heritage

MDPI

Article

NFTs and the Danger of Loss

Andreia Nogueira *, Célio Gonçalo Marques, António Manso and Paula Almeida

TECHN&ART—Technology, Restoration and Arts Enhancement Center, Polytechnic Institute of Tomar, Quinta do Contador, Estrada da Serra, 2300-313 Tomar, Portugal; celiomarques@ipt.pt (C.G.M.); manso@ipt.pt (A.M.); paula.almeida@ipt.pt (P.A.)

* Correspondence: andreia-nogueira@ipt.pt

Abstract: This research contributes to the discussion around the importance of the long-term preservation of non-fungible tokens (NFTs) and minted digital artworks. The paper is based on a review of the literature on blockchain in art and heritage management and conservation, with particular attention to references related to the production, marketing, maintenance, and distribution of NFT-based digital art. The aims of this paper involve anticipating potential problems in the oversight of NFTs and setting out good long-term management principles and practices as well as specific preservation strategies. Despite the fact that it also discusses issues over authorship, copyright, creative commons, and open access, the paper is particularly devoted to raising concerns about the high energy consumption associated with blockchain technology and its impact on climate change. It also highlights how the preservation of NFTs cannot be neglected, despite the belief that they last forever. Most studies dedicated to analysing the impact of blockchain technology on the cultural heritage sector ignore the most important issue: preserving not only the minted digital artworks themselves but also the respective blockchain networks. Overall, this paper seeks to foster a collective awareness of the need to reflect on blockchain-related art practices and their implications for the long-term protection of cultural property.

Keywords: digital heritage; preservation; digital technology; blockchain; artworks

Citation: Nogueira, A.; Marques, C.G.; Manso, A.; Almeida, P. NFTs and the Danger of Loss. *Heritage* **2023**, *6*, 5410–5423. https://doi.org/10.3390/heritage6070285

Academic Editors: Nicola Masini and Jason J. Jung

Received: 1 June 2023
Revised: 30 June 2023
Accepted: 12 July 2023
Published: 15 July 2023

1. Introduction

According to UNESCO's Memory of the World Programme document, "In this digital age, the digital preservation of humanity's collective memory can easily be taken for granted". The proliferation of freely available cloud-based platforms for the storage of digital content might lead to the belief that nowadays nothing is forgotten. "However, the new challenges of digital preservation cannot be underestimated" [1].

Similarly, the preservation of non-fungible tokens (NFTs) cannot be overlooked despite the belief they will endure forever [2]. NFTs are, however, also prone to premature disappearance because of their reliance on always-changing and evolving digital technologies, which pose a clear risk of obsolescence. Digital materials and content are generally vulnerable to the loss of bits, information, and access [3], and yet most studies dedicated to analysing the impacts of blockchain technology on the cultural heritage sector ignore the most important issue: the preservation (i) of the actual minted digital artworks and (ii) of the respective blockchain network.

Thus, the aims of this paper involve foreseeing potential problems in maintaining NFTs and their linked digital artworks and collectibles, envisioning good long-term stewardship principles and practices, and targeting preservation strategies. A discussion on whether or not heritage professionals can ethically oppose the maintenance of NFTs is also gaining traction due to the high rate of energy consumption associated with blockchain technology. This is particularly concerning given the urgent need to fight climate change and achieve a green transition.

The methodology applied in this paper draws on a literature review of blockchain-related writing in the arts and heritage management and conservation. This paid special attention to references related to the production, commodification, maintenance, and distribution of NFT-based digital art. The rhetorical method underlined by this paper also aims at opening up a dialogue among different caretakers while fostering a collective awareness of the need to reflect upon blockchain-related artistic practices and their impacts on the long-term protection of cultural property, both considering the maintenance and sustainable preservation of the NFTs themselves and the preservation of cultural property (latu senso) given the nefarious impact of blockchain technology on the environment. This discussion is occasionally also driven by questions of authorship, copyright, creative commons, and open access, as it is hard for heritage professionals to situate their actions according to legal procedures, which do not necessarily relate to digital preservation actions [1].

Blockchain technology has changed the way digital art is traded and will certainly change the way heritage professionals engage with their own practices. They cannot ignore the implications that blockchain technology has brought to the fore, given the clear need to accompany new developments. "Ignoring it within the field of the arts does not make it go away; ignoring it empowers actors outside the field to act without the field's participation" [4] (p. 23). Hence, it is of the utmost importance to have heritage professionals engaged in discussions around the continuity of blockchain, and particularly of NFTs, in the arts.

2. Blockchain Technology and the Ethereum Protocol

Put simply, blockchain constitutes a special and tamper-resistant data structure made of a chain of blocks containing transactions chronologically related to each other. In other words, it is made of a distributed, immutable, and digital ledger of time-stamped recorded information of any kind that cannot be changed subsequent to the recording and verification of a new transaction. This structure is organized into mutually chained blocks in a decentralized and peer-to-peer system, as this is subject to constant verification by a network of peers [5,6]. The ledger exists in many interconnected copies on different computers that serve as nodes, removing the usual need to entrust the data structure governance to any particular central authority because each node maintains an encrypted copy of the records [4,6]. Any new transaction is cryptographically signed by the respective node, which generates its unique cryptographically generated code—the hash value. This value is then added to the next block of transactions while chaining the blocks together [7].

Node operators are constantly required to solve complex mathematical puzzles to find the nonce (a number used only once) through the so-called Proof-of-Work (PoW) mechanism. This involves complex mathematical calculations that are easy to validate but extremely complex to solve [4,7–9]. In return, node operators are rewarded with cryptocurrency (bitcoin, among others) for their work. This computation labour is also known as "blockchain mining" [7,10]. In other words,

> "When a new block is created using the latest transactions, and before it is added to the existing blockchain, the nodes of a peer-to-peer network try to find such a value (a nonce) for the block that will result in a certain number of leading zeros when the block is hashed. Once a node finds such a nonce, the candidate block along with the nonce is sent to the entire peer-to-peer network for verification. If correct, this new block becomes a part of the blockchain, while its link to the existing blockchain is ensured by including the hash of the formerly last legitimate block" [11] (pp. 3–4).

This thereby secures the integrity of the information recorded on the blockchain, as each block is interconnected and dependent on all previous blocks. This means that any attempt to modify a given block will trigger not only the need to modify all the blocks subsequently added but also the need to communicate and validate those changes over the network of nodes [12] (p. 320). Hence, blockchains are exceedingly difficult to break [10].

This also means that, through a consensus mechanism, all the information recorded on blockchains and distributed over the nodes is verified each time new information is added. This thus requires constant synchronization between the interconnected copies of information. Blockchain thereby interrelates "the authority of the algorithm and the consensus of the crowd" [4] (p. 38).

It is also worth mentioning here that both the Bitcoin and Ethereum blockchains, the most widely known examples, consist of public-yet-anonymous ledgers. This means that users have private keys and their corresponding public keys. In this case, transactions are linked to addresses that correspond to users' public keys and not to their names. This provides for a digital signature that enables public tracking and verification of ownership [9,11].

Furthermore, the best-known blockchain data structure is undoubtedly Bitcoin, an extremely popular online cryptocurrency first launched by Satoshi Nakamoto [5]. However, the invention of the time-stamping structure is attributed to Stuart Haber and Scott Stornetta in the early 1990s. Nevertheless, it was Nakamoto's Bitcoin white paper, circulated in 2008, and the launch of the Bitcoin blockchain, in 2009, that projected blockchain technology and brought about waves of discussion within the field of computer programming and beyond [4]. In November 2008, Nakamoto (whose real identity is not known) posted a message entitled "Bitcoin P2P e-cash paper" to "The Cryptography Policy Mailing List", making reference to a "new electronic cash system that's fully peer-to-peer, with no trusted third party" [13]. This message was linked to the paper "Bitcoin: A Peer-to-Peer Electronic Cash System" [14], known as Nakamoto's Bitcoin white paper, which introduced the concept of mining, which incorporates the act of consenting to receive rewards in bitcoins for solving the complex mathematical puzzles necessary to verify the transactions added to the blockchain [4].

The Ethereum blockchain was introduced in 2014 by Vitalik Buterin [4,15]. It is based on a smart contract structure that allows for tokenization [6]. "As a result", and according to Valeonti et al. [5] (p. 4), "the fundamental difference between Ethereum and the Bitcoin blockchain network is that an Ethereum token is created and managed by a so-called "smart contract"" which "can be described as a self-executing contract between two parties, whose terms of the agreement are written into lines of code and whose execution and related transactions are trackable, irreversible, and exclusively controlled by code". This means that smart contracts are executed automatically whenever the specified conditions are met. Over time, several smart contracts became standards. One such contract is the token type ERC-20. Ethereum tokens based on this standard are, however, fungible. This conveys how they are replaceable and interchangeable with other tokens of the same type, just as happens with real-world currencies. By launching the ERC-721 smart contract standard in 2017, Dieter Shirley paved the way for the implementation of non-fungible Ethereum tokens capable of providing for the tracking and transfer of ownership of digital collectibles [5]. The ERC-721 smart contract standard is now most commonly used for trading non-fungible tokens (NFTs) on the Ethereum blockchain [4]. This is also the most popular means of trading NFTs in general, as around 90% of total NFT sales in 2021 took place on the Ethereum blockchain [16].

However, NFTs were first introduced in 2012. Rosenfeld wrote a paper about colored coins, perhaps the first example of a blockchain-based non-fungible asset. Since then, there has been exponential growth in the diversity, quantity, and valuation of NFTs [5,17], even if it was not until 2017 that they gained momentum with Shirley's virtual game CryptoKitties [5], made up of digital collectibles of breedable and adorable cats. These CryptoKitties are not only unique but also cannot be replaced, taken away, or destroyed [18]. This is the same as saying that an NFT is a unique token that certifies the ownership of a given asset, be it material (i.e., artworks, real estate, etc.) or digital (i.e., collectibles, digital artworks, etc.).Valeonti et al. [5] (p. 4) define an NFT "as a *cryptographically unique, indivisible, irreplaceable and verifiable token that represents a given asset, be it digital, or physical, on a blockchain*".

During the pandemic, when physical art events were on hiatus, NFTs attained a soaring level of popularity within the Crypto Art movement.

3. NFTs and the Cultural and Creative Industries

Blockchain technology is being applied generally across the cultural and creative industries for various purposes, including: improving provenance and authenticity; securing ownership; creating artificial digital scarcity; creating new sources of funding or incoming-generating schemes; preserving cultural heritage; among others.

The use of certificates of authenticity to authenticate works of art, especially conceptual or performance-based productions, is current practice for works created by several contemporary artists, such as Sol LeWitt or Felix Gonzalez-Torres, among others. With blockchain technology, authentication may also be combined with provenance, as this allows for establishing a chained record of ownership that nevertheless still depends on the truthfulness of the original recording. The Verisart company, launched in 2015, allows anyone to create trusted certificates for physical or digital artworks. The Artory company also offers collectors the possibility of obtaining certificates of authenticity, in this case, encoded on the Ethereum blockchain. However, Artory only lists those works that have already been vetted by trusted institutions (auction houses, galleries, to name a few) engaged in prior provenance research [4].

Clara Bacciu et al. [12] developed the blockchain-based application MApp (which stands for Minor Artworks Application) aimed at protecting what they called "minor artworks", those that are relevant but not as famous as masterpieces. According to the authors, this application takes advantage of the use of the IPFS (InterPlanetary File System) system for the storage and management of the associated digital archives. Clara Bacciu et al. [12] argue that MApp enables authenticated users to register their artwork. This thereby secures their protection, as, on the one hand, records cannot be erased, preventing any malicious attempt related, for instance, to stolen artworks. On the other hand, the recorded information will serve as a memory keeper in case of destruction caused by natural-related hazards or armed conflicts [12].

In the case of intangible cultural heritage, it has been argued that its future preservation depends on developing digital preservation strategies based on blockchain technology as these enhance security and traceability within the scope of protecting digital information against malicious tampering or attacks [19] as well as providing invaluable and immutable documentation records [6].

Blockchain has also been applied to enable users to track changes in web-based digital content, which is prone to retrospective modifications as it is neither tamper-resistant nor time-stamped. Stealth editing regularly occurs in online content (e.g., news articles, blogs, tweets, etc.). This is particularly problematic when one considers that most information nowadays is digital-only, and it is crucial for future generations to be able to access untampered information. Ensuring its preservation, integrity, and originality represents a major current concern for heritage professionals entrusted with the maintenance of digital cultural heritage, whether born digital or made accessible through digitization [20]. For instance, Bela Gipp has introduced OriginStamp [21], "a web-based service that can be used to create automatic trusted timestamps for any online content" [20]. This works very similarly to the Internet Archive service Wayback Machine. OriginStamp, though, ensures tamper-proof trusted timestamps through its application of blockchain technology.

However, in the cultural and creative industries, blockchain technology has mostly served to deal with a complex and difficult topic: introducing artificial digital scarcity and securing ownership of digital artworks that are easy to reproduce, change, and disseminate [4,5]. One of the first attempts was carried out by the artist Kevin McCoy together with the technologist Anil Dash in 2014 [4,10,22,23]. They together created and developed Monegraph, which stands for "monetized graphics", which allows artists to trade their digital artworks through a smart blockchain contract in which they "specify sales conditions and sharing rights for their works" [4] (p. 35). Monegraph was designed

with the objective of enabling artists to generate financial revenue from their digital artworks by tying them to virtually unforgeable identities. This makes such digital artworks artificially unique and hence have commercial value. Thus, digital scarcity only exists within the blockchain network. An artist can thereby mint an NFT from already thoroughly disseminated digital artwork. Blockchain technology correspondingly introduces a new way of trading digital assets without changing their nature. Currently, blockchain allows artists to take advantage of digital reproducibility to increase the value of their works. This happens because the blockchain protocol does not restrict the proliferation or circulation of digital assets [10].

There is now a common reference to how NFTs allow for the trading of digital assets of whatever kind by securing ownership and introducing artificial digital scarcity. Indeed, NFTs make it possible to record proof of ownership of unique assets in the public blockchain network registry [5]. For instance, this allows artists to sell their digital works in a process that is in many respects very similar to the traditional art trade market and also extends across such aspects as intellectual property rights and copyright law [4–6].

Thus, tokenization interrelates with the crypto art movement, as crypto artworks are accompanied by cryptographic certificates, which are themselves NFTs [24]. There are now several crypto art marketplaces, such as SuperRare, OpenSea, Rarible, and Nifty Gateway, among others. When an artwork is uploaded onto SuperRare, for instance, a transaction is generated on the Ethereum blockchain in the form of an NFT, which is then transferred to the owner's cryptographic wallet. Usually, any subsequent sales also reward the original artist or owner [25].

The interest in using NFTs to create new revenue opportunities not only for artists but also for the GLAM (galleries, libraries, archives, and museums) sector and beyond was sparked by the multimillion-dollar sale of the cryptographic token for the work *Everydays: The First 5000 Days*, created by the digital artist Mike Winkelman, also known as Beeple. This NFT was sold, in March 2021, by Christie's auction house for an astonishing record of $69 million [5,26]. *Everydays* was then "ranked as the third most expensive work sold at auction by a living artist, causing many in the art world to pause and evaluate the potential of NFTs" [5] (p. 5). Almost simultaneously, Jack Dorsey sold Twitter's first-ever tweet as an NFT for about $2.9 million [5,27].

In the article "Crypto Collectibles, Museum Funding, and OpenGLAM: Challenges, Opportunities, and the Potential of Non-Fungible Tokens (NFTs)", Foteini Valeonti et al. (2021) analyse the potential of NFTs for GLAM sector fundraising. As a matter of fact, several institutions are already generating financial gains by selling cryptographically signed copies of digital images, usually representing the physical artworks they hold in their collections [5,28]. Taking the lead in the GLAM sector, the Uffizi Gallery, for instance, was the first major art museum to sell an NFT. The token was created or minted as a cryptographically signed digital copy of the Uffizi Gallery's Michelangelo masterpiece Doni Tondo. The NFT was sold for $170,000 in May 2021 [5]. Another example is the Cinello company, which has established collaborations with several museums in Italy to create digital representations of masterpieces, which they named DAW (Digital Artwork). For each DAW, an NFT is created or minted on the Ethereum blockchain. 50% of revenues return to the museum that owns the artwork [29].

The study undertaken by Ertürk et al. (2021) in this field is also of interest [30]. They introduced a blockchain-based platform, called Heirloom, which allows for the creation of NFTs, under the ERC-721 smart contract standard, tested and implemented on the Ethereum and Avalanche blockchains, designed to fundraise for the protection of old olive trees [30].

NFTs are currently also supporting the people of Ukraine in their fight against the Russian invasion [31]. The Ukraine Government launched the NFT museum, the *Meta History: Museum of War*, which encompasses an ever-growing collection of NFTs, on the Ethereum blockchain, related to major events of the war artistically represented and interpreted by well-known artists. The aim is to preserve the history and the memory of

the war for eternity while simultaneously raising funds for Ukraine's army and civilians to protect against the Russian invasion. The MetaHistory NFT museum, as one can read on its Webpage, was established "to commemorate the history of the current events in Ukraine, preserve the truth, and collect donations for humanitarian aid" [32]. The total funds raised stood at $1,487,145 as of 14 May 2023 [32].

Despite their advantages, NFTs and other blockchain-related products have also attracted strong criticism because these structures of blocks and chains nevertheless display certain vulnerabilities:

First—The mining is theoretically carried out by many disconnected computers and their actors in a decentralized manner. However, the problem stems from how, in practice, mining is undergoing geographic and organizational concentration. Before China's share of global bitcoin mining capacity plummeted to zero in July and August 2021 due to the crackdown on cryptocurrencies enforced by the Chinese authorities, 65% to 75% of the world's bitcoin mining took place in China's mining hub. The United States of America now occupies the first place in crypto mining [33]. There are also several mining pools, such as F2Pool, AntPool, Poolin, and ViaBTC, among many others.

Second—Despite the belief that blockchain technology is tamper-free, the fact remains that it is still prone to malicious attacks. The case of the so-called "51 Percent Attack" is a matter of current concern because a mining hub controlling more than half of the total hash rate can theoretically (though unlikely) lead to a 51% attack on the network by manipulating transaction records retroactively [10,34].

Third—Mining consumes high amounts of energy because of the computing power required to find the nonce through the high-energy-consuming PoW validation method [4,5,35]. For instance, according to Amy Whitaker, writing in 2019, "the computer power required by the Bitcoin network alone is equivalent to all the power consumed by Ireland" [4] (p. 31). Furthermore, Valeonti et al. (2021) stress that as of May 2021, the Ethereum energy consumption was estimated at 48.7 Tera-Watt Hours (TWh) per annum, equating to the annual energy consumption of Malta [5]. In the article "Cultural Heritage Preservation by Using Blockchain Technologies", published in 2022, Denis Trek points out that "the global energy consumption for Bitcoin (mining) exceeds the needs of some developed economies such as Switzerland" [11] (p. 4). This clearly demonstrates an increasing level of energy consumption over the last three years. Fortunately, on 15 September 2022, Ethereum completed its transition to the Proof-of-Stake (PoS) consensus mechanism. This transition is more commonly known as "the merge". According to the Ethereum Foundation, this transition reduces Ethereum's energy consumption by about 99.95%. The Ethereum website states that the transition "eliminated the need for energy-intensive mining and instead enabled the network to be secured using staked ETH". "It was a truly exciting step in realizing the Ethereum vision—more scalability, security, and sustainability" [36]. Expressed simply:

> "Rather than finding a nonce, a node is selected to mine the next block using a pseudorandom lottery. The larger the node's stake of coins in proportion to the rest of the network, the higher the chance of being selected to mine a block. Similarly, to PoW, the header is hashed, but rather than spending large amounts of electricity, constantly hashing different nonces, PoS does one calculation. If the coin age > blockhash/target, the node can create a new valid block" [9] (p. 6).

The merge is, however, too recent for any accurate analysis of its success in comparison to the PoW mechanism. This transition does not directly reduce gas fees, for instance. Other improvements to the Ethereum blockchain are also planned for the near future in order to strengthen it and counter other weaknesses [36].

Fourth—Despite not being commonly recognized, blockchain technology increases the production of electronic waste (e-waste). E-waste constitutes a problem that extends far beyond the blockchain industry, but the fact remains that node operators are constantly seeking to upgrade their computing power. This means computers and peripheral devices are frequently replaced by new versions with higher performance standards. This becomes quite problematic considering that the global production of e-waste is approximately

50 million metric tons a year and is forecast to reach an annual level of 120 million metric tons by 2050. Unfortunately, only 20% of the e-waste produced is formally recycled [37].

Fifth—When a buyer purchases an NFT, he or she only gains access to the token through the blockchain platform that mediates the process. So, the collector does not actually have control over the NFT or the digital asset it represents, as this is normally stored off-chain on proprietary systems [24,38–40]. This happens due to the expensive gas fees associated with any blockchain-related operation due to the great computation inputs required. Gas fees are paid to node operators for their work. They lend their computers' resources to store copies of blockchains and record their new transactions [5,41]. Therefore, the problem with NFTs and cryptocurrencies, in general, is that they "can only be taken advantage of via unreliable third-party applications" [40].

Sixth—Due to the public-yet-anonymous crypto space, there are already some attempts to gain financial advantage from the images made freely available through cultural institutions and organizations adopting the OpenGLAM movement principles [5]. Other examples exist of individuals attempting to extract money out of the works of other artists, sometimes even using their names without their consent or permission [23,41,42]. As expressed by the computer scientist Elian Carsenat, "an NFT is essentially a unique ID associated with a unique wallet address". Nothing prevents creating multiple NFTs associated with the same digital object on a blockchain, or even on multiple blockchains. This process (be it "copy minting", plagiarism, or even self-plagiarism) is really hard to circumvent, as any image or digital object with a tiny difference is effectively a different object [43].

Seventh—Collectors also face the danger of accidentally selling NFTs for a price significantly lower than their value due to human errors in crypto art marketplaces [44]. Technology does have its disadvantages and remains at the mercy of humankind! Or perhaps humankind does not show mercy to themselves and is bent on taking advantage of whatever appears (especially in the digital realm) to make a profit without taking into consideration what is at stake and the Other. The traditional art trade market is more physical and face-to-face and thus not as susceptible to this sort of event.

Eight—NFTs are prone to early obsolescence due to their utter dependence on software and hardware equipment, making them extremely vulnerable to the passage of time and the constant actualization of digital technologies [24]. However, this topic has not yet received much debate but is nevertheless of the utmost importance. The following section thoroughly analyses and discusses this factor.

4. On Digital Preservation: The Danger of Loss

When a purchaser buys an NFT, he or she usually buys the right to own the digital material linked to the non-fungible token purchased, which is correspondingly transferred to the new owner's cryptographic wallet. Therefore, preserving NFTs involves actively engaging with the preservation of digital assets alongside maintaining the environment and context they live in as well as ensuring ongoing access (as also applies to other forms of digital heritage [45]).

The ICCROM (International Centre for the Study of the Preservation and Restoration of Cultural Property) report *The Digital Imperative: Envisioning the Path to Sustaining our Collective Digital Heritage. Summary of research findings & opportunity assessment* (2021), included findings highlighting the needs, challenges, and goals of heritage professionals dealing with the maintenance of digital heritage. The report stemmed from interviews with over 30 heritage professionals who raised a number of critical points and concerns. They particularly stressed how they are struggling to decide what to collect or keep, given the vast amount of digital material produced nowadays. They also identified the difficult task of keeping up with access to digital content, as this demands the maintenance of a reliable storage environment as well as constant data migration procedures while also ensuring the prevailing security of data. The respondents also reported challenges in dealing with and communicating with technologists, who usually do not grasp the needs of heritage professionals. Several interviewees also addressed the issue of high energy

consumption involved in maintaining digital archives, pointing to the urgent need for a commitment to design systems with low energy demands. Other interviewees proposed that new training programs approaching the best digital formats and standards for the long term, coupled with clear guidance concerning what to keep, were of the utmost importance and prominence. Heritage professionals cannot save and preserve everything. This correspondingly reflects the following:

> "It is difficult to be faced with the enormity of the challenge sustaining digital heritage and not feel the need to try to do everything. Collect everything. Digitize everything. Catalogue everything. Make everything accessible. But the truth is, sustainability requires prioritization. We can't do everything at the same time, all the time, forever. Attempting to do so can often lead to suboptimal results and overwhelming backlogs" [46] (p. 27).

This is even more important when considering that institutions are forecast to experience an estimated 42% annual growth rate in their data volumes [47]. Indeed, not everything can be maintained, and there is also discussion around who should decide what to keep and how to accordingly manage limited financial resources. Heritage institutions and their professionals thus face challenges in providing ongoing resources for maintaining their digital archives, which are often at odds with the current project-based funding schema. In short, as underlined by the report's authors, "our entire digital heritage is at stake" [46] (p. 7). This has already been underlined in the Charter on the Preservation of Digital Heritage adopted by UNESCO on 15 October 2003. In Article 3, one can read that "digital heritage is at risk of being lost to posterity. Contributing factors include the rapid obsolescence of the hardware and software that bring it to life, uncertainties about resources, responsibility, and methods for maintenance and preservation, and the lack of supportive legislation". Due to the rapid evolution of digital technology, institutions, and governments have not been able to keep pace with developing timely and informed strategies for long-term preservation. This means that "unless the prevailing threats are addressed, the loss of the digital heritage will be rapid and inevitable" [45].

Born-digital material should be given priority and acknowledged as an urgent issue of global concern. Likewise, the preservation of NFTs and the digital assets they are linked to should be considered an urgent matter, given the novelty of the digital technologies employed and the lack of studies devoted to questions of sustainability, maintenance, and archive.

The fact remains that digital has now become by far the most common and dominant mode of cultural expression and communication. To keep up with the digital world, heritage professionals are asked to constantly remain updated as digital technologies quickly evolve. However, this is not easy to accomplish. Contemporarily, "for many heritage professionals, the prospect of maintaining a digital presence that serves both audiences and artifacts often feels *unsustainable*. Sustaining digital heritage feels like an imperative—digital is clearly here to stay—but simultaneously an impossibility" [46] (p. 6). How can we then achieve sustainability in this context? And more particularly, how can we deal with the preservation of NFT-based digital art without calling into question the quest for sustainability?

One of the fundamental components of sustainable digital preservation practices is storage and deploying reliable storage environments and infrastructure [46]. The digital assets (i.e., images, sounds, etc.) the tokens are linked to are often stored either on centralized or distributed storage systems. Origin NFT Launchpad, for instance, uses the company's own centralized servers [5]. A link may then be inscribed on the token metadata to establish the necessary connection between the token and the digital asset it represents. However, the distributed or peer-to-peer storage system IPFS is the most widely used in this context [5,48,49]. IPFS assigns each content an immutable address by applying a hash function to every content [12]. The IPFS Webpage states that it is able "to store large files off-chain and put immutable, permanent links in transactions—timestamping and securing content without having to put the data itself on-chain" [50]. It also declares that

"for long-term storage, users can use the Filecoin network!" [51]. Filecoin is an open-source and decentralized cloud storage network [52].

The marketplace Rarible applies the IPFS system by default while making it clear that "collectibles created on Rarible have their collectible descriptors stored on the IPFS system through an IPFS node operated by Rarible Company, but Rarible Company cannot guarantee continued operation of such an IPFS node or the integrity and persistence of data on IPFS" [53]. This, however, is not the common and widespread perspective of the IPFS inner workings. For example, Cuesta Valera et al. (2021) stressed that the IPFS is more suitable for preservation purposes than other centralized systems as it achieves greater compatibility with current long-term digital preservation practices, which rely on the maintenance of multiple copies of the same material distributed over different storage environments [24]. Maybe for this reason, Bacciu et al. state that the "use of IPFS for recordkeeping can guarantee digital preservation" [12] (p. 322). Unfortunately, this is not the case. The continual maintenance of IPFS is dependent on the continual existence of Protocol Labs, the organization that supports IPFS. Moreover, IPFS node operators are constantly clearing out some of their previously cached resources to make space for new resources through a process called garbage collection. Hence, financial incentives are required for nodes to pin the content they would want to maintain infinitely on IPFS [49]. This is to say that both centralized and decentralized storage systems require financial incentives to ensure the continuous maintenance of stored material. There is simply no guarantee that digital assets will be maintained forever.

Therefore, when someone buys an NFT, he or she has to make sure that the digital assets the token is linked to are being taken care of. The worst-case scenario is to have the NFT connected to an URL link that is prone to change and early loss. No one can guarantee its integrity or maintenance over time [39,49]. Therefore, "when someone buys an NFT, they're not buying the actual digital artwork; they're buying a link to it. And worse, they're buying a link that, in many cases, lives on the website of a new start-up that's likely to fail within a few years" [23]. In several cases, buyers can see the NFT transaction logged on the blockchain, but they cannot see or find the digital artwork, collectible, or other digital asset the token should supposedly link to. There are also cases of NFTs disappearing from the buyers' cryptographic wallets because of the system's reliance on mediating platforms, which are sometimes incompatible with new smart contract standards [40].

NFT purchasers also face the danger of losing access to cryptographic wallets and keys. This is applicable to any token or cryptocurrency. Some NFT platforms were developed to manage the cryptographic keys of users (allowing for password recovery and account retrieval), acting on their behalf as custodial wallets. However, should these platforms ever become compromised, users will no longer be able to access their NFTs because they are not stored in their own cryptographic wallets [5]. There are already cases of some exchanges being hacked, including Mt. Gox, QuadrigaCX, BTC-e, and Bitstamp [54]. Nevertheless, users relying on non-custodial crypto wallets—those they manage directly—also face the danger of loss because a retrieval system for cryptographic keys and wallets has yet to be developed without compromising the blockchain network. For instance, a user who forgets his or her wallet's cryptographic key will immediately lose access to the wallet's content as there are no means of retrieving keys [5].

Last but not least, collectors also face the risk of losing their NFTs because of the precarious system which was set up to keep ledgers updated. According to Denis Trček [11] (p. 5) "the current incentives to keep ledgers operational are rather rudimentary—direct payment (monetary reward) in return for the efforts expended, while this monetary reward is highly volatile".

Hence, blockchain still has to cope with several drawbacks that are not easily overcome. One may even question whether blockchain technology is, after all, sustainable and suitable for the trading of digital artworks or collectibles. For instance, certificates of authenticity have long since functioned for the trading of conceptual art, generating a much lower carbon footprint than NFTs [48]. Trevor Owens and Jon Ippolito share the perspective

that one does not need NFTs to write contracts to establish ownership rights or to secure provenance and authenticity [42,48]. NFTs are dependent on the veracity of the blockchain-recorded information, which in some cases does not do justice to the truth [4,42]. To provide just one example, in June 2018, Terence Eden listed the Mona Lisa on the Verisart blockchain, claiming to have created the work in 1506 [4]. According to Owens, "NFTs look to be a non-solution to a non-problem" [42], because he considers there are a range of other traditional ways to trade digital assets, mostly based on the establishment of written contracts or certificates, along with the necessary documentation [42].

The future of NFTs remains uncertain, along with the multi-millionaire investments made by some collectors. The Tara Digital Collective, a consultancy and gallery program that hosts an on-chain artist collective, has developed an NFT conservation toolkit precisely to assist artists in dealing with the "fragility" and "volatility" of NFTs as well as to "help both artists and collectors navigate the preservation challenges that remain both before work is minted and well after it is purchased" [55].

5. An Ethical Controversy

To add further depth to the discussion on the preservation of NFTs and their linked artworks, we also need to return to environmental issues and related ethical concerns.

Bacciu et al. [12] (p. 319) state: "Blockchain technology can prove to be effective in keeping digital archives of works of art secure and up-to-date, providing an aid for protection against natural and environmental disasters, war damages, and organized crime". The missing link in this reasoning is that blockchain does not preserve anything forever and that its high energy consumption also threatens the future preservation of cultural heritage, whether born-digital or otherwise. It is thus rather curious that the same technology that claims to be preserving our cultural heritage is also killing it. While there are a number of authors advocating in favour of the benefits of using blockchain technology for preservation purposes (as already demonstrated), there are others already warning of its devastating impact on the climate and consequently on the protection of natural and cultural heritage monuments, sites, etcetera.

And this is clearly of the utmost prominence given that, on 18 April 2022, the International Day for Monuments and Sites, UNESCO warned that one in three natural sites and one in six cultural heritage sites are already under threat due to climate change-related hazards [56]. The UNESCO 2021 report *World Heritage forests: Carbon sinks under pressure [57]* reveals that a staggering 60% of World Heritage forests are threatened by climate change-related events. We should also reference that two-thirds of marine sites are equally under pressure according to the UNESCO 2021 *Marine World Heritage: Custodians of the globe's blue carbon assets* [58].

This demonstrates the urgency of the need to ensure the culture and creative industries' support for carbon budgets. There is a private sector-led Crypto Climate Accord, which aims to decarbonize the global blockchain and cryptocurrency industry and achieve net-zero emissions by 2040 [59]. Is this going to succeed? Is the planet capable of waiting for so long?

The artist Everest Pipkin claims that "the only viable option is total moral rejection" of blockchain technology because other, more eco-friendly systems, based, for instance, on the energy-efficient PoS method, have been under development almost since the beginning and yet they still lack success [60]. NFTs are already registered and traded on energy-efficient PoS blockchain networks, as is the case of Tezos, Cardano, and Algorand, among others, but without the same degree of success as NFTs based on high energy-consumption PoW blockchain networks [5]. The transition made by Ethereum to the PoS mechanism in September 2022 is too recent to be evaluated. Nevertheless, this provides an important and long-awaited change that can effectively alter the course of future developments and inspire a new and more promising future for blockchain technology.

Furthermore, this question of energy consumption is not restricted to NFTs, as it reflects an overarching concern for all digital archiving. NFTs just make things worse. This

is effectively the same as asking, Is it ethical to preserve what is destroying our planet? Is it ethically permissible to have museums and heritage professionals support technology that consumes such high levels of energy, causing even greater climate change? How should these issues be analysed from a legal perspective?

Legal frameworks are generally put in place to support communication, commodification, and dissemination. However, these legal frameworks do not necessarily cater to digital preservation actions. This is even more evident in the case of NFTs. The absence of any clear legal framework for commodification and trade jeopardizes the development and application of new and clear guidance regarding authorship and copyright rights.

This inevitably makes it difficult for heritage professionals to situate their actions according to ethical and legal procedures. This means that "preservation practitioners would benefit from clear copyright laws that explicitly address the digital preservation scenarios" [1], while also exploring the potential ethical implications of an environmental crime against humanity.

Overcoming this issue requires a Creative Commons license. This might involve a CC0 license, making the work public without an identified author, or using any of the other possible combinations [61]. This represents only a temporary solution while new regulations are put in place to address these new digital possibilities [62].

Nevertheless, even this use of Creative Commons licenses raises several questions. Assigning a CC0 license means that everyone has the right to copy, alter, and distribute works, even though this does not affect ownership of the token. However, if everyone can access the work, what reason is there for investing in it? Here, acquiring the token may hold meaning for the buyer when it is his or her intention to be the author's patron [61]. Copyright and token ownership remain two different facets that are not necessarily overlapping. Thus, the token can be sold again with the copyright remaining unchanged.

CC0 allows everyone to use a work in the same way and cannot be made conditional on usage for commercial purposes. When creating an NFT, the copyright must be respected, if this does not extend to commercial usage, then the author's permission must be sought. Creative Commons licenses do not have specific rules for NFTs; however, they safeguard the copyright of creative works. Unfortunately, NFT creation does not always respect copyright, which must inherently be contested.

6. Conclusions

NFTs do not preserve artworks for eternity, despite common belief. While NFTs do embody permanence because of their immutability, their endurance nevertheless depends on the continuous maintenance of the blockchains themselves, for which there are no particular guarantees. Any NFT only preserves the history of transactions related to a particular blockchain ledger and the selected metadata associated with the minted artwork, usually pointing to a link to Google Drive, DropBox, the owner's personal server, or the IPFS network, to name but a few. Therefore, the artwork will only survive:

First—as long as that link is maintained, along with the artwork itself. For that reason, compressed formats should be avoided so as to avert early bit degradation, which can also compromise long-term access. Migration procedures should also be taken into consideration in order to keep digital formats updated and readable. Whenever possible, the digital artwork should also be stored on external hard drives distributed over different geographic locations to prevent any eventual loss.

Second—as long as the blockchain network itself is maintained, as well as those third-party platforms that usually mediate communications between the buyer or seller and the blockchain mining community. For long-term preservation purposes, open-source blockchain-related platforms should be given priority because, should the platform become compromised, anyone can retrieve the information as the underlying code is open and freely available.

This demonstrates that traditional approaches to cultural heritage preservation remain a good standard for the preservation of NFTs and linked artworks or collectibles. It is not

clear, however, who is responsible for maintaining the artwork itself and its link to the token. This raises certain questions: Years from now, who can guarantee whether the linked artwork will survive and that it is exactly the same as when it was minted as an NFT? Can collectors trade NFTs with broken links or lost artwork? What is likely to happen to their economic value? How do you deal with this when such great sums of money are involved and susceptible to loss with just one click? How will blockchain platforms and crypto art marketplaces deal with this? How do you manage ownership rights and intellectual property rights in this context? To further deepen this discussion, it is also important to ask: Is it ethical for heritage professionals to oppose the preservation of NFTs? How would this be analysed from a legal perspective?

As far as preservation is concerned, there is still an ongoing discussion that particularly requires attention considering the potential for ethical controversy around NFTs. The main ethical problem with conservators or heritage professionals dealing with NFTs stems from how they encourage the continual maintenance of the blockchain industry and, through this, the destruction of other cultural assets due to the enormous carbon footprint of blockchains. This position is thus controversial because one is forced to choose what to preserve. It is not possible to maintain market-traded NFTs without jeopardizing other cultural and natural sites that are particularly prone to natural hazards brought about by the increasingly advancing climate changes.

Are NFTs likely to become lost in the near future? Only time will tell how long they survive.

Author Contributions: Conceptualization, A.N.; methodology, A.N.; validation, A.N., C.G.M., A.M. and P.A.; formal analysis, A.N., C.G.M., A.M. and P.A.; investigation, A.N., C.G.M., A.M. and P.A.; writing—original draft preparation, A.N., C.G.M., A.M. and P.A.; writing—review and editing, A.N., C.G.M., A.M. and P.A.; visualization, A.N., C.G.M. and P.A.; supervision, C.G.M. and A.M.; All authors have read and agreed to the published version of the manuscript.

Funding: Work funded nationally by the Portuguese National Funding Agency for Science, Research and Technology (FCT) under the project UID/05488/2020-TECHN&ART.

Data Availability Statement: Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Documentary Heritage at Risk: Policy Gaps in Digital Preservation, Prepared by the Preservation Sub-Committee of the International Advisory Committee of the UNESCO Memory of the World Programme. UNESCO 2021. Available online: https://en.unesco.org/sites/default/files/documentary_heritage_at_risk_policy_gaps_in_digital_preservation_en.pdf (accessed on 20 May 2022).
2. Sycip, G. Crypto, Non-Fungible Tokens and the Potential of the Metaverse in Cultural Heritage Preservation. Global Heritage Fund 2021. Available online: https://globalheritagefund.org/2021/12/08/crypto-nft-metaverse-cultural-heritage-preservation/ (accessed on 7 June 2022).
3. Falcão, P.; Ensom, T. Conserving Digital Art. In *Springer Series on Cultural Computing*; Springer: Cham, Switzerland, 2019; pp. 231–251. [CrossRef]
4. Whitaker, A. Art and Blockchain. A Primer, History, and Taxonomy of Blockchain Use Cases in the Arts. *Artivate A J. Entrep. Arts* **2019**, *8*, 21–46. [CrossRef]
5. Valeonti, F.; Bikakis, A.; Terras, M.; Speed, C.; Hudson-Smith, A.; Chalkias, K. Crypto Collectibles, Museum Funding and OpenGLAM: Challenges, Opportunities and the Potential of Non-Fungible Tokens (NFTs). *Appl. Sci.* **2021**, *11*, 9931. [CrossRef]
6. Vacchio, E.D.; Bifulco, F. Blockchain in Cultural Heritage: Insights from Literature Review. *Sustainability* **2022**, *14*, 2324. [CrossRef]
7. McConaghy, M.; McMullen, G.; Parry, G.; McConaghy, T.; Holtzman, D. Visibility and digital art: Blockchain as an ownership layer on the Internet. *Strateg. Chang.* **2017**, *26*, 461–470. [CrossRef]
8. Whitaker, A.; Bracegirdle, A.; de Menil, S.; Gitlitz, M.A.; Saltos, L. Art, antiquities, and blockchain: New approaches to the restitution of cultural heritage. *Int. J. Cult. Policy* **2021**, *27*, 312–329. [CrossRef]
9. Auhl, Z.; Chilamkurti, N.; Alhadad, R.; Heyne, W. A Comparative Study of Consensus Mechanisms in Blockchain for IoT Networks. *Electronics* **2022**, *11*, 2694. [CrossRef]

10. Zeilinger, M. Digital Art as 'Monetised Graphics': Enforcing Intellectual Property on the Blockchain. *Philos. Technol.* **2018**, *31*, 15–41. [CrossRef]
11. Trček, D. Cultural heritage preservation by using blockchain technologies. *Herit. Sci.* **2022**, *10*, 6. [CrossRef]
12. Bacciu, C.; Duca, A.L.; Marchetti, A. A Blockchain-based Application to Protect Minor Artworks. In Proceedings of the 15th International Conference on Web Information Systems and Technologies (WEBIST 2019), Vienna, Austria, 18–20 September 2019; pp. 319–325. Available online: https://www.scitepress.org/Papers/2019/83479/83479.pdf (accessed on 3 June 2022).
13. Bitcoin P2P e-Cash Paper. Available online: https://www.mail-archive.com/cryptography@metzdowd.com/msg09959.html (accessed on 31 May 2022).
14. Nakamoto, S. Bitcoin: A Peer-to-Peer Electronic Cash System. Available online: https://bitcoin.org/bitcoin.pdf (accessed on 31 May 2022).
15. Buterin, V. Ethereum White Paper. A Next-Generation Smart Contract and Decentralized Application Platform. Available online: https://blockchainlab.com/pdf/Ethereum_white_paper-a_next_generation_smart_contract_and_decentralized_application_platform-vitalik-buterin.pdf (accessed on 31 May 2022).
16. CoinTelegraph Research. Available online: https://cointelegraph.com/news/blockchains-vie-for-nft-market-but-ethereum-still-dominates-report (accessed on 31 May 2022).
17. da Veiga, P.A. The Everywhere Museum of Everything: The Curatorship Challenge, from Digital Urban Art to NFTs. In *Art, Museums and Digital Cultures. Rethinking Change*; Barranha, H., Henriques, J.S., Eds.; Institute of Art History, School of Social Sciences and Humanities, Universidade NOVA de Lisboa: Lisbon, Portugal; MAAT: Lisbon, Portugal, 2021, ISBN 978-989-54405-4-2.
18. Cryptokitties. Available online: https://www.cryptokitties.co/ (accessed on 31 May 2022).
19. Huang, W.; Dai, F. Research on digital protection of intangible cultural heritage based on blockchain technology. *Inf. Manag. Comput. Sci. (IMCS)* **2019**, *2*, 14–18. [CrossRef]
20. Gipp, B.; Meuschke, N.; Beel, J.; Breitinger, C. Using the Blockchain of Cryptocurrencies for timestamping Digital Cultural Heritage. *Bull. IEEE Tech. Comm. Digit. Libr. (TCDL)* **2017**, *13*. Available online: https://www.gipp.com/wp-content/papercite-data/pdf/gipp2017a.pdf (accessed on 30 May 2022).
21. Originstamp. Available online: https://originstamp.com/?utm_source=org (accessed on 30 May 2022).
22. Lotti, L. Contemporary art, capitalization and the blockchain: On the autonomy and automation of art's value. *Financ. Soc.* **2016**, *2*, 96–110. [CrossRef]
23. Dash, A. NFTs Weren't Supposed to End Like This. The Atlantic 2021. Available online: https://www.theatlantic.com/ideas/archive/2021/04/nfts-werent-supposed-end-like/618488/ (accessed on 6 June 2022).
24. Valera, S.C.; Valdés, P.F.; Viñas, S.M. Salvador. NFT y arte digital: Nuevas possibilidades para el consumo, la difusión y preservación de obras de arte contemporáneo. *Artnodes Rev. Arte Ciência Tecnol.* **2021**, *28*, 2. [CrossRef]
25. Franceschet, M.; Colavizza, G.; Smith, T.; Finucane, B.; Ostachowski, M.L.; Scalet, S.; Perkins, J.; Morgan, J.; Hernández, S. Crypto Art. A Decentralized View. *Leonardo* **2021**, *54*, 402–405. [CrossRef]
26. Kaczynski, S.; Kominers, S.D. How NFTs Create Value. Harvard Business Review 2021. Available online: https://hbr.org/2021/11/how-nfts-create-value (accessed on 7 June 2022).
27. Shapira, A. On Heritage and NFT: Challenging the Meaning of Legacy Itself. Cointelegraph 2021. Available online: https://cointelegraph.com/news/on-heritage-and-nft-challenging-the-meaning-of-legacy-itself (accessed on 7 June 2022).
28. Hardaker, A. Making Sense of NFTs in Museums. Museums + Heritage 2022. Available online: https://advisor.museumsandheritage.com/features/making-sense-nfts-museums/ (accessed on 7 June 2022).
29. Cinello. Available online: https://www.cinello.com/en/ (accessed on 8 June 2022).
30. Ertürk, E.; Doğan, M.; Kadiroğlu, Ü. NFT based Fundraising System for Preserving Cultural Heritage: Heirloom. In Proceedings of the 2021 6th International Conference on Computer Science and Engineering (UBMK), Ankara, Turkey, 15–17 September 2021; pp. 699–702. [CrossRef]
31. Robertson, A. Ukraine Is Selling a Timeline of the Russian Invasion as NFTs. The Verge 2022. Available online: https://www.theverge.com/2022/3/25/22996168/ukraine-ministry-digital-transformation-nft-crypto-drop-fundraising-war-timeline (accessed on 7 June 2022).
32. Meta History: Museum of War. Available online: https://metahistory.gallery/about-us (accessed on 7 June 2022).
33. Browne, R. Bitcoin Production Roars Back in China despite Beijing's Ban on Crypto Mining. CNBC 2022. Available online: https://www.cnbc.com/2022/05/18/china-is-second-biggest-bitcoin-mining-hub-as-miners-go-underground.html (accessed on 23 May 2022).
34. Hertig, A. Bitcoin Cash Miners Undo Attacker's Transactions with '51% Attack'. CoinDesk 2019. Available online: https://www.coindesk.com/tech/2019/05/24/bitcoin-cash-miners-undo-attackers-transactions-with-51-attack/ (accessed on 23 May 2022).
35. Calma, J. The Climate Controversy Swirling around NFTs. The's a Case for More Sustainable Crypto Art, but It's Hotly Contested. The Verge 2021. Available online: https://www.theverge.com/2021/3/15/22328203/nft-cryptoart-ethereum-blockchain-climate-change (accessed on 7 June 2022).
36. Ethereum Foundation. Available online: https://ethereum.org/en/upgrades/merge/ (accessed on 22 November 2022).
37. A New Circular Vision for Electronics. Time for a Global Reboot. Platform for Accelerating the Circular Economy (PACE) 2019. Available online: https://www3.weforum.org/docs/WEF_A_New_Circular_Vision_for_Electronics.pdf (accessed on 7 June 2022).

38. O'Dwyer, R. Limited edition: Producing artificial scarcity for digital art on the blockchain and its implications for the cultural industries. *Converg. Int. J. Res. New Media Technol.* **2020**, *26*, 874–894. [CrossRef]
39. Benson, J. Yes, Your NFTs Can Go Missing—Here's What You Can Do about It. Most NFTs Don't Really Permanently Live on a Blockchain. That's Potentially a Huge Problem When It Comes to Storing Them. Decrypt 2021. Available online: https://decrypt.co/62037/missing-or-stolen-nfts-how-to-protect (accessed on 6 June 2022).
40. Munster, B. People's Expensive NFTs Keep Vanishing. This Is Why. Motherboard Tech by Vice 2021. Available online: https://www.vice.com/en/article/pkdj79/peoples-expensive-nfts-keep-vanishing-this-is-why (accessed on 7 June 2022).
41. Stephen, B. NFT Mania Is Here, and So Are the Scammers. Artists Are Seeing Their Work Showing up in NFTs They Did Not Mint Themselves. The Verge 2021. Available online: https://www.theverge.com/2021/3/20/22334527/nft-scams-artists-opensea-rarible-marble-cards-fraud-art (accessed on 6 June 2022).
42. Owens, T. Are NFTs Nonsense for Digital Cultural Heritage Collections? Trevor Owens, User Centered Digital Memory 2021. Available online: http://www.trevorowens.org/2021/06/are-nfts-nonsense-for-digital-cultural-heritage-collections/ (accessed on 7 June 2022).
43. Carsenat, E. NFTs and the Museum Part 5: Art Collections on the Blockchain. LACMA un Framed 2021. Available online: https://unframed.lacma.org/2021/12/03/nfts-and-museum-part-5-art-collections-blockchain (accessed on 7 June 2022).
44. Ongweso, E., Jr. Someone Sold a $1 Million Clipart Rock NFT for under a Penny by Mistake. Motherboard Tech by Vice 2022. Available online: https://www.vice.com/en/article/y3ve8b/someone-sold-a-dollar1m-clipart-rock-nft-for-under-a-penny-by-mistake (accessed on 7 June 2022).
45. Charter on the Preservation of Digital Heritage. UNESCO 2009. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000179529 (accessed on 19 May 2022).
46. Van Malssen, K.; Tandon, A.; Hazejager, K. The Digital Imperative: Envisioning the Path to Sustaining Our Collective Digital Heritage. Summary of Research Findings & Opportunity Assessment. ICCROM Report 2021. Available online: https://www.iccrom.org/publication/digital-imperative-envisioning-path-sustaining-our-collective-digital-heritage-summary (accessed on 19 May 2022).
47. Goodwin, P.; Smith, A.; Burback, R.; Rydning, J. Rethink Data: Put More of Your Business Data to Work—From Edge to Cloud. IDC and Seagate 2020. Available online: https://learn.seagate.com/web-rethink-data-infobrief (accessed on 19 May 2022).
48. Ippolito, J. Contemporary Conversations: Non-Fungible | The New Market for Rare Digital Items. Sothebys.com 2021. Available online: https://www.sothebys.com/en/series/sothebys-talks/contemporary-conversations-non-fungible-the-new-market-for-rare-digital-items (accessed on 6 June 2022).
49. Rosenthal, D. NFTs and Web Archiving. DSHR's Blog 2021. Available online: https://blog.dshr.org/2021/04/nfts-and-web-archiving.html (accessed on 6 June 2022).
50. IPFS. Available online: https://ipfs.io/ (accessed on 2 June 2022).
51. IPFS. Available online: https://docs.ipfs.io/install/ (accessed on 2 June 2022).
52. Filecoin. Available online: https://filecoin.io/ (accessed on 8 June 2022).
53. Rarible Terms and Conditions. Available online: https://static.rarible.com/terms.pdf (accessed on 2 June 2022).
54. Wood, J. Custodial Wallets vs. Non-Custodial Crypto Wallets. CoinDesk 2022. Available online: https://www.coindesk.com/learn/custodial-wallets-vs-non-custodial-crypto-wallets/ (accessed on 2 June 2022).
55. Tara Digital Collective. Available online: https://www.taradigitalcollective.com/nft-conservation-toolkit-why-this-toolkit (accessed on 9 June 2022).
56. United Nations. Available online: https://news.un.org/en/story/2022/04/1116382 (accessed on 13 May 2022).
57. Carvalho-Resende, T.; Gibbs, D.; Harris, N.; Osipova, E. *World Heritage Forests: Carbon Sinks under Pressure*; UNESCO World Resources Institute: Washington, DC, USA, 2021; ISBN 978-92-3-100480-3. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000379527.locale=en (accessed on 13 May 2022).
58. Duarte, C.M.; Atwood, T.B.; Kairo, J.G.; Kennedy, H.; Krause-Jensen, D.; Lovelock, C.E.; Serrano, O. UNESCO Marine World Heritage: Custodians of the Globe's Blue Carbon Assets. UNESCO 2021. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000375565 (accessed on 13 May 2022).
59. Crypto Climate Accord. Available online: https://cryptoclimate.org/ (accessed on 7 June 2022).
60. Pipkin, E. Here Is the Article You Can Send to People When They Say "But the Environmental Issues with Cryptoart Will Be Solved Soon, Right?", Cryptocurrencies and NFTs Are an Absolute Disaster for So Many More Reasons than the Ecological. Available online: https://everestpipkin.medium.com/but-the-environmental-issues-with-cryptoart-1128ef72e6a3 (accessed on 6 June 2022).
61. Creative Commons. FAQ: CC and NFTs. Available online: https://creativecommons.org/cc-and-nfts/ (accessed on 15 May 2023).
62. Creative Commons. Direito Autoral e NFTs: O Que Tem a Ver? Available online: https://br.creativecommons.net/2021/07/27/creative-commons-direito-autoral-e-nfts-o-que-tem-a-ver/ (accessed on 15 May 2023).