NFTs in Smart Cities: Vision, Applications, and Challenges

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***Abstract*—Non-Fungible Tokens (NFTs) have recently received widespread attention as their market has experienced massive growth since early 2021. NFTs are blockchain-based tokens used to represent ownership of digital and physical assets in a manner that is transparent, traceable, tamper-proof, secure, and trustworthy. Although NFTs have enabled new applications in the gaming and art industries, their full extent and potential are yet to be explored. In this paper, we outline the vision of using NFTs in smart cities. We describe the main components of NFTs and how smart city applications, such as smart governance, smart services, smart economy, smart industry, smart environment, and smart mobility and transportation, can benefit from them. In addition, we show how leveraging NFTs can add value to the metaverse. Finally, we discuss research challenges that hinder the adoption of NFTs in smart cities.**

NON-FUNGIBLE TOKENS (NFTS) are unique and non-exchangeable crypto tokens. An asset is fungible if the owner can exchange it with similar assets with no change in property or value. For instance, the US dollar is fungible because a person can exchange any one-dollar paper currency equivalently with any other one-dollar paper currency. On the other hand, a student can not exchange the bachelor's degree certificate with any other certificate because each bachelor's certificate is bound to a particular student; thus, the bachelor's certificate is a non-fungible asset. NFTs are based on blockchain technology, which is a shared and immutable ledger that records data in decentralized nodes connected by a peer-to-peer network. Miners are nodes that maintain the ledger, validate new transactions, and perform mining of new blocks. The blockchain ledger is tamper-proof as changing one block requires a change in all previous blocks stored in all the mining nodes.

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NFTs have gained immense popularity in recent years. They can act as digital certificates to prove the ownership of assets. Also, NFT owners can trade them smoothly by transferring ownership of the token from the owner's account to the buyer's. The most famous and widely known application of NFTs is digital collectibles [1], [2]. However, NFTs' use cases are not limited to digital collectibles. For instance, the authors in [3] used NFTs to create wildlife collectibles. The motivation behind their idea is to sell NFTs to tourists in return for money that will be used to finance wildlife conservation efforts. Real-estate NFTs can also facili-

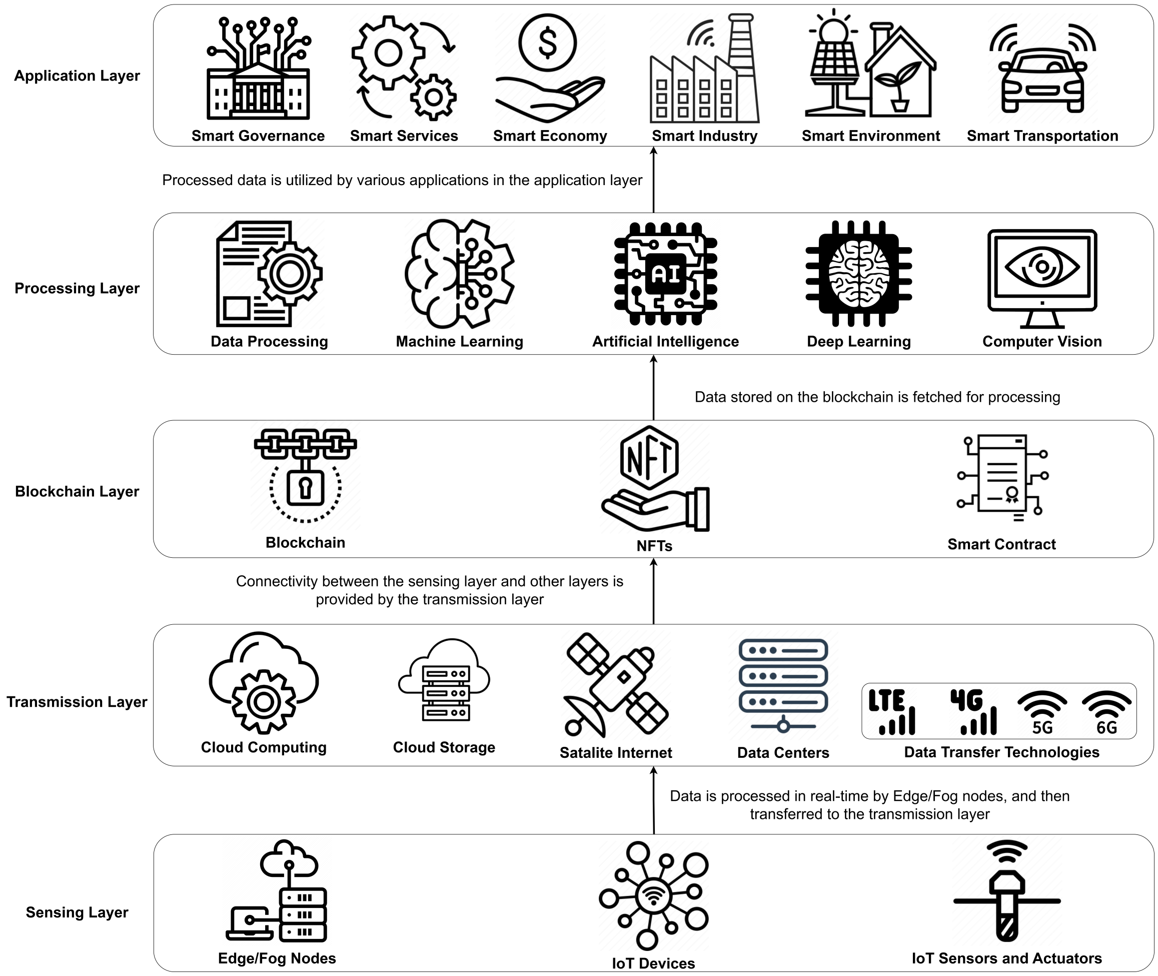

Figure 1. Smart city layered infrastructure [12]

tate real-estate trade and increase transparency in real-estate auctions, as all bidding against the property is seen by all bidders [4].

Nowadays, people living in urban areas exceed those living in rural areas. More people are migrating daily from rural areas to cities because of the higher standard of living and the availability of job opportunities in cities. The United Nations (UN) estimates that 7 billion people, or 68% of the world's population, will live in urban areas by 2050 [5]. Therefore, the government must plan future cities to be smart and sustainable. Otherwise, the quality of life in cities will deteriorate as the number of inhabitants increases with no proper action from the government. There are many definitions of "smart cities," and it isn't easy to find a universal definition [6]. Therefore, we try to give examples of life inside smart cities.

Artificial Intelligence (AI) [7], Internet of Things (IoT) [8], and sustainable development [9] play a crucial role in smart cities. In smart cities, devices are connected via secure and fast internet connections, and people interact digitally with physical objects and receive services through digital interfaces. Transportation is improved in smart cities via the use of clean energy sources and intelligent traffic control. Cars are self-driving, and home appliances are smart. Further, government services are more accessible to the public through digital and smart applications, and citizens can monitor the government's performance through open access reports and statistics [10], [11]. Figure 1 depicts a smart city layered infrastructure that comprises five main layers. First, the sensing layer, which enables real-time data processing by deploying Edge/Fog nodes in a location that is close to where data is generated [12]. Second, the transmission layer, which is responsible for handling data that is received from the sensing layer and transmitting it to the upper layers via various networking technologies such as satellite internet, LTE, and 4G. In addition, future networking technologies such as 5G and 6G can play an important role in improving the overall performance of the transmission layer. Moreover, cloud computing and storage solutions operate at this level to provide smooth and secure data transmission. Further, centralized or decentralized data centers can be facilitated at this layer to further improve the handling of large data [13]. Third, the blockchain layer enables data management, tokenization, and tasks' automation in a decentralized, transparent, and secure manner by facilitating smart contracts and NFTs. Fourth, the processing layer is responsible for receiving data from lower layers and processing it using different technologies, such as Machine Learning (ML), Artificial Intelligence (AI), Deep Learning (DL), and Computer Vision (CV), to produce meaningful and useful information. Finally, the application layer contains the different domains of a smart city, which utilize the produced data and information from the lower layers to improve their operations and performance.

Although NFTs and smart cities have been extensively researched in the literature, these two areas have been researched and studied separately. To the best of our knowledge, there is currently no work that reviews the conjunction between these two areas. In this paper, we envision using NFTs in different smart city applications. We present the role of NFTs in the metaverse. We discuss the major challenges to NFT adoption in smart cities as well as potential solutions. Finally, we provide future research directions for the use of NFTs in smart city applications.

The remainder of the paper is organized as follows: Section 2 briefly describes smart contracts, decentralized storage, and NFTs. Section 3 describes the potential applications of NFTs in smart cities. Section 4 discusses challenges that might hinder the broader adoption of NFTs and their potential solutions. Section 5 concludes the paper, summarizes the main findings, and points out future research directions.

Background

This section presents a brief description of smart contracts, decentralized storage, and NFTs.

Smart Contracts

Smart contracts are programs stored in the blockchain [17]. They include metadata about the application and the logic governing the smart contract. The smart contract creator (owner) writes the set of functions to be called by the user and embeds the logic controlling the behavior of each function. Then, the owner deploys the contract to the blockchain network. A smart contract does not run by itself; a user must call it, specifying the function to be executed by miners. To call a function, the caller sends a transaction to the miners. The transaction includes the function name along with the function parameter.

Miners validate the transaction before adding it to a block, execute the specified function with the input parameter, and store the execution result in the ledger. A function may contain an infinite loop or take a long time to finish, stopping miners from processing other transactions. To avoid lengthy calculations and infinite loops, each execution step costs a predetermined fee (gas fee), and the function caller must allocate the money in advance. If the money allocated runs out, miners stop function execution and return to the state before function execution.

Decentralized Storage

The use of centralized cloud storage poses security and privacy threats to user data because the host of the centralized storage system can alter, censor, or even disclose data to third parties without the data owner's consent. Furthermore, because they are typically located in one or a few locations, centralized cloud storage introduces the single point of failure risk; thus, they can be easily targeted by malicious users to compromise the stored data, or in the event of a power outage, the provided services are paralyzed, and the stored data is sometimes permanently lost. To address these issues, decentralized storage systems that store data in decentralized nodes have been proposed [18]. Each storage node is rewarded based on the amount of stored data, available time, and other metrics that ensure fairness among the involved nodes. In addition, the upload and download speeds are much higher than centralized storage solutions because a centralized server might cause a network bottleneck with many connections. Data is also safe in decentralized storage systems because it is split up and duplicated, and each copy is stored on a different node.

NFTs

NFTs are digital assets that reside on the blockchain with a unique identifier and metadata that distinguish them from each other. The ERC-721 stan-

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dard on the Ethereum blockchain was the first standard that supported the use of NFTs [19] which was followed by a more sophisticated standard that is called ERC-1155, which was introduced and implemented for Semi-Fungible Tokens [20]. Such standards are essential for providing the basic functionality for NFTs, which are tracing, tracking, and transferring NFTs.

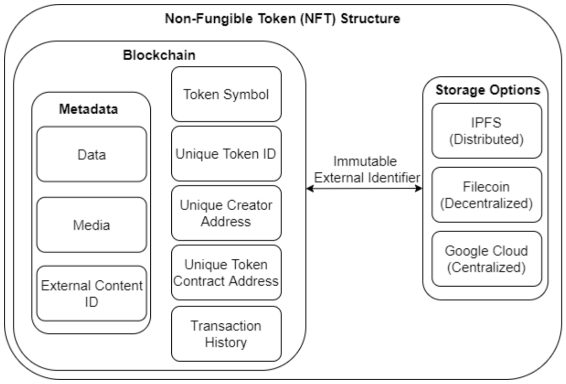

Figure 2. The structure and main components of an NFT

Figure 2 shows the structure and main components of an NFT. First, the blockchain is the backbone and core component of an NFT because it contains and maintains the unique features of the NFT that distinguish it from other NFTs. First, each NFT belongs to a smart contract with a unique contract address that cannot be replicated, which is necessary to ensure that users are aware of the authenticity of the NFT smart contract they interact with. Second, the deployer of the smart contract is identified by a unique address, which is referred to as the Unique Creator Address. Third, a token symbol can be specified within the smart contract for a certain NFT collection. However, the symbol alone is not enough to distinguish it from other NFT collections, and the unique token contract address is still needed to ensure that the user is interacting with the correct smart contract. Fourth, each NFT within the smart contract is identified by a unique token ID that is generated during its minting event, and it cannot be duplicated. Fifth, the transaction history of each NFT smart contract is immutable and permanently stored on the underlying blockchain, which can be used to track and trace NFTs. Finally, the metadata of each NFT can be either stored on-chain or off-chain, depending on the size of the data involved. In the former, no external content ID and storage options are required as the data is directly stored on-chain and users can inspect the content directly. In the latter, the metadata is stored on external storage options such as distributed, decentralized, or centralized storage, and an external content ID is produced and stored on the blockchain to make it immutable. However, the existence of the actual metadata will be completely dependent on the chosen storage option.

Applications of NFTs in Smart Cities

In this section, we present applications of smart cities that can benefit from NFTs' adoption, as illustrated in Figure 3.

Smart Governance

Smart governance refers to the process of utilizing new technologies to develop innovative governance approaches. In particular, these developments are aimed at providing evidence-based policymaking and collaborative governance [24]. In the context of smart city governance, achieving efficient and effective policymaking requires the participation of citizens in the decision-making process transparently, which creates and maintains a healthy relationship between the policymakers and citizens [25]. One of the major challenges facing smart governance in smart cities is voting fraud, which refers to manipulations that occur during the voting period that result in misleading outcomes. Additionally, participation in governmental proposals lacks transparency as there is no transparent authentication mechanism for voting. Based on [26], the use of decentralized authentication mechanisms is essential for the success of smart cities, and although this study discusses the importance of decentralized authentication mechanisms for IoT devices, the same principles apply for individuals participating in electronic voting. NFTs can provide a unique identity for each participant in an electronic voting system, where only the holders of the NFTs that are issued from a verified ERC-721 smart contract can participate in the voting process. Moreover, NFTs inherently ensure transparency, immutability, and security because they are part of a blockchain, which provides a decentralized authentication mechanism.

Figure 4 illustrates a potential use case for NFTs to facilitate a governmental voting process. First, the government will create and deploy an ERC-721 smart contract that is identifiable by its unique contract address, and citizens will be able to own a unique NFT that makes them distinguishable from each other. Additionally, the ERC-721 smart contract can be customized to make the NFTs non-transferrable to ensure

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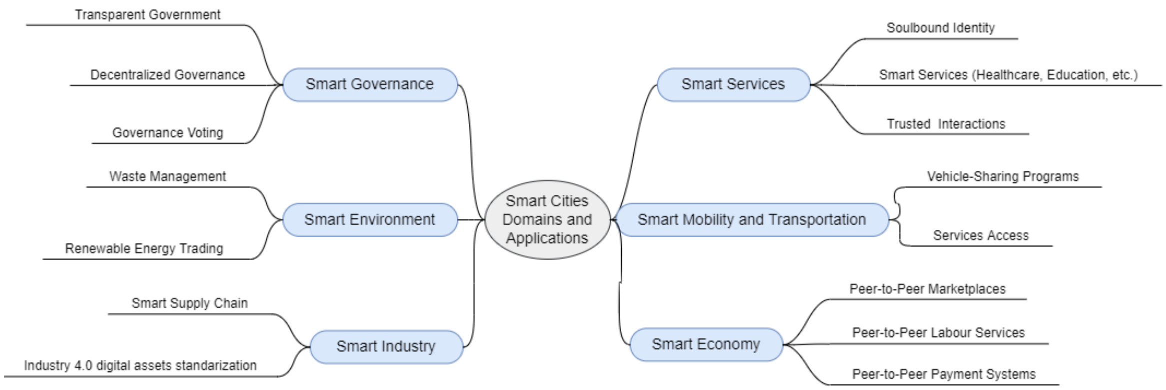

Figure 3. The main domains and applications of NFTs in smart cities

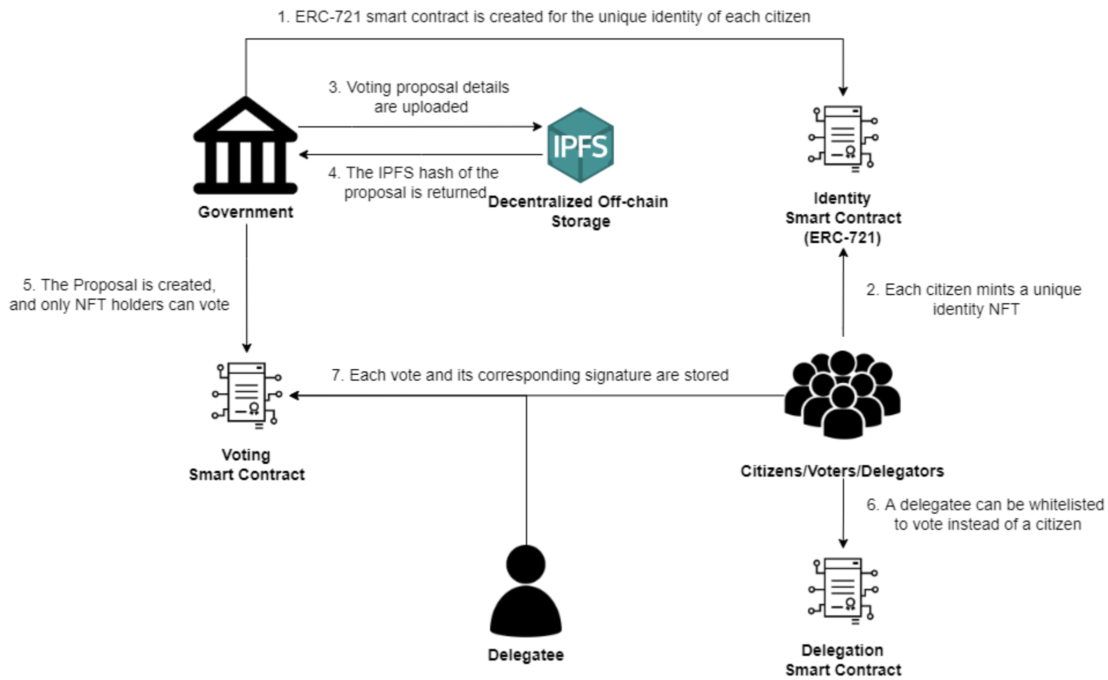

Figure 4. Flow diagram of NFTs application in governance voting

that the NFTs remain with their original owners. Second, whenever the government wants to create a proposal that requires the vote of the NFT holders, the proposal details will have to be uploaded to off-chain storage such as IPFS to avoid storing large-sized files on the blockchain. Voting can be done on the blockchain or off-chain. In the former, a voting smart contract can be used to record all the votes of the participants, which can be then audited in a transparent and trusted manner. In the latter, the signature of the voters can be obtained off-chain by having them sign their vote with their private keys, which allows the authors to verify if a vote is legitimate or not. Finally, the voters can have the option to delegate their votes to someone else whom they believe has a better understanding and perception of the created proposal.

Smart Services

Smart cities are designed to integrate digital and physical systems within a city. Therefore, having a digital identity that represents the people living in that city is necessary. A digital identity is required to standardize the way people and systems interact with each other. Moreover, the identification method in a smart city has to be secure, private, and portable to ensure that smart city services are utilized in an efficient and secure manner. The traditional identification method, using government-issued ID cards, is not ideal as they do not fulfill the requirements of the identification method in smart cities. Because NFTs are inherently secure, private, and portable, they can be used as a replacement for the physical government-issued ID cards with magnetic stripes.

Figure 5 demonstrates how an NFT can be utilized as a digital identity. First, citizens will be eligible to apply for soulbound NFTs. A soulbound NFT is a non-transferrable NFT that can represent the social status of an individual [27]. Second, the government mints a soulbound NFT for each eligible citizen. Third, the soulbound NFT can carry different types of information, such as medical records, educational qualifications, and personal information. Any sensitive information should be encrypted, and the NFT holder has the option to grant access to such information off-chain by using a solution such as Proxy Re-Encryption [28]. Fourth, authorized institutions will be able to update the records attached to the NFT. Finally, citizens will be able to use the NFT as a secure and trusted identity proof in various applications and programs.

Smart Economy

The smart economy refers to the ability to create an interconnection between the local and global markets in an innovative way that provides higher productivity and delivery [29]. Furthermore, the smart economy seeks to incorporate the concept of sharing economy by allowing citizens and stakeholders to offer their work and experience in a seamless and peer-to-peer manner [30]. In the context of smart cities, having a prosperous economy where all individuals are capable of benefiting from it is essential. One of the major challenges to having a successful sharing economy is trust and security, because a peer-to-peer marketplace requires both peers to trust each other [31]. NFTs are permanently stored on the blockchain, which is inherently transparent, immutable, and secure. Therefore, it enables participants to inspect the history and authenticity of the listed NFT without the need for a trusted third party. These inherited features from blockchain technology allow NFTs to have the potential to overcome the existing security and trust issues in existing peer-to-peer systems.

Figure 6 illustrates how an NFT-based peer-to-peer marketplace can function to resolve the security issues in the existing models. There are two main smart contracts to facilitate NFT creation and trading, which are the ERC-721 smart contract and the Marketplace smart contract, respectively. First, a seller chooses a storage option for the metadata of the offered product that produces an external immutable identifier. Second, the ERC-721 smart contract is used to mint the NFT that represents the offered product. Third, the Marketplace smart contract is used by the seller to facilitate the listing process of the minted NFT. Third, an interested buyer places a bid. Fourth, the bid is either accepted or rejected by the seller. Finally, if the bid is accepted, the NFT ownership is transferred to the buyer and the NFT value is transferred to the seller by the Marketplace smart contract. The use of NFTs in this context ensures that the transactions related to a product are immutable, transparent, and secure.

Smart Industry

Smart industry, or industry 4.0, is the integration of digital assets with the physical world by using advanced technologies such as digital twins, which aim to improve efficiency and productivity [32]. The existing literature reveals various barriers that currently exist to the adoption of industry 4.0. For example, there is a lack of secure standards and norms for the integration of digital assets with the physical world. Another example is the cyber-security challenges, where the interconnected components can be vulnerable to security breachs [33]. Furthermore, a case study for the use of Decision Support Systems (DSS) for the management of the smart industry has been proposed [34]. The authors of this study discuss the importance of having historical data to perform historical-based predictions to achieve optimal accuracy, and it also shows how there is currently an open issue with such predictions because of the lack of historical data, which leads to poor decision-making models for energy management. The use of blockchain and NFTs can act as the backbone of industry 4.0, where all the transactions are secured by the blockchain, and the digital assets can be represented in the form of an NFT, which ensures ownership, transparency, and data provenance. Moreover, all NFTs are designed using the same ERC-721 standard, which can be a potential solution to the standardization issue that currently exists in industry 4.0. Furthermore, energy management is an important aspect of smart industry, which is highly dependent on the availability and authenticity of historical data [34]. Tokenizing assets in the form of NFTs provides a potential solution to the data availability issue because NFTs are inherently immutable and their history is

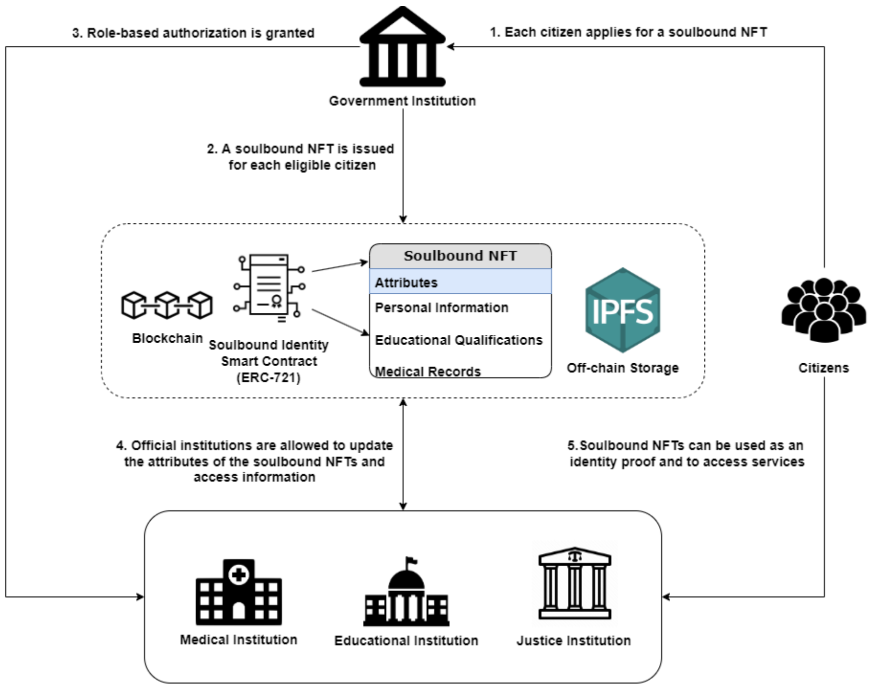

Figure 5. Flow diagram of NFTs application in soulbound identity

permanently stored on the blockchain, which provides decision-makers with a reliable source of information to enhance their energy management solutions.

Smart Environment

A smart environment describes how a government utilizes technology to improve the livability of citizens and to introduce and implement regulatory and cultural changes that encourage sustainable standards and practices [35]. The domain of the smart environment includes environmental data management, pollution and waste reduction, efficient green energy trading [36]. An interesting application for NFTs is in the smart energy chain, where citizens can participate in a peer-to-peer transaction application in which green energy is generated and traded. One of the most common trades that occur in green energy trading is the trading of green certificates [37]. In such trading, a major challenge that is currently facing the green energy sector is tracing and identifying generating assets, because the larger the number of participants in the network, the more difficult it is to track and trace. Moreover, there is no mechanism or method for the distinction between electrons that are generated from renewable energy and those from fossil fuels [38]. The Energy Web Foundation (EWF), a global non-profit organization that utilizes blockchain technology in the energy sector, introduced Energy Attribute Certificates (EACs) which are awarded to renewable energy assets based on the amount of generated power [37]. Each EAC includes the source of the power, the geographic location of the generating asset, the exact amount of electricity generated, and the date and time. Therefore, an EAC is considered a non-fungible asset. NFTs can represent such assets because their design and standards fit the needs of non-fungible assets. Also, using NFTs can make it easier to keep track of these assets and ensure their immutability, data provenance, and accountability.

Smart Mobility and Transportation

Smart mobility and transportation aim to increase the quality and efficiency of urban transportation, adoption of new mobility technologies, and people mobility. Moreover, smart mobility and transportation introduce the concept of Mobility-as-a-Service (MaaS), where a smart Internet-of-Things (IoT) infrastructure is utilized to connect different actors and entities [39]. A major sector in mobility and transportation is vehicle management, trading, and sharing [40]. One of the challenges that faces vehicle users is diagnosing a problem within their vehicles, and having a full record of the history of the vehicle can be very beneficial in diagnosing the problem faster and cheaper. NFTs can

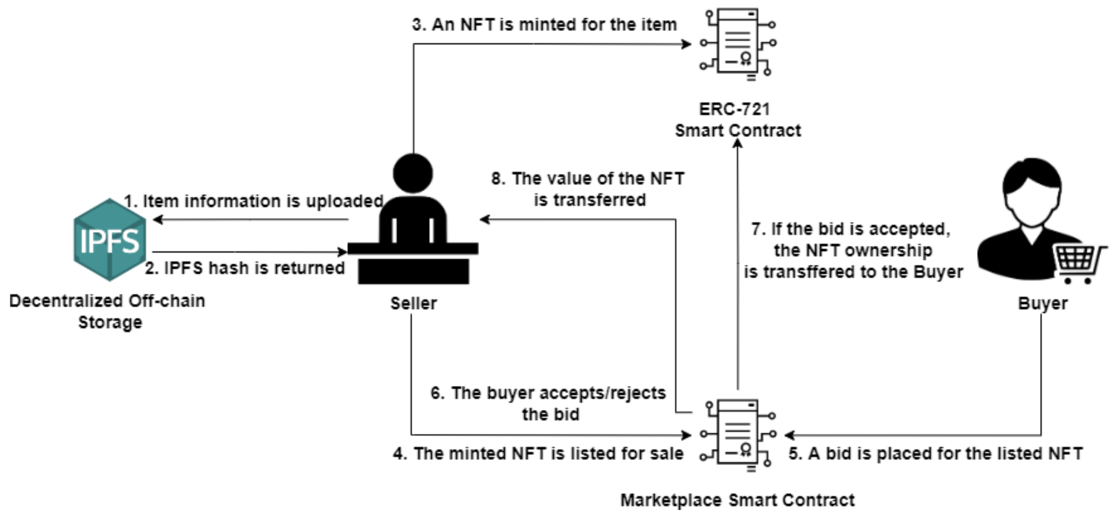

Figure 6. Flow diagram of NFTs application in a peer to peer marketplace

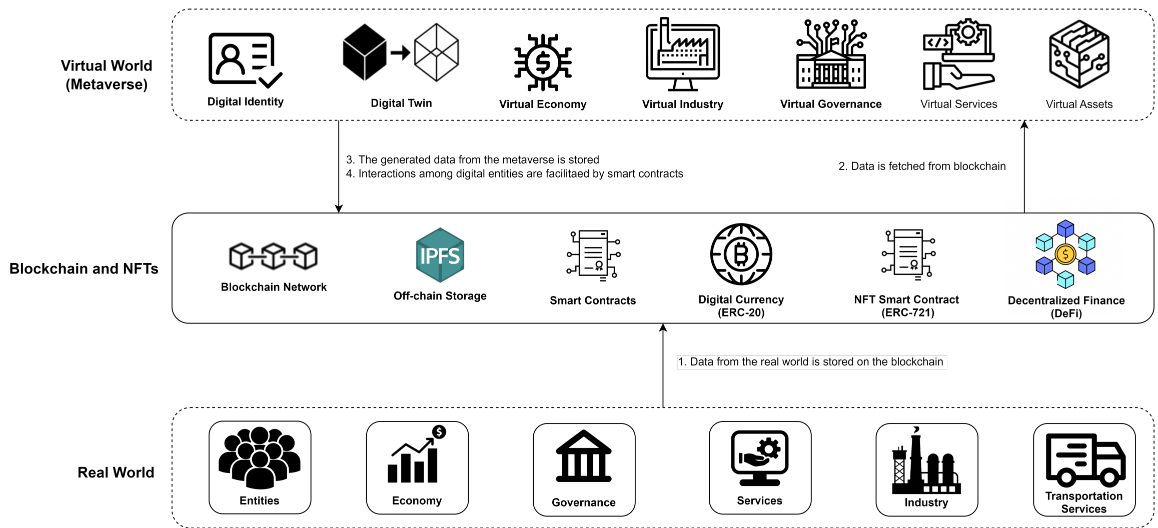

Figure 7. The role of NFTs in Smart City-based metaverse

provide a potential solution to this problem as they are suited for the representation of non-fungible assets and can permanently store all the records of a vehicle. Moreover, having the history of the vehicle fully recorded in an NFT can provide a solution to the trust issue in vehicle trading. Finally, some of the hurdles that face the vehicle sharing market are the limited access to such a market and the difficulty of sharing the vehicle key with the customer, which can make this model bad in terms of the customer experience. For the former, an NFT marketplace can be developed where users can list their vehicles for sharing, and an interested customer can view the history and reputation of the vehicle owner before renting the vehicle. For the latter, NFTs can be used as an access key to the vehicle, where a smart contract can be used to facilitate the access process by granting a customer's NFT access to the vehicle once a successful payment is made to the vehicle owner.

NFTs in Smart City-based Metaverse

The metaverse is an immersive virtual world that allows people and entities to interact with each other through their digital representations using technologies such as 3D computing, augmented reality (AR), and virtual reality (VR) [41]. The integration of the real world with the metaverse requires a secure, trusted,

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and decentralized infrastructure to ensure that users are always protected [42]. Building a smart city-based metaverse requires the inclusion of all the main domains of a smart city, such as the economy, governance, industry, transportation, and other services. Figure 7 illustrates the role of blockchain and NFTs in the integration of the real world with the virtual world (Metaverse). First, to facilitate monetary transactions, a digital currency that is backed by a real currency is needed to ensure that users are able to redeem it at any given moment. Since a digital currency is fungible, the ERC-20 standard is needed to facilitate the process of issuing and exchanging it [43]. Second, any real asset that needs to be represented digitally will be based on the NFT ERC-721 standard to ensure that the records and information about the asset are secure and immutable. Third, distributed or decentralized off-chain storage is facilitated for storing large-sized files that do not fit the blockchain. Finally, general-purpose smart contracts are utilized to facilitate the process of trading and using NFTs in different applications such as marketplaces and asset sharing.

Research Challenges

This section presents the challenges that hinder the widespread adoption of NFTs in smart cities. We outline the key causes of each challenge as well as provide potential solutions, as can be seen in Table 1.

Blockchain-Related Challenges

NFTs use blockchain to persist the data and incorporate smart contracts to add the logic and standards that control the token's behavior. Therefore, NFTs inherit blockchain and smart contract issues. For instance, mining a block in blockchain networks takes time, which is not suitable for large-scale applications [44]. For NFTs to be adopted and incorporated into smart cities, the throughput of the blockchain needs to be high enough to handle such a high transaction rate.

To improve the overall throughput and efficiency of the Ethereum blockchain, Ethereum Foundation started developing scaling solutions [45]. The scaling solutions are twofold: First, there is the on-chain scaling solution, which aims to make direct changes to the Ethereum protocol's mainnet, such as Sharding. Second, off-chain scaling solutions, such as Rollups, Sidechains, Plasma, and Validium [46]. The recent Ethereum Merge that changed the consensus algorithm of the blockchain from PoW to PoS has not directly impacted the scalability of the blockchain, however, it made it easier for second layer platforms to be built [47].

Security and Privacy

Most blockchain networks are public networks where everyone sees all transactions. They have been designed to be public to ensure transparency in the system, making blockchain data transparent, traceable, and auditable. However, fully transparent systems do not preserve the privacy of users. In some cases, the value NFTs add is based on their publicity and visibility. For instance, an owner of an NFT representing a patent will undoubtedly prefer that the NFT be visible to everyone because more users of the patent will lead to an increase in annual profits.

In other cases, publicly-traded NFTs might not be preferred by the token's owner or suitable due to privacy regulations. For example, a house owner needs NFT to prove ownership but does not necessarily want everyone to know his ownership of the house or its location. Similarly, an NFT that corresponds to the medical records of a patient should be private due to privacy regulations, and the sensitivity of the data [48]. A potential solution to the privacy issue is using private or permissioned blockchain networks instead of public ones. However, trust in private networks is less than in public networks due to the lack of transparency. The security challenges facing NFT developers are summarized in [49]. Moreover, the data stored on the blockchain can be encrypted, and the owner of the NFT can grant access to such data based on his own will. This can be achieved by utilizing solutions such as Proxy Re-Encryption (PRE) [28].

There are several security risks associated with the use of NFTs. First, a major NFT security risk is associated with the fact that NFT trading is currently being facilitated by third-party platforms that provide storage capabilities for NFT content, which means that if the platform goes out of business, users might be left with NFTs with a broken content identifier. Second, a major NFT security risk is related to smart contracts, which can be susceptible to exploits if not coded and audited properly. Finally, the metadata of NFTs is sometimes stored on centralized storage, which exposes the owner of the NFT to critical vulnerability, where the stored data is lost or changed, making the NFT worthless.

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Table 1. Open challenges impeding NFT adoption and potential solutions

Challenge Domain	Challenge	Potential Solution
Blockchain-related Challenges	- High transaction fees - Low throughput - High energy consumption	- Use of private-permissioned blockchain - Utilizing on-chain and off-chain scaling solutions - Choosing a low-energy consuming consensus algorithm
Privacy and Security Challenges	- Storing sensitive and confidential data - Fake and malicious assets	- Encrypting data before storing it on the blockchain - Verifying the unique contract address of the NFT
Rapid Changes and Storage Challenges	- High entry barrier and lack of experts - Limited storage space on the blockchain	- Organizing awareness campaigns and workshops - Utilizing off-chain storage solutions such as IPFS
Law Enforcement Challenges	- Regulation frameworks are nonexistent	- Establishing and implementing regulatory standards

Rapid Changes and Limited Storage

Although NFTs have recently drawn tremendous attention, the technology is still in its infancy. Therefore, crossing the chasm to reach the early majority and eventually laggards requires the establishment of standards and regulations. The application developed today might not work well with the standard set in the future due to the lack of backward compatibility. Furthermore, there are no proper development tools to assist programmers in writing high-quality and efficient code, and NFTs face interoperability issues due to different established standards on different blockchains.

Another critical challenge facing NFTs is the storage problem, because the actual file is not stored in the blockchain. The metadata of any NFT has a unique identifier that points to the file stored off-chain. Thus, the link to the file is permanently stored in the blockchain and is tamper-proof. However, the actual file is not tamper-proof and could be changed by the owner. In fact, the file could be deleted from the storage location, and the link will be pointing to nothing [50]. The storage issue is serious since people are paying money for these tokens. There are currently solutions such as IPFS and Filecoin that are focused on providing solutions to this issue [51].

Law Enforcement, Regulations, and Legal Issues

Since the adoption of cryptocurrencies, there have been many attempts to regulate them. However, there is currently no complete regulatory framework for them [52]. NFTs also face the same issue because there are no laws that govern usability and protect the rights of each entity [53]. There is no way to penalize NFT owners if the object associated with the NFT turns out to be incorrect or missing. Recently, there have been a lot of scams where people bought tokens that turned out to be fake, and the NFT seller ran off with the money. The absence of regulations affects NFT owners as well. For example, if a programmer creates an NFT for a code, the programmer cannot do anything to other people using the code without their permission. All the previously discussed applications of NFTs in smart cities would not work if there is no legal system that penalizes malicious behaviors. Moreover, the tokenization of physical assets is expected to implicate governmental laws that address several legal issues. First, ownership and license rights may be poorly communicated to the buyer of the NFT. Therefore, the ownership and license terms should clearly delineate what the buyer actually owns and what the buyer can and cannot do with their NFT. Second, intellectual property (IP) rights are not necessarily obtained by minting an NFT that represents content such as artwork, music, or trademarks, which can make the NFT owner liable for infringing third-party IP. Third, volatile and high-value NFTs may be used to facilitate money laundering, which is considered illegal and a crime. Therefore, platforms that facilitate NFT trading must be properly regulated to ensure such acts do not take place. Fourth, securities law may apply to NFTs that have security-like features, such as NFTs granting their holders a share of the revenue from the underlying asset. Therefore, a proper and robust regulatory framework and standards must be implemented to ensure that such NFTs are properly monitored and managed. Finally, other legal issues that may be associated with the use of NFTs include gambling, sanctions, and NFT insider trading.

Conclusion and Future Directions

In this paper, we outlined the vision of using NFTs in smart cities. We presented the key components and features of NFTs, and described how they can be utilized in different smart city applications. We presented the role of NFTs in the metaverse. We discussed the key challenges that hinder the adoption of NFTs in the applications of smart cities and outlined potential solutions. The findings of our paper can be summarized into three main points. First, NFTs can be used to represent digital assets in a smart city that are required to be immutable, secure, and traceable. Second, NFTs are not a standalone technology, as they require a well-configured blockchain and an efficient off-chain data storage solution in order for them to function properly and as intended. Finally, there are several technical and adaptive challenges that must be overcome to increase the adoption of NFTs in smart cities. Some future research directions are described below.

- Concepts such as 5G/6G technologies are expected to have a massive impact on existing technologies, including NFTs. Therefore, further research is required to understand and predict the potential impact of NFTs and their adoption process.
- The impact of NFTs on various Quality of Service (QoS) factors that are associated with the domains of smart cities can be further studied and evaluated. This might be done by estimating the overall performance of a certain domain in a smart city after implementing NFTs and comparing it with existing QoS to decide if it has a substantial impact or not.
- A well-established regulatory framework is required to protect the users of NFTs and prevent forgeries. Therefore, more research is required in this field to come up with the best practices and standards for NFTs.
- Scalability is one of the major challenges that hinders the adoption of NFTs and blockchain technology. The current blockchains that support NFTs, like Ethereum, can't handle high network congestion well because gas fees change and transactions take a long time. This isn't good for creators or NFT users in general because it makes the blockchain less useful.
- NFT-based applications and blockchain-based applications in general have a hard time getting into the market because the technology is still new and most people think it's too hard to understand. This keeps them away from using these applications.

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