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NFTs at the Nexus of Innovation and Sustainability: A Framework Aligning NFT Affordances with the Sustainable Development Goals

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The United Nations' Sustainable Development Goals (SDGs) are goals associated with the most significant global issues, which include climate, health, security, and poverty. The goals are part of an agenda for making progress on environmental, social, and economic issues while ensuring peace and leaving no one behind. Meeting these goals requires effort and innovation on all fronts, including technology. Information and communication technologies have long contributed to these efforts, and more recently, blockchain for good projects have begun to bear fruit. Non-fungible tokens (NFTs), which are, in essence, certificates of ownership stored on a blockchain, can also contribute to sustainable development. However, to this point, they have been underutilised. NFTs have inherent capabilities that can make them ideally suited to contribute towards the SDGs. Their unique capacity to validate ownership, identity, claims, and history of events makes them valuable for a variety of purposes. To date, NFTs have been employed primarily for trading digital assets such as collectibles, in-game items, digital art, and event tickets. However, their affordances—the actionable properties NFTs offer to users—make them suitable for use in ways that can significantly affect the health and well-being of humans and the planet. This article provides a framework for linking NFT affordances with the SDGs and examples of how NFT use cases are addressing, or could address, these urgent global needs.

Keywords: *Digital Assets, Non-Fungible Tokens, NFTs, Affordances, Sustainable Development Goals, SDGs, Sustainability***JEL Classifications:** *L31, L86, O14, O19, O33, O34, Q01, Q55***1. Introduction**

In 2015, all 193 member-states of the United Nations developed and agreed to 17 Sustainable Development Goals (SDGs) that address the world's most important and challenging problems. The SDGs set out specific targets for global progress in climate, health, security, poverty, and other critical areas of development, to be achieved by 2030. The world is not on track to meet these targets. Experts argue that there is a need for far-reaching efforts to achieve these goals [1]. Collaboration and innovation on approaches and solutions are urgently needed.

Blockchain and distributed ledger technologies (hereafter “blockchain”) have been employed for a variety of use cases targeting social impact. The World Food Programme, for example, has used blockchain for cash transfers and access to food assistance [2]. Non-Fungible Tokens (NFTs), however, have received little attention in this realm, and yet they offer vast, untapped potential. This article addresses the research question: Can NFTs provide utility in achieving the SDGs?

To answer the question, I begin by exploring academic and professional literature for consensus on the inherent qualities

of NFTs. Building on these qualities, I define four affordances, or functionalities, that NFTs can offer. They can signify identity, establish ownership, institute claims, and convey history. These affordances imbue NFTs with the potential to promote the SDGs in ways that cannot be replicated using other technologies. I build a framework intersecting these affordances with the development goals and then explore numerous current and potential use cases that demonstrate how the affordances can be realised within each of the SDG categories. The framework presented in this article provides a starting point for using NFTs for social change.

Comprehensive studies provide taxonomies that purport to define the full range of potential uses for NFTs (e.g. [3, 4–6]). Such taxonomies have largely ignored or overlooked the potential for NFTs to contribute to social impact. The studies tend to examine extant and adjacent use cases, usually with an eye towards commercial and investment potential. Although some use cases address important social impacts, such as privacy of medical records and rights to intellectual property, sustainable development has not been a focus. While taxonomies can contribute significantly towards understanding the potential of this technology, I do not review them here. Instead, I explore how NFTs can be used in a much broader range of contexts and for social and environmental purposes.

As I will demonstrate, NFTs have a powerful role to play in creating social change. Even in the hands of highly skilled designers and users, the effectiveness of NFTs is a function of the broader sociotechnical systems within which they are embedded. Exploring their potential for social impact provides a foundation for multi-layered interventions that can address global challenges.

Figure 1: The United Nations' Sustainable Development Goals

People—Eliminate hunger and poverty in all forms, guarantee dignity and equality for all human beings SDG 2: Good Health and Well-being: Ensure healthy lives and promote well-being for all at all ages SDG 4: Quality Education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. SDG 5: Gender Equality: Achieve gender equality and empower all women and girls. SDG 6: Clean Water and Sanitation: Ensure availability and sustainable management of water and sanitation for all.
Planet—Protect the planet's natural resources and climate for future generations; SDG 11: Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient, and sustainable. SDG 12: Responsible Consumption and Production: Ensure sustainable consumption and production patterns. SDG 13: Climate Action: Take urgent action to combat climate change and its impacts. SDG 14: Life Below Water: Conserve and sustainably use the oceans, seas, and marine resources. SDG 15: Life on Land: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss.
Prosperity—Ensure prosperous and fulfilling lives in harmony with nature; SDG 1: Zero Hunger: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture. SDG 7: Affordable and Clean Energy: Ensure access to affordable, reliable, sustainable, and modern energy for all. SDG 8: Decent Work and Economic Growth: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. SDG 9: Industry, Innovation, and Infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. SDG 10: Reduced Inequalities: Reduce inequality within and among countries.
Peace—Promote peaceful, just and inclusive societies which are free from fear and violence SDG 16: Peace, Justice, and Strong Institutions: Promote peaceful and inclusive societies, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels.
Partnerships—Implement the 2030 Agenda through solid partnerships SDG 17: Partnerships for the Goals: Strengthen the means of implementation and revitalize the global partnership for sustainable development.

2. Sustainable Development Goals

The United Nations' 17 SDGs and the 169 specific targets associated with the goals comprise part of a global agenda to be completed by 2030. This agenda "provides a shared blueprint for peace and prosperity for people and the planet, now and into the future" [7]. The goals were formed over a three-year period with input from hundreds of organisations. Nonet et al. [8] consider the SDGs to be "the most all-encompassing, ambitious, as well as action-oriented agenda for progress on a global scale, ever agreed upon by humankind."

The 17 goals cover five overlapping themes: social, environmental, economic, peace, and partnership (see Figure 1). Descriptions of the 5Ps are from Richiedi and Pezzagno [9]; descriptions of the SDGs are from the United Nations [10].

The intention of the SDGs is to mobilise social change. Stakeholders at every level and across sectors are called to contribute investments and strategies [11]. When commercial initiatives and organisations use the concepts covered by the SDGs, they often focus on reducing negative social and environmental impacts rather than making positive movement towards the goals. Nonetheless, their impacts can be significant [12]. Businesses have been called to evaluate their performance, align business activities with relevant goals, and report outcomes [13] as a means to monitor and improve progress. Technology can play an essential role in these processes [14], and as will be discussed, the impact of NFTs could be profound. In the remainder of the paper, I refer to topics addressed by the SDGs as "social issues" and to outcomes relating to these issues as "social impacts."

3. Non-Fungible Tokens

Broadly speaking, NFTs are digital files that function as certificates of ownership, typically for digital or physical assets. They enable the holder to prove their ownership as well as the provenance of the certificate. NFTs are stored in digital wallets and can be transmitted between owners through blockchain transactions. Blockchains, in this context, are lists of transactions that are timestamped, validated, and stored in multiple locations, providing assurance that the transactions have not been modified or deleted. NFTs are typically governed by smart contracts—small programs that define the features and functions of the NFT. These contracts are also stored on blockchains. NFTs often take the form of static tokens that include the URL of the location where an associated digital asset, such as a .jpg file, is stored. NFTs can have more complex features. For example, high-value NFTs themselves can be tokenised [15]. Some types of tokens are dynamic. Their contents can change based on conditions specified in the smart contract or on events occurring outside of the contract [5]. The versatility of NFTs will continue to increase over time, expanding their potential roles in social impact creation. Greater depth on NFTs and their technological underpinnings can be found in [16–18].

4. Research Method

Addressing the research question of how NFTs can provide utility in the achievement of the SDG involved four steps. The first was a systematic literature review (SLR), described below. The SLR approach is appropriate in this context because the article seeks to push the knowledge frontier by conducting exploratory research on a topic for which little established theory exists [19]. I began the literature search using Web of Science (WoS) and the term “non-fungible tokens” as a starting point, following citations forward and backward. Further details are described in the next section.

I explored the professed qualities or characteristics of NFTs and summarised these characteristics using narrative review and synthesis. Next, I researched NFT use cases associated with the SDGs. I searched WoS and Google Scholar for academic research and used Google and Brave to search for grey literature. I included publications by the United Nations and other multilateral agencies, international non-governmental organisations, and global consulting firms with blockchain practices. I expanded the search terms beyond NFTs to include blockchain and information and communication technology (ICT). These technical terms were combined with sustainable development, SDGs, and individual goals such as poverty and peace, as well as with terms related to social impact in the business press: environmental, social, and governance, corporate social responsibility, and sustainability. I used meta-narrative techniques [20] to extract themes for categorising use cases along SDG dimensions.

5. NFT Characteristics

NFTs share inherent characteristics that differentiate them from other technologies. As a result of these characteristics, NFTs can perform functions and solve problems that cannot be effectively addressed using alternative technologies, whether centralised or decentralised. Significant differences exist in the characteristics attributed to NFTs by different authors. Core characteristics are important in the context of SDGs because they position NFTs to contribute in unique ways towards the achievement of positive social impact. Identifying a set of consensus characteristics began with a thorough review, analysis, and synthesis of claims made about NFTs.

A WoS search using “non-fungible tokens” as the key term returned 139 publications, the majority in computer science, engineering, and telecommunications. Beginning with eight publications classified as review papers, and 58 having multiple citations, I selected papers that directly identified and described inherent characteristics of NFTs, most notably [21], [22–24]. There is still relatively little academic research on NFTs, and much of the existing analysis is focused on the economic potential for creators, investors, and traders [21]. Most review articles present a narrow perspective on the relevant characteristics of NFTs;

for example, Taherdoost [24] focused on digital scarcity. The domain covered by these papers was also narrow. Bao and Rouboud [21] and Nadini et al. [25], for example, focused on economic and finance domains and considered a limited scope of NFT use cases, primarily focusing on collectibles, artwork, and gaming.

The academic literature was expanded and validated using trade publications (e.g. [16, 17, 26, and 28]). This yielded a comprehensive list that I then synthesised into four core NFT characteristics. NFTs gain some of their attributes from the underlying qualities of the blockchain, and the characteristics listed here are also common to many types of blockchain tokens and ledger entries [29].

Four foundational NFT characteristics resulted from this process. They are uniqueness, ownership, transferability, and authenticity.

1. **Uniqueness:** NFTs are non-fungible; they can't easily be exchanged with other assets. Distinct from cryptocurrencies and other fungible tokens, each NFT has a unique identifier that is included in its metadata. It can therefore be differentiated from every other token, even if it is one in a series of tokens that appear to be identical. This is akin to limited-edition prints, where numbers are used to uniquely identify individual prints.
2. **Ownership:** An NFT resides in a single wallet and is therefore associated with or “owned by” whoever controls that wallet. The owner is likewise said to own the digital asset to which the NFT refers or the physical asset represented by the title, deed, licence, or other form of ownership to which the NFT refers. Depending on the asset and its community of interest, ownership conveys value in various forms that include status and access.
3. **Transferability:** NFTs are typically transferable from one owner to another. Because the capabilities of NFTs are governed by code, rules for transfer can be embedded. For example, the number of times an NFT can be transferred or the allowable wallets the token can be transferred to can be programmed in. Because they reside on blockchains, NFTs can be transferred directly, securely, and rapidly, as is the case with cryptocurrency. In some cases, interoperability exists, and NFTs can be transferred from one blockchain platform to another.
4. **Authenticity:** The origin, evolution, and transmission of NFTs are often fully transparent and can be found through simple searches using free software such as Etherscan. Because NFTs reside on blockchains, they are essentially immutable and cannot be deleted. Once the NFT is recorded on the blockchain, its location and state can be viewed and tracked throughout its lifespan. If the validity of the entity(ies) responsible for creating the asset and minting the NFT can be trusted, the ability to establish subsequent authenticity is a valuable attribute.

Many studies included scarcity and/or rarity when enumerating attributes (e.g. [24, 29–31]). These are directly related to uniqueness but are not inherent to NFTs. Instead, creators intentionally mint a limited supply of similar or identical items, often to increase their exclusivity and market value, but the quantity need not be limited. Most studies did not include programmability, a function of smart contracts that has not been heavily researched in this arena but which gives them profound advantages in a variety of contexts [26], [22]. This feature can unleash potential for social impact beyond that discussed in the examples provided here.

In addition to capabilities, the literature review uncovered a litany of problems, including transfer of copyright and other rights, legal status of NFTs, know your customer (KYC) and privacy regulations such as GDPR, loss of or damage to the digital or associated physical asset, and errors or fraud in the smart contract code. These are significant concerns that are not well understood by participants in NFT markets, and that will take time to resolve. Further discussion of these issues can be found in [21, 18, 32–34, 35].

Also significant, particularly when stakeholders include the world's most vulnerable populations, are concerns about security of private data and biometrics, the digital divide that puts Web3 technologies out of reach for many, and the “first mile problem” of ensuring that the code, data, assets, and validators for NFTs can be trusted. These and other issues present challenges for blockchain implementation in developing countries [36] and will need significant attention for the potential of NFTs to be realised.

6. NFT Affordances

As a result of their fundamental capabilities, NFTs have affordances that make them uniquely valuable in the pursuit of the SDGs. Different from inherent properties, affordances represent the potential; they are realised when technology is applied by humans to appropriate uses [37]. For example, an affordance of a meal is to reduce hunger when eaten. In an entrepreneurship context, affordances of a particular technology enable its use in creating and capturing economic value [38]. Affordance here will refer to the potential of NFTs to address problems or opportunities that advance the SDGs.

Chalmers et al. [29] describe NFT affordances as the potential to enable users to perform new actions or perform old actions differently. They identify two general affordances enabled by NFTs: ownability, which confers value for digital assets, and verifiability, the ability to evaluate and validate asset ownership [29]. In this section, I explore affordances in depth within the context of sustainable development, focusing on the potential of NFTs to create, deploy, and capture social value.

Beyond ownability and verifiability, NFTs have affordances that position them to make significant contributions towards the SDGs. I propose four critical affordances: NFTs can signify identity, establish ownership, institute claims, and convey history. As a result of their unique attributes and

capabilities, NFTs can play a profound role in promoting the goals and generating social value.

6.1 Signify Identity

The identity affordance refers to the use of NFTs to uniquely signify the identity of persons and things. These things can include digital assets, such as files, domains, transactions, or data. NFTs can replace paper records that identify physical assets, such as land, machines, or Internet of Things (IoT) devices. Identity can also be assigned to digital representations of physical identifiers such as passports and land titles. Because NFTs are unique and tamper-proof, they can reliably and durably represent individual identities. When identities are linked to persons, they are typically associated with access to passwords (“something they know”), biometrics (“something they are”), physical devices (“something they have”), or a combination of the three. For privacy and security, personal information may be stored in a manner in which it can be accessed and shared only by the person, a model known as self-sovereign identity [3, 23, 39].

6.2 Establish Ownership

Identity provides the foundation for ownership to be established. Digital assets and digital representations of physical assets identified by NFTs can be said to be owned by whoever controls them, typically a wallet address or a person or organisation with an identity. NFTs typically reside in digital wallets that are owned by individuals, but they can be owned by groups, organisations, or other entities. What makes NFTs unique is that ownership claims can be publicly verified, and in the absence of human fraud or coercion, they cannot be erased or stolen [3].

6.3 Institute Claims

Claims here refer to rights and credentials conferred to the holder of a token. Claims can be instituted through information about who the holder is, what they own, or what they have earned, purchased, or been given. For example, a token held by a verified citizen may entitle them to vote; a token representing a ticket may entitle its holder to enter an event. NFTs can also be used to represent credentials earned by the holder, such as certificates of attendance, diplomas, and licences, or to provide documentation of work performed or payments made. NFTs representing credentials may confer rights, such as entitling the owner to hold a certain job or practice a profession. Rights can be given to NFT holders by outsiders. For example, food aid might be awarded to NFT holders located in a region experiencing drought. Rights can be attached to NFTs through their smart contracts, and these rights can change based on events and conditions. For example, crop insurance may pay out based on weather.

6.4 Convey History

The term “history” is used here to refer to the historical record of NFT states that can be conveyed through records on the

blockchain. An NFT's history typically includes its provenance—the conditions under which it was created along with its original owner and rights—and a record of all events that have occurred since that time. For static NFTs, this is simply a record of each transfer of ownership. Each transfer is timestamped, and the sending and receiving entities are known. For dynamic NFTs, histories can include almost anything, as the nature and attributes of the NFT can evolve over time. The tamper-proof, time-stamped record of events imbues NFTs with the affordance of verifying history. In addition to the history of the NFT, the history of a wallet, and by extension, the individual holding the wallet, can be verified. For example, NFTs representing signed invoices or receipts for payments held in a wallet can be used as evidence of creditworthiness. NFTs representing medical procedures and receipts could be used as evidence of health status.

Through these four affordances, NFTs can be used to generate trust—trust that someone is who they represent themselves to be, that an object is owned by its purported owner, which a person does possess valid claims, and that events have occurred as attested. While I separate them for analytical purposes, these affordances intersect and complement each other. For example, a person owning land has claims to the use of that land as evidenced by historical records.

7. Illustrative Use Cases

The introduction of NFTs has spurred an explosion of entrepreneurial activity, particularly in 2021 when crypto markets were booming and sales of NFTs were exceeding expectations and creating new markets. In addition to sales, collection, and speculation, there have been efforts on many fronts to begin to use this new technology for the pursuit of social and environmental goals.

To date, the most visible and impactful use cases have been associated with fundraising for charitable organisations that issue NFTs, which are purchased by donors. [40]. Many artists, celebrities, investors, and others have developed new approaches to raise and funnel cash to organisations committed to social change. For example, in 2023, several NFT collections were designed to draw attention to and raise funds for earthquake victims in Syria and Turkey [41, 42]. A web search for NFT and charity renders thousands of projects, which are associated with all of the SDGs. UNICEF, for example, launched a 1,000 NFT project to raise funding for a school connectivity project [43]. Even Charity Navigator, an organisation that evaluates the effectiveness of US charities, touts the potential fundraising benefits of NFTs [44].

Efforts to employ NFTs for direct use in pursuing social goals are far less common. However, a broad range of use cases is now being pursued or considered. These use cases provide a breadth of insights that can be applied creatively in a variety of settings. These efforts are illustrated through two exemplar projects: Ripple's carbon trading efforts and Everest's humanitarian work. These projects serve as case studies of

innovative uses of NFTs and adjacent technologies. Each promotes progress spanning SDG categories and delivers on multiple affordances.

7.1 Ripple

Ripple is a technology company that uses blockchain, crypto, and tokens to provide finance solutions that enable safe, economical, and sustainable exchanges of value. Ripple's carbon trading initiative is enabled by its XRP ledger (XRPL), a public, permissionless blockchain. The XRPL platform and its consensus mechanism, the protocol that ensures that copies of the ledger are synchronised, enable high-velocity transactions with very low financial and environmental costs [45]. Ripple has made significant commitments to support companies building climate infrastructure by providing functionality and tools for XRPL that optimise the ledger for carbon trading [46]. Carbon trading plays an important role in compliance with the Paris Agreement, a binding, multilateral treaty on climate change [47]. Carbon offsets can be earned in two primary ways, through avoidance of emissions, such as through switching to efficient or renewable sources, or through removal, such as through reforestation and sequestering. Self-regulation, incentives, and lack of government oversight result in a market overwhelmed with poor-quality or "junk" credits that do not achieve the claimed reductions [48, 49].

Ripple and its partners use NFTs to represent carbon credits. NFTs can improve the quality of credits by exposing claims about these credits and the authorities making them. This helps to solve problems that have plagued carbon trading markets—in particular the lack of transparency and verifiability that reduces trust in claims relating to the source and validity of credits [50]. With the transparency and security provided by NFTs, carbon markets can function more effectively, and the auditability of sustainable finance is improved. Efficient markets can significantly reduce trading costs, freeing resources for emission reduction efforts [71].

To reduce the cost of compliance, firms can purchase high-quality credits and build portfolios of carbon credits that help achieve sustainability goals [51]. The identities of both the parties that mint NFTs and those that validate the NFTs can be established, which helps to ensure that the credits are original and authentic. The ability to accurately track the identity of purchasers and the timing of the purchases serves to establish ownership of the credits and rights to use those credits in climate reporting. The visible history of purchase and deployment of the credits helps to ensure that they are not re-sold or double-counted.

Efficient and trustworthy carbon markets play an important role in carbon management and reduction. The progress in climate affects all life on the planet and provides differential advantages to populations in lesser developed countries. On the whole, these populations are much more vulnerable, personally and financially, to the impacts of climate change relative to populations in other regions. Ripple and its

collaborators, by establishing markets and facilitating credit trades on XRPL, harness the multifaceted benefits of NFT technology, effectively championing the People, Planet, and Prosperity objectives outlined in the United Nations' SDGs.

7.2 Everest

Everest provides a platform for combining biometric identity with a digital wallet using NFT technologies. The platform offers users the ability to verify identity, transfer value, and access financial services. Everest's humanitarian projects are built around their novel identity solution that cannot be "lost, stolen, denied or transferred" [52]. Biometric data is used to uniquely identify individuals who may not possess an ID card, certificate, or cell phone or other connected device. Biometric data can be combined with other information to provide a richer identity story that can confer additional rights. Information such as membership in a family, village, or tribe, for example, can be established using a variety of triangulation methods for verification and can be reinforced by birth, school, and other records. With identity information stored privately in a wallet that only its owner can open, individuals are able to access a variety of critical humanitarian services while their privacy is protected [53].

Tokens representing rights and entitlements can be delivered to these wallets by agencies and organisations supplying resources. The tokens can be transferred directly and immediately to authorised wallets. Clients can identify themselves to agents who scan clients' biometric data using their own devices. Clients can then exchange their tokens for material or financial resources or for access to services.

One project in Indonesia used Everest's ID and token system to deliver vouchers for fuel tanks. Because the blockchain-based system ensured that tokens were distributed to and exchanged only by recipients entitled to fuel subsidies, fuel resources were directed to their intended purpose. This greatly reduced fraudulent access to fuel and improved accessibility for valid recipients. The natural gas fuel subsidies were used to replace kerosene, a cheap but dirty fuel that damages the health of its users and the environment [53].

By enabling more efficient allocation and delivery of fuels to the people who are entitled to it, Everest used the affordances of NFTs to create social good. Such efforts contribute to furthering the People, Planet, and Prosperity categories of the SDGs.

8. Framework: NFT Affordances and the SDGs

The framework presented in Table 1 showcases a variety of additional use cases that highlight the potential of NFTs to promote the SDGs. The rapidly evolving NFT landscape includes both implemented and proposed applications that serve as examples of how foundational NFT and blockchain technologies can be leveraged within development contexts. These use cases demonstrate the diverse ways in which the unique properties of NFTs can be utilised to address and advance global development objectives.

Table 1: Framework: NFT Affordances and the SDGs

	Signify Identity	Establish Ownership	Institute Claims	Convey History
People	Birth and citizenship records	Proof of livestock ownership	Storage of medical records	Combatting drug counterfeiting
Planet	Smart cities	Community energy	Plastic recycling	Biochar credits
Prosperity	Access to finance	Tokenised leasing	Locally grown coffee	Credit history

8.1 People

Within the people category, NFTs can contribute to goals relating to the provision of basic needs such as sufficient food, clean water and sanitation, education for all, affordable and accessible healthcare, and gender equity. Examples of NFT use cases in this theme include birth and citizenship records, proof of livestock ownership, storage of medical records, and combatting drug counterfeiting.

Birth and citizenship records. A basic need of people everywhere is the ability to prove their identity and citizenship. According to the World Bank, birth registration is less than 50% in many African countries [54]. Proof of identity is needed for accessing services, such as healthcare and education. Lack of access can have devastating personal and social consequences. Everest's Ever ID, discussed above, is designed to address the specific needs of low-income regions. Self-sovereign identity systems give individuals greater control over their personal information [55]. Birth registration and passport information stored via NFT could have further benefits in contexts of war, unstable government, or disaster, where identification may be needed to cross borders or access aid. Wallets and NFTs are also used in developed markets. For example, the UAE, a leader in blockchain and NFT technology, also uses wallets to validate the identity of token holders and uses NFTs for KYC compliance.

Proof of livestock ownership. NFTs for livestock have been proposed for use in the United States, enabling cattle owners to verify the healthcare status and genetic traits of cattle they plan to sell [56]. In developing countries, where many rely on livestock for their primary form of sustenance, NFTs could be used to help people prove their ownership for sales or to aid in recovering stolen cattle. Farmers in South Africa alone have lost tens of millions in USD to livestock theft. Even small losses can be devastating for resource-poor ranchers [57], whose risks may be higher as a result of nomadic seasonal grazing patterns. NFTs could be used to store data from images or hair samples that could be managed and verified by farming authorities.

Storage of medical records. Recent experience with COVID has familiarised the developing world with the importance of proving health or vaccination status. In developing countries,

proof of health status may be necessary for travel and access to services, and it is also valuable information for determining additional healthcare needs. For people living without an easy way to store and maintain paper records, NFTs could be used to record health information linked to decentralised systems and could be accessible to any health provider with access to the internet and permission from the patient. This could improve treatment choices and health outcomes. VeChain has developed an eNFT vaccination certificate that is verifiable worldwide and has partnered with the state of San Marino as its first client [58].

Combatting drug counterfeiting. The World Health Organization [59] reports that “an estimated 1 in 10 medical products in low- and middle-income countries is substandard or falsified.” NFT use in supply chains could help in the tracking and tracing of legitimate pharmaceutical supplies. By embedding token-linked IoT devices, manufacturers can establish provenance and provide for traceability of products through the pharmaceutical supply chain. Authena.io has developed one solution using NFTs. The company reports that smart contracts associated with these NFTs ensure that all participants adhere to agreed-upon terms and conditions for product movement [60]. Through improved tracking security of medical products, NFT technologies can play an important role in global health.

8.2 Planet

In the planet theme, NFTs can be used to promote and support sustainable cities, sustainable consumption and production, climate action, and conservation of life below water and on land. Because air, water, and land systems are tightly interconnected, improvements in one region of the world can have impacts elsewhere. Impoverished regions are among those most heavily impacted by climate change and degradation. Economic and social well-being in these regions is tightly interwoven with environmental health. Examples of NFT use cases in this theme include smart cities, community energy, plastic recycling, and biochar sequestering.

Smart cities. Efficient mobility and transportation in cities are associated with reduced energy consumption, and effective vehicle management plays an important role [61]. Smart city paradigms use IoT devices and artificial intelligence to help manage city functions, including traffic congestion, energy consumption, and emissions [62]. IoT devices need unique identities. In smart cities, NFT-based identification can be used in a number of ways. Ren et al. [63] propose using NFTs to gather intelligence relating to connected autonomous vehicles and to exchange data with other NFTs, thereby reducing the energy cost of networking. Schaar and Kampakis [64] and Li and Chen [65] argue that NFTs can be used for strategic business model expansion. Musamih et al. [61] propose using NFTs for increasing the use of rideshare vehicles. NFTs could be used as simple access keys and, more importantly, could store detailed information about vehicles or users. Improving the efficiency, ease, and quality of vehicle

and ride sharing processes could reduce the use of private vehicles and the need for parking spaces.

Community energy. Energy cooperatives, which fill service gaps in rural regions, also operate in urban regions, promoting use of renewable energy through management of solar panels, energy storage devices, and other systems. Researchers from a Brazilian energy institute have developed a framework that uses NFTs to tokenise the emissions of energy generators, register them as NFTs, and include them in energy portfolios that can be used to manage efficiency [66]. Viable peer-to-peer energy trading models, in which excess electricity is tokenised and traded with neighbours and community members, have been demonstrated by LO3 Energy [67] and Power Ledger [68]. The model enables coops and other purchasers to target the energy characteristics that align with their missions. Increased visibility, transferability, and consumer voice can promote the use of renewables and further the United Nations’ climate goals.

Plastic recycling. Ocean-borne plastic waste is damaging to plants and animals in the ocean and on land. Nozama’s Plastiks platform provides an NFT marketplace that promotes ocean waste recycling [69]. Recyclers are awarded NFTs when they produce invoices for the plastics they have retrieved and sold. Recyclers can sell these NFTs to parties seeking to reduce or offset waste. Producers such as Gravity Wave, which makes products from recycled plastic, can use the NFTs to certify the recovered plastic. This innovation incentivises plastic clean-up and reuse [69].

Biochar credits. BiocharLife teaches smallholder farmers who would otherwise engage in open field burning to sequester biochar. This removes CO₂ from the atmosphere and improves soil health [70]. Farmers are awarded certified carbon sink certificates and can sell them on The Blue Marble platform (thebluemarble.io), which has been supported by the Stellar Community fund. The certificates, which can be stored as NFTs, capture and validate detailed histories of biochar activities. Through this process, farmers improve the air quality and health in their locations, improve their crop yields, and earn extra income from carbon credits.

8.3 Prosperity

Prosperity refers to material and financial wealth and security, particularly in less developed regions. Themes include hunger, affordable energy, poverty, decent work, infrastructure, and inequality. Use case examples in this category include access to finance, lease to own, product claims, and credit history.

Access to finance. In 2017, the World Bank estimated that 1.7 billion adults are unbanked, lacking access to savings and other basic financial services [71]. Savings is often difficult and risky, as individuals lack safe ways to store cash. Informal savings services have arisen to address this problem. For example, in Ghana, susu collectors charge an upfront fee of 3%; money is saved an average of 15 days. Although

expensive, this is a valuable service not widely available globally. NFTs for proof of identity, issued by banks and held in customer wallets, could be used by customers to open accounts and deposit or withdraw savings at multiple locations. Biometric systems tied to individual banks and retail networks have been tested in places like Malawi [72].

Lease to own. Empowa, a partner of Mercy Corps Ventures, uses NFTs to make affordable, climate-smart housing more accessible [73]. In most developing countries, housing represents half of the wealth of the household, and the World Bank has called for new approaches to lending [74]. Through tokenisation, NFTs representing property titles for housing units can be held by real estate companies or could be purchased by impact investors or donors. Renters of these properties would gradually purchase their units through rent payments [75], which can be used to repay investors or fund future housing aid. Tokenisation has also been proposed as a method for making real estate investment accessible to small investors [76].

Product claims. Producers and distributors of some products produced in developing countries can make claims about these products that enable them to capture greater returns than they might otherwise. Products in developing regions may be grown organically or in a region associated with desirable qualities, for example, Blue Mountain Coffee [77]. The inability to validate claims can cause producers to compete with others making false claims, which can dilute the market and damage reputation. NFTs can be used for awarding or storing certifications, making it possible to demonstrate the provenance and characteristics of the products. EverLedger has been a pioneer in this area, using NFTs for holding digital twins and chain-of-custody histories of diamonds, enabling support for the claim that diamonds were mined in conflict-free zones [78].

Credit histories. In low-resource economies, many people lack credit histories, which limits their access to personal and business loans. In subsistence marketplaces, customers lacking the ability to demonstrate creditworthiness are often at the mercy of vendors and other lenders. It is common to be temporarily unable to pay for the food and other resources needed for their families, farms, or small businesses. It is not unusual to pay interest rates of 100% to short-term money lenders [79] or to take on risk by co-guaranteeing group members' microloans [80]. Through the use of NFTs by microlenders or marketplace managers, lending and repayment histories could be stored, and customers could use them to reduce the cost and risk of credit and other ills resulting from the temporary lack of funds. Using blockchain transactions and NFTs to build and demonstrate credit history is being tested in developed markets [81].

SDG 16, which focuses on peace, justice, and strong institutions, and SDG 17, which encourages international partnerships, are broad goals that cannot be addressed easily by individual companies or governments. However, there are a

number of NFT uses that could be employed to address these categories as well. For example, Tracr tracks diamonds to ensure that they are sourced from conflict-free zones [82]. NFTs can be used as digital diamond certificates to ensure transparency of custody and proof-of-ownership [83]. Similar projects could address other conflict minerals and promote peace by reducing financial flows to warring factions in conflict zones. NFTs can promote international partnerships, such as collaboration on humanitarian aid. NFTs can be used to represent physical aid and relief items as well as associated digital manuals, distribution targets, and other information, which can be attached to the NFT. The increased ability to track and manage resources across agencies and organisations can support joint efforts of these entities in the pursuit of social goals.

9. Concluding Remarks

NFTs stand at the frontier of technological innovation, holding vast untapped potential. Mobilising this potential for the advancement of the SDGs can catalyse significant and lasting societal advancements. The inherent attributes of this technology, including uniqueness, ownership, authenticity, and transferability, create potential for addressing problems in new ways. They enable NFTs to be used to signify identity, establish ownership, institute claims, and convey history.

The framework developed here provides a structure for exploring how each of these affordances can be employed in the service of the SDGs. The numerous use cases illustrate how NFTs can be used to promote sustainable development. The examples provide insights into how this tool can be applied in a broad range of contexts. This article thus provides a foundation from which innovative and impactful use cases can be envisioned and ultimately actualised in a way that contributes to positive social change. As progress is realised, the impact on the world's most vulnerable communities and on sustainable development in general can be profound.

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