discourage adoption and limit the broader accessibility of NFTs.

2) SCALABILITY

The scalability issue is becoming more critical in the NFT field as its popularity grows. The underlying blockchain technology for NFTs has certain limitations regarding transaction throughput, scalability, and economic efficiency [82]. Congestion on the network might cause transaction times to lengthen and costs to rise as more people use NFTs. During busy times, such as when popular NFT falls or digital marketplaces see many customers, this congestion may be a significant issue. The smooth experience essential for mass adoption might be hampered by slow transaction times and high costs.

3) QUALITY CONTROL

The vast number of NFTs being made and sold makes it difficult to maintain quality control in the NFT ecosystem. It becomes more challenging to verify the authenticity and quality of NFTs as more digital assets enter the market [83], which may lead to problems like fraud, scams, and a possible loss in the reputation of NFTs. Centralized quality control methods are difficult to adopt due to the decentralized and open nature of NFT markets. NFTs are transacted on blockchain networks, which value decentralization and immutability above centralized authority and the ability to regulate and enforce quality standards. As a result, platforms and markets must develop their own set of rules and regulations to solve these issues.

Marketplaces and platforms may validate the identity and ownership of creators via verification methods to reduce the risk of fraud and scams. KYC (Know Your Customer) processes may be used for this purpose, during which authors verify their identities, ownership, and rights to their works of art. Platforms may increase confidence among investors and collectors by ensuring artist's originality and works. To set and maintain quality control standards, the NFT community must work together. Artists, collectors, and industry stakeholders may collaborate to create best practices, exchange knowledge, and educate users about the value of quality control. By creating a responsible production and trading culture, this group effort may improve the general standard and legitimacy of NFTs.

4) STORAGE AND INACCESSIBILITY

For NFT owners, storage and inaccessibility are crucial factors since safe storage of NFTs assures their long-term integrity and accessibility. The amount of security and accessibility, however, might fluctuate across various NFT markets and platforms, raising questions about the security of NFTs and the owner's future access to their assets [84].

The owner's ability to access their assets while NFTs are kept on a particular platform relies on its uptime and stability. NFT owners might lose access to their assets forever if the platform were to go out of business or encounter technological difficulties. NFT owners are urged to look at possibilities for self-custody or decentralized storage solutions to mitigate this worry. By keeping their NFTs

in private digital wallets, self-custody enables people to maintain total control over their NFTs. Using blockchain technology, owners may own and govern their NFTs without depending on a third-party platform. Decentralized storage options, such as IPFS (InterPlanetary File System), provide a decentralized and robust infrastructure for storing NFTs [51], providing accessibility even if certain platforms go out of business. Also, marketplaces and platforms can put security steps at the top of their lists to protect NFTs that are kept on their platforms. This includes establishing strong encryption methods, multi-factor identification, and regular security checks to protect NFTs from unauthorized access and possible hacking attempts.

5) TECHNICAL COMPLEXITY

Buying and selling NFTs might be a difficult and technical procedure for those unfamiliar with blockchain technology and its accompanying ideas. The broad use of NFTs is hampered by the fact that many individuals have yet to learn what NFTs are and how they work. Tokenization, decentralized ownership, and immutability are all features of NFTs that need technical expertise to understand properly. Users must be familiar with blockchain networks, smart contracts, digital wallets [85], and transaction methods before participating in the NFT business. NFTs are often minted and stored on blockchain platforms like Ethereum. Therefore, familiarity with blockchain technology is necessary for their development [1], [86]. Users require an understanding of cryptographic keys, decentralized networks, and the function of digital wallets in the safekeeping and management of NFTs [87], [88].

Furthermore, trading NFTs requires familiarity with various technical markets and platforms. Users need to be comfortable with the features and interfaces of these platforms, which often include communicating with decentralized exchanges, linking wallets, and handling transaction information.

6) SLOW CONFIRMATION

The smart contract is used to handle NFT-related procedures (such as minting, selling, and exchanging) in a trustworthy and transparent manner. However, current NFT systems are tightly connected with their underlying blockchain platforms, which results in poor performance (Bitcoin achieves 7 TPS (Transactions Per Second) [89] and Ethereum only 30 TPS). As a result, the confirmation rate of NFTs is extremely low.

7) INTEGRATION OF AI/ML

Several challenges to overcome when integrating AI/ML into the NFT ecosystem include data security and privacy concerns. Copyright and intellectual property concerns arise when AI creates or edits digital content for NFTs since it may use copyrighted materials without proper authorization. AI-generated content may not always meet the standards of human-created art or media. It may not be easy to guarantee the quality and originality of AI-generated NFTs. NFT markets can be highly volatile, and AI/ML-based pricing predictions may struggle to account for sudden market fluctuations or speculative behavior. AI models often need historical data to o make accurate predictions and recommendations. Since the market for NFTs is still relatively young, getting enough historical data for modeling might not be easy.

B. REGULATORY AND LEGAL CHALLENGES

NFTs can cause legal problems because of how they are created, owned, and transferred. NFTs face the same issues that most cryptocurrencies do, such as strict control by the government. On the other hand, it is also hard to figure out how to control this new technology and the market that goes with it. Some key legal challenges associated with NFTs are:

1) LEGAL AND REGULATORY ISSUES

Uncertainties exist in several countries about the legal and regulatory concerns related to NFTs. Questions of ownership rights, intellectual property protection, and contractual duties emerge because of the NFT's unclear legal position, which poses risks for users and investors [90]. As a result, there is a pressing need for strong security measures and authentication processes in the NFT market to combat fraud and money laundering. Concerns about fraud, investor safety, and market manipulation raise the prospect of action by authorities. Clarity on ownership rights, licensing agreements, and royalty arrangements is essential in the complicated intellectual property and licensing domain.

In addition, international cooperation and standardization efforts are required to create a legal framework that cuts across national borders because of the complexity of global problems. Regulators must establish transparent rules and structures that protect investors and maintain the market's honesty while encouraging creative thinking and economic progress [1]. Developing a complete and efficient legal and regulatory framework for NFTs requires close cooperation between industry players, legal experts, and regulators.

2) INTELLECTUAL PROPERTY CONCERNS

The rapid growth of NFTs has raised several issues related to intellectual property protection. The question of who owns the intellectual property rights to the assets represented by NFTs is a major one. When an NFT is made without the original creator's or rights holder's consent, this becomes an important consideration [10]. For instance, concerns about ownership and management of intellectual property rights emerge when a person develops an NFT of an artwork without the appropriate rights or license from the original artist. Unless otherwise specified in a written assignment or license agreement, the original work's copyright may remain with the artist who created it.

In such cases, the original artist and the NFT's inventor may have competing rights. The author of the NFT may claim ownership or control over the digital version of the artwork. In contrast, the original artist may claim

that their intellectual property rights have been violated. These disagreements may be difficult to resolve and require legal action to establish ownership and protect intellectual property. NFT creators, platforms, and markets must get the necessary permits and licenses before tokenizing any assets protected by intellectual property laws [91]. Platforms may add measures to confirm the validity of assets, such as checking the credentials of the asset's creator.

C. PRIVACY AND SECURITY CHALLENGES

NFTs present specific privacy and security challenges that users and platforms need to consider. Two significant issues that directly affect the security and privacy of NFTs are discussed below:

1) PRIVACY CONCERNS

When it comes to NFTs, privacy is a major issue. Since NFTs are recorded on a public blockchain, the world can see their transaction history and who owns them. While the decentralization and immutability of blockchain are typically cited as advantages, they may also provide privacy problems for users who would rather wish not to broadcast that they are the legal owners of certain assets. The danger of theft or fraud of digital material is increased, for instance, when someone can easily ascertain the owner of a high-value NFT [92]. In addition, users may choose to keep some information about themselves or their possessions private for safety or security reasons [93]. People in this category could be artists or collectors who value their privacy or the security of their intellectual property.

2) CYBERSECURITY RISKS

The storage of NFTs on a blockchain introduces cybersecurity risks that can severely affect users. While blockchain networks are difficult to hack, they are nevertheless vulnerable to other forms of cybercrime [94]. A hacker may steal, transfer, or destroy NFTs linked to a compromised account or platform if they acquire access to the private key or smart contract for that account or platform. Private keys must be kept in a secure environment to authenticate and authorize transactions utilizing NFTs. Malicious actors may acquire access to a user's NFTs if their private key is compromised by phishing, malware, or poor security procedures [95]. Hackers who access a user's private key may use it to transfer or sell the NFTs on the blockchain, causing severe financial harm to the victim.

The formation and transfer of NFTs may be exploited if they have bugs in their code or security flaws. These flaws let hackers misuse smart contracts and cause unintended actions, including transferring, replicating, or destroying NFTs [40]. Loss of valuable NFTs owing to breached smart contracts might negatively affect the NFT ecosystem, including financial losses.

D. MARKET CHALLENGES

Market challenges of NFTs refer to the obstacles and issues within the NFT marketplace ecosystem. Some key market challenges associated with NFTs are as follows:

1) HIGH GAS PRICES

The high costs of issuing and selling NFTs are a major barrier to their broad use and accessibility. Many people, particularly those in poor nations or with little means, may find NFTs financially out of reach due to these prices. Due to the high price, NFTs cannot reach a wide audience.

Transaction charges and gas fees on blockchain networks are typically necessary for producing and minting NFTs, which may be very costly [96]. Costs like this might shift based on factors like the underlying blockchain technology and the need for network resources. Individuals with fewer resources may be discouraged from participating in the development and minting of NFTs because of the high transaction costs they may incur. In addition to being charged to make an NFT, costs are incurred while selling or buying an NFT. A good example of how these fees could limit access is those who want to buy or invest in NFTs but get discouraged by the higher prices. New research claims that as cryptocurrencies evolve, their exchange rates will become more stable [97]. Even the blockchain community and developers are working hard to control and stabilize the costs of using smart contracts.

2) MARKET VOLATILITY

The value of NFTs may vary substantially and be vulnerable to speculative behaviors, making market volatility a key concern within the NFT ecosystem [98]. Due to this volatility, users may find pricing and valuing NFT assets more challenging. It might be difficult for investors and collectors to evaluate the risks and benefits of NFTs if they are unaware of their underlying significance. The problem is made much worse by the unavailability of appropriate appraisal techniques. Unlike more conventional financial assets, NFTs often lack standard valuation criteria and norms. The value of an NFT is based on several measures, including its scarcity, perceived uniqueness, historical importance, and cultural relevance. Nevertheless, these elements are highly subjective, which may lead to disagreements in valuation.

The NFT market is still in its early stages. Hence, limited data is available to analyze market patterns or project future worth. Price fluctuations and perhaps irrational market behavior might arise when well-established price discovery procedures and standardized pricing models are not in place [99]. To overcome these obstacles, users must thoroughly understand the dangers and advantages of NFT investments. Education and research are essential in understanding the elements affecting NFT values and making intelligent decisions.

3) PERCEIVED VALUE

More than any underlying economic or technical considerations, supply and demand, as well as public opinion, drive

the value of NFTs [100]. The value of NFTs is based on the demand for and perceived rarity of the digital material they represent, as opposed to the underlying fundamentals or physical attributes of conventional assets like equities or commodities.

There are dangers for both buyers and sellers in relying on market demand and perceived worth. Due to variables including cultural trends, celebrity endorsements, and media attention, buyers may struggle to determine an NFT's genuine value. Overpaying for an NFT that loses value or fails to sustain its original attraction is possible if the buyer lacks specialized market knowledge. Similarly, it may be challenging for sellers to set fair prices for NFTs. Because there may not be reliable standards or historical data, setting the right asking price for an NFT might be difficult [101]. Price fluctuations and speculative behaviors might occur if sellers establish inflated pricing based on their optimistic market demand forecasts.

4) LACK OF USE CASES

Although NFTs have become more popular, they have yet to find widespread adoption outside of the art and collectibles markets. NFTs are often associated with digital art, music, and other forms of intellectual property due to their dominance in the art industry [102]. New and creative applications that may promote greater adoption of NFTs must be identified and explored if their growth and influence are to be sustained over time. There are several reasons why NFTs need to find new applications outside the art and antiques market. First, it facilitates the expansion of the NFT market, attracting more businesses and consumers. By demonstrating the usefulness and potential of NFTs in various settings, their adoption in fields like gaming [103], real estate [52], supply chain [56], and finance [104], among others, becomes more feasible.

E. ENVIRONMENTAL CHALLENGES

People are encouraged to use NFTs and their parent technologies even though several studies have shown their negative environmental impacts. NFTs have faced criticism and concerns regarding their environmental impact.

1) ENVIRONMENTAL CONCERNS

Energy usage by NFTs is a major cause of environmental worry. Blockchain networks, particularly those using the proof-of-work consensus method, need many resources to facilitate the creation and trade of NFTs. Since blockchain networks are so high in power consumption, many are worried about their carbon footprint and how NFTs will affect the environment. Mining and validating transactions on these networks need a lot of power, and much of that power comes from fossil fuels, which adds to global warming and other negative environmental impacts [105], [106].

F. ETHICAL AND SOCIAL CHALLENGES

NFTs present various ethical and social challenges that must be addressed. The ethical and social challenges NFTs may face in getting adopted for real-world applications are discussed below:

1) CULTURAL AND SOCIAL ISSUES

Many difficult questions arise when digital assets with cultural or social value are represented as NFTs. The potential for commercializing and exploiting these assets inside the NFT ecosystem is a crucial cause for worry. Questions of ownership rights and appropriate remuneration may arise when NFT transactions take place without the participation or knowledge of the original creators or owners [107].

The preservation of cultural heritage and commercializing cultural assets might conflict with each other due to the NFT market's ability to digitize and monetize cultural and creative works. Some worry that NFTs may devalue cultural artifacts by turning them into fungible digital assets that can be traded for profit. Because blockchain technology is decentralized and the NFT market is still quite new, developing clear rules and ways to deal with cultural and social issues is hard. It is primarily up to individual users, platforms, and groups to figure out how to deal with these complicated problems [108].

2) ETHICAL CONCERNS

NFTs pose ethical questions when used to create and trade controversial or offensive assets. Due to the lack of regulation and centralization in the NFT market, any digital content, including potentially offensive or discriminating items, may be tokenized and traded without the permission of the original artists [109].

The potential for NFTs to be used to distribute information that promotes violence or discrimination is a serious cause for worry. The simplicity with which NFTs may be minted and sold enables the spread of such material, prompting inquiries about the roles played by platforms, artists, and purchasers. This raises moral questions about how far the right to free expression should be extended, how this would affect marginalized people, and whether or not NFTs might be used to spread bad ideas or behavior. Within the context of NFT, exploitation is also a major ethical problem. Personal information, photographs, and creative works belonging to vulnerable persons or communities may be tokenized and sold without their knowledge or agreement [110].

VI. FUTURE DIRECTIONS

NFTs have become increasingly popular recently in various domains, especially in the art and collectibles industries. One important research direction will be the development of NFT standards and protocols. Currently, several NFT standards are in use, making it difficult for users to exchange NFTs across other platforms. Researchers may focus on standardizing NFT protocols, making it easier for NFTs to be traded and used across different platforms. Another

future direction will be facilitating the wide-scale adoption of NFTs in different industries. While NFTs have gained popularity in the art and collectibles industries, many other potential applications exist for these tokens. Researchers may investigate the use of NFTs in sectors such as gaming, sports, or real estate, exploring how these tokens can represent ownership or access to unique assets or experiences.

Research may also focus on the potential of NFTs to promote sustainable practices, such as using carbon offsets or other environmental incentives. NFTs have been criticized for their potential environmental impact, as minting and trading these tokens require significant energy. Researchers may investigate ways to mitigate this impact, such as using renewable energy sources or other sustainable practices. Overall, future research in NFTs will likely focus on improving the usability and accessibility of these tokens, exploring new applications for them in different industries, and addressing concerns related to their environmental impact. As NFTs continue to gain popularity and become more widely adopted, research in this area will likely continue to expand and evolve in new and innovative ways. Some of the potential areas of focus for NFTs are discussed below:

3) SCALABILITY

As the use of NFTs increases, scalability solutions will be needed to support a more significant number of transactions. Researchers are considering implementing new blockchain features like sharding or other consensus methods to improve scalability. Splitting the blockchain into smaller pieces, or shards, enables faster transaction processing and greater scalability. The scalability issues that NFTs experience may be eased with the help of these developments, which seek to improve the capacity and efficiency of blockchain networks. Additionally, the introduction of alternative blockchain networks like Flow and Tezos designed for NFTs hopes to solve scalability issues [111]. It is important to remember that scalability is an ongoing challenge that needs rigorous testing, agreement, and acceptance throughout the NFT ecosystem to find success.

4) INTEROPERABILITY

NFTs are currently isolated within their respective ecosystems and cannot be easily traded across different platforms. Stakeholders in the sector need to collaborate towards developing common standards and protocols to overcome these interoperability difficulties. For NFTs to be easily traded and used across platforms, interoperability solutions must be developed via close cooperation between platforms, developers, and the blockchain community. Cross-chain or cross-platform protocols are being developed and implemented as a possible solution [112]. These protocols are designed to facilitate the movement of NFTs across distinct blockchain networks or platforms. If interoperability standards are established, NFTs may benefit from improved market visibility, liquidity, and value.

5) SECURITY

The security of NFTs is paramount to their value. Strong security practices must be a top priority to reduce the severity of these cyber threats. Private keys should be encrypted, safe storage solutions should be promoted, and users should be urged to adopt best practices, including using hardware wallets and two-factor authentication [113]. Strict security assessments should be performed on all platforms and markets that deal with NFTs.

6) GOVERNANCE

The governance of NFTs is a crucial consideration, as it impacts the ability to make changes or updates to the underlying protocols. Future research may investigate decentralized governance models for NFTs, such as DAOs (Decentralized Autonomous Organizations), to ensure they remain transparent and decentralized.

7) TECHNICAL COMPLEXITY

Newcomers without technological experience may feel overwhelmed by the platform's specific needs and processes. Improving the user experience and making instructional materials available are two key ways to break down these barriers to access. Individuals without technical skills may be encouraged to join the NFT business if the onboarding process is simplified by developing user-friendly interfaces, simple platforms, and clear documentation. Efforts to educate the public about NFTs and blockchain technology may include guides, tutorials, workshops, and other forms of community outreach. Simplifying user interfaces and making NFT platforms more intuitive may also aid in closing the knowledge gap. Making NFTs more approachable for those without strong technical backgrounds may be accomplished by developing user-friendly interfaces.

8) USE CASES

While NFTs have gained popularity in the art and collectibles, there are many other potential use cases for these tokens. Future research may explore how NFTs can be used in other industries, such as gaming, sports, healthcare, agriculture, education, or real estate, to represent ownership or access to unique assets or experiences. The technology behind NFTs and their future uses may be further explored if their scope of application is broadened. The blockchain technology upon which NFTs are based offers the benefits of immutability, transparency, and distributed ownership. By finding relevant use cases, these benefits can be put to work to improve operational procedures and address pressing issues in the real world.

9) SLOW CONFIRMATION

The technology follows a rigorous verification and authentication protocol to ensure secure transactions, which may affect transaction speed. So, this can be overcome by redesigning the blockchain or by upgrading the consensus mechanisms [114].

10) INTEGRATING AI/ML TO NFT

Integrating AI/ML into the NFT ecosystem presents challenges that can be addressed through a combination of technological, regulatory, and ethical measures. To ensure data privacy and security, robust encryption, access controls, and compliance with data protection regulations should be implemented. Copyright and intellectual property issues associated with AI-generated content can be managed by establishing clear guidelines and obtaining proper authorization when using copyrighted materials. To enhance the quality and uniqueness of AI-generated NFTs, continuous improvement of AI models and incorporating human curation can be adopted. Dealing with the volatility of NFT markets requires real-time data integration and risk management strategies. Collecting and augmenting available data can mitigate the need for more historical data availability.

11) PRIVACY CONCERN

Privacy is a major concern that NFTs may face. Since NFTs are stored on a public blockchain accessible to all users, there is a higher risk of theft and fraud. So, to overcome this challenge, a researcher needs to develop a blockchain network that includes privacy options. While some blockchain networks include privacy options, they have not yet found widespread adoption in the NFT sector due to scalability and efficiency problems. Zero-knowledge proofs [115] is one such privacy feature, which is a cryptographic mechanism that enables transaction verification without disclosing private information. Other existing privacy-preserving solutions like homomorphic encryption [116] and multiparty computation [117] have been proven to enhance privacy on blockchain networks significantly, but as their security assumptions and cryptography primitives are hard to understand, they haven't been used with NFT methods yet.

12) ENVIRONMENTAL CHALLENGES

Energy consumed in the minting and transferring of NFTs is a major cause of environmental worry. There is a rising movement within the NFT ecosystem to implement environmentally responsible practices in response to these issues. One solution is to switch to proof-of-stake or any other energy-efficient consensus protocol instead of the more traditional proof-of-work. Proof-of-stake blockchains minimize the need for processing power by validating transactions depending on how much Bitcoin the participants own [118].

Powering blockchain networks with sustainable energy is also very important. To make the process of producing and trading NFTs more environmentally friendly, many projects have been developed to encourage and incentivize the use of renewable energy in mining and transaction processing. Several initiatives have promised to buy carbon credits or fund renewable energy initiatives to make up for the pollution caused by their NFT dealings. Efforts to reduce NFT's destructive effect on the environment have driven the sector's development in recent years. Adopting energy-efficient practices and encouraging renewable energy sources call for cooperation between blockchain developers, markets, and participants. The NFT ecosystem may help create a greener, more accountable digital economy by placing a premium on sustainability, which aligns with larger environmental aims.

VII. CONCLUSION

NFT is a new and developing technology in the domain of blockchain. This paper discusses how NFT technologies could revolutionize the market for digital and virtual assets. First, the technical component of NFT and its related features that allow readers to understand the mechanism behind such technology better is discussed. Then, how the evolution of NFTs has occurred from RFID to blockchain and then to NFTs is explored. Different token standards required to build an NFT token on the Ethereum blockchain are also discussed. Various applications like agriculture, education, healthcare, gaming, smart cities, etc., where NFTs can be adopted are also discussed. Different challenges the NFT must solve to allow its large-scale adoption are also addressed. Finally, the future scope of NFTs and the solutions related to some of the challenges so that the NFTs can be adapted to different real-world scenarios are discussed. This paper provides a timely analysis and summary of proposed solutions and projects, making it easier for newcomers to follow progress in NFTs.

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