heritage

Review

Blockchain and NFTs in the Cultural Heritage Domain: A Review of Current Research Topics

Helena Stublić [1,*], Matea Bilogrivić [2] and Goran Zlodi [1]

[1] Department of Information and Communication Sciences, Faculty of Humanities and Social Sciences, University of Zagreb, 10000 Zagreb, Croatia; gzlodi@ffzg.hr
[2] Croatian Conservation Institute, 10000 Zagreb, Croatia; mbilogrivic@hrz.hr
* Correspondence: hstublic@ffzg.hr

Abstract: In the last few years, blockchain technology and NFTs have been the subject of much research in different sectors ranging from informatics, to medicine, to economics. Although it is most often associated with cryptocurrencies, due to its features of immutability and durability, this technology has found its place in various fields, including GLAM institutions. This article will review the literature from 2017 to 2022 dealing with blockchain and NFTs in the heritage sector. Topics covered, proposed models, and projects will be highlighted. Archives are currently leading the research into the use of blockchain technology and have already developed models such as TrustChain. However, libraries, museums, and galleries are also beginning to show an interest in the new technology and its potential benefits. Therefore, we also approached the GLAM sector as a whole, to emphasize the importance of the joint development on the advancement of shared approaches and protocols in utilizing blockchain technology to enhance the trustworthy management and preservation of digital resources. This is particularly important because GLAM institutions care for a shared heritage and serve a common audience. In the second part of the article we will discuss the proposed uses of the technology and highlight still unexplored topics that should be elaborated in further research. The aim of this paper is to make a synthesis of previous research and bring the potential of blockchain technology and NFTs closer to experts in the heritage field, given that they are still quite unknown.

Keywords: blockchain technology; NFT; cultural heritage; GLAM sector; museums; archives; libraries; galleries; metadata standards; interoperability

check for updates

Citation: Stublić, H.; Bilogrivić, M.; Zlodi, G. Blockchain and NFTs in the Cultural Heritage Domain: A Review of Current Research Topics. *Heritage* **2023**, *6*, 3801–3819. https://doi.org/10.3390/heritage6040202

Academic Editor: Xavier Granier

Received: 22 March 2023
Revised: 15 April 2023
Accepted: 18 April 2023
Published: 20 April 2023

1. Introduction

The first blockchain-like protocol was inaugurated in the 1980s by American computer scientist and cryptographer David Chaum and was further developed in the 1990s by Haber and Stornetta [1]. A significant breakthrough happened in 2008 when a person (or persons) known as Satoshi Nakamoto designed the first decentralized blockchain [2]. Blockchain is best described as a digital record-keeping technology that forms a decentralized network and is run by a set of protocols ensuring authenticity, as it is almost impossible to alter digital records inscribed in the blockchain. It holds a great potential to change and revolutionize many aspects of our daily lives. It started as a technology that enabled the use of cryptocurrencies and challenged the existing finance and payments systems, but this is not its only possible use. A new and advanced use of blockchain technology has already been implemented within the archival sector that deals with the issues of digital-born documents and the need to provide their security and authenticity.

Technological development advances fast, and adoption into traditional institutions and everyday life is almost always slower because different possibilities of its everyday use must be investigated. The same rule almost always applies to GLAM (galleries, libraries, archives, and museums) institutions also. However, when we talk about blockchain

technology and NFTs, interestingly, GLAM institutions show a certain discrepancy and departure from this rule. The rapid development of communication technologies and the digitization and computerization of various aspects of our lives [3] have enabled a situation where practice precedes research. Therefore, there is a visible trend of interest in NFTs [4,5] and the need for institutions within the GLAM sector to keep up with trends and innovations without first thoroughly researching the application itself, which necessarily includes looking at advantages and disadvantages and possible dangers. Major world museums such as the British Museum and Uffizi Gallery have already started to design art collections of NFTs or other similar applications with still uncertain outcomes and success [6–8]. Although this is a sufficient reason for a deeper insight into the area and issues of the application of blockchain technology and NFTs in the heritage sector, one of the motives and reasons for this literature review is the recently published paper by Vacchio and Bifulco [9], who in their literature review of blockchain in cultural heritage identify three thematic units: provenance and authenticity, tokenization and fractional capital, and rights management and protection. Research based on case studies, heritage users and development of guidelines for the use of technology in heritage institutions are proposed.

The Collins Dictionary Word of the Year 2021 was NFT. It is interesting to note that this year was still strongly marked by the COVID-19 pandemic, but despite that, and in addition to "NFT", the first 10 most popular words also included "crypto" and "metaverse" [10]. NFT is short for non-fungible token, and describes a digital asset based on blockchain technology. In this sense, a special focus will also be on NFTs in the context of cultural heritage, especially due to their unique and unchangeable nature in a form of digital record on the blockchain, which cannot be copied, but can be transferred or traded. There is a visible trend of creating new digitally born works of art by artists who are looking for new ways to market their work, but also to avoid intermediary houses such as galleries, etc. In addition, the applicability of specific properties of NFTs has already been considered wider than just in artistic circles, mainly in the heritage sector, which will be discussed later in the paper.

Although much has been written about the blockchain technology itself, and there are numerous examples of the application of this technology in areas such as economics, information technology, law and system management, healthcare, etc., the heritage sector is not particularly present in the field of research and examples of its application are rare. Therefore, the goal of this paper is to give a clear overview of what has been researched so far and the state of the art, which would serve as a basic framework for further research in this area. Moreover, a heritage studies perspective and approach to this issue is emphasized, keeping in mind researchers in the heritage field, especially those with a stronger humanities and social sciences background. This paper will provide an answer to the question of which topics in this context have been researched or mentioned so far, and which were not in focus, and it is necessary to pay attention to them in further research. A thorough research of the relevant scientific literature will enable a scientific research framework and new theories, and accordingly, new possibilities of application in practice.

1.1. Blockchain Technology

Blockchain is a distributed ledger that contains time-stamped records organized into blocks, which are interconnected by repeating a hash code as the first part of one block and the last part of the previous one [11]. In other words, blockchain is a database on a distributed network and all nodes on the network contain a stored copy of it. A distributed network is used to eliminate central institutions such as banks, which store data on their ledgers, thereby reducing transaction costs and increasing data security. In order to ensure data protection from malicious modifications, the ledger is shared with all nodes, thereby achieving record security, which is one of the main features of blockchain technology. The technology was primarily associated with cryptocurrencies, which use it to carry out transactions, but today it has a much wider use.

Despite these advantages of this technology, there are certain obstacles that have not yet been fully overcome. One of the main disadvantages and the most common criticism is the high consumption of energy that occurs during the verification of transactions (mining) [12]. Critics of blockchain technology emphasize the great environmental risk, which in today's time of global warming should be considered. Therefore, most blockchains are trying to find an environmentally friendly solution for verifying transactions, such as the proof of stake in lieu of proof of work. Additionally, another problem is the potential loss of the private key which is necessary for doing transactions and accessing one's assets. To be able to do business through the blockchain, a person must have a public and private key and a digital wallet (crypto wallet). Public and private keys are generated addresses that are assigned to each user and without which transactions cannot be performed. Each public key has an associated private key. The purpose of the keys is to preserve anonymity and at the same time ensure authentication [13]. Given that it is a matter of human error, there is a certain risk of carelessness and loss of all assets that a person has in a digital wallet.

Although considered completely secure, there is theoretically a way to modify a record on the blockchain. This would require the so-called "51% attack", which means that if 51% of the nodes on the network were to become malicious and work against the correct verification of the data on the blocks, it could be altered. Another theoretical possibility is the development of a quantum computer that would have the ability to login and manage other people's accounts and private keys, thus stealing individuals' assets [13]. However, for now, such examples are only theoretical and do not represent a real danger for blockchain technology.

1.2. Non-Fungible Tokens

An NFT, or non-fungible token, is a unique digital item that represents a physical or digital asset and is recorded on the blockchain [14], in most cases on Ethereum. Unlike classic cryptocurrencies, where every coin is equal, each NFT is unique and has its own value, therefore they cannot be exchanged for one another, hence the name "non-fungible". Ethereum blockchain was built in 2013, and the new Ethereum protocol created in 2014 [15] made it possible to create applications and smart contracts which have enabled tokenization: the process of turning any asset into a digital token which represents that asset [11]. Thus, non-fungible tokens (NFTs) were developed, but their popularity skyrocketed only in 2021 after the sale of Beeple's NFT The First 5000 Days for USD 69 million at Christie's auction house. Originally, the concept of smart contracts was designed by Nick Szabo in 1994, and today it is the foundation on which NFTs rest. It enables two parties to perform a secure exchange, without intermediaries, and to determine the terms of the purchase in advance.

NFTs can be used in a variety of fields, from art, video games, music, and ticket sales to collectibles. They are exhibited and sold on special platforms such as OpenSea, Axie Infinity, and Rarible, and can be purchased exclusively with cryptocurrencies. When an NFT is minted, a smart contract is created, and the process ends with a record on the blockchain. Information about the owner, conditions of sale, information about each subsequent sale of that NFT and change of ownership are written on the blockchain; therefore, this information is immutable. They are especially important in the case of digital assets, such as digital art, when it is often difficult to determine the true owner due to the many reproductions of the work. In the case of NFTs, they can also be copied and stored, like a digital image, but because of their unique ID and the on-chain record, they are unique and verifiable [16].

However, as with blockchain technology, they have some risks and limitations. To mint and sell NFTs on the platforms one is charged with a gas fee which can be very high, depending on the number of transactions taking place at a certain time. Additionally, there is a risk of losing the digital wallet and private key and thus all NFTs, and since they are stored on the blockchain, they are part of the already mentioned environmental problem [14,17,18]. Although information about NFTs is stored on the blockchain and is therefore secure, the digital assets they represent are usually stored on special servers due to their size, such as IPFS (InterPlanetary File System). This raises questions about the

durability of asset storage as well as the security of the connection of blockchain data to digital and physical assets.

2. Research Methodology

The literature search was started by identifying key words that served as descriptors when researching selected scientific databases. The following descriptors were chosen: blockchain technology, NFT, non-fungible token, tokenization, cultural heritage, heritage institution, museum, gallery, exhibition, archive, and library.

First, the Google Scholar search engine was used, which provided the most frequently used articles. After that, databases such as Scopus, Web of Science, IEEE Xplore, ScienceDirect, Directory of Open Access Journals (DOAJ), MDPI, JSTOR, EBSCO, and Academia.edu were searched. The use of a large number of databases was partly redundant, but it made it possible to identify some more cited and relevant articles that were found in several databases. During database searches, keywords were grouped to yield as many results as possible, e.g., (Blockchain AND technology OR blockchain OR NFT OR non-fungible AND token) AND (museum OR gallery OR archive OR library OR GLAM). A greater number of published works was observed in 2017 compared to previous years. Therefore, this defined the time frame from 2017 to the end of 2022 (articles available online until December 2022), considering that the aim of this literature review is to present the latest works and research topics in the defined GLAM sector.

In the first step, over 50 works were identified that partially or fully correspond to the previously mentioned descriptors. In the second step, it was necessary to reduce the number of articles that will be included in this literature review, and the following criteria were used: year of publication in 2017 or newer, publication in a peer-reviewed journal, primary source research, analysis of abstracts, and keywords in articles that must match given research questions. Part of the work was identified and chosen using the snowball method. In this case, it was used with the original intention, so that we could identify some relevant articles used in part of the already identified literature, but also as a confirmation of already found sources through databases, which meant a double confirmation of relevance. Articles that did not have open access or that could not be accessed through the institution were not included in the scope of further research.

This was followed by an in-depth analysis of the content of the selected articles, which were classified according to the year of publication, the topics they cover in the context of archives, libraries, museums, or the GLAM sector in general. The in-depth analysis was carried out in such a way that the content of all the selected articles was analyzed, the main topics and research questions were identified, and the same was grouped according to GLAM sector and topics (Figure 1).

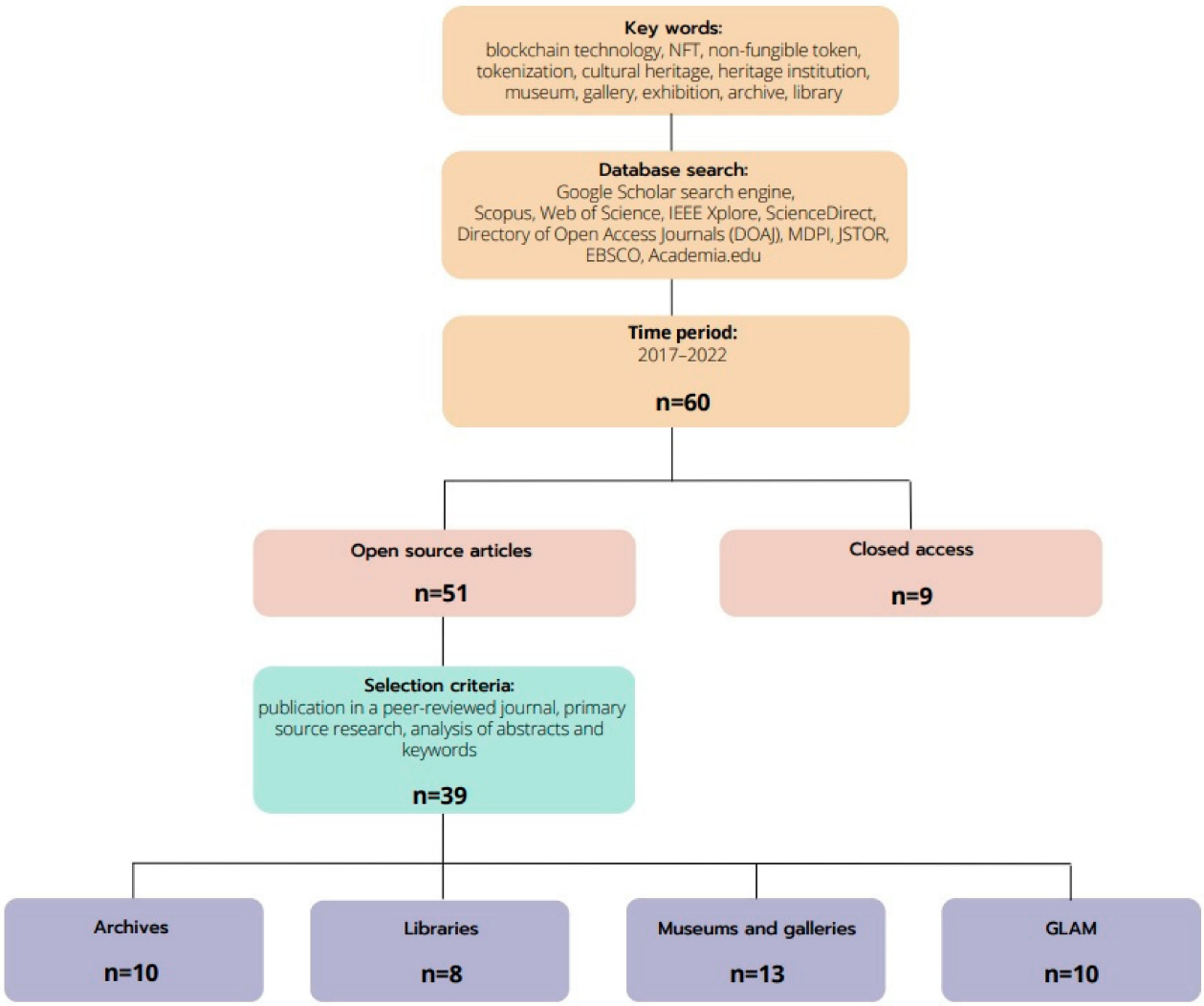

Figure 1. Graphic representation of the process of selecting articles for the literature review (n = number of articles; * some articles are included in multiple categories).

3. Results

After applying the above-mentioned methodological criteria and analysis, 39 articles were selected for this literature review (Figure 2). The presentation of the analysis and results of literature research will be grouped according to GLAM sector in four subsectors: archives, libraries, museums and galleries, and GLAM in general for easier navigation, and keeping in mind the scientific areas and researchers who will use this paper. In the second part, we will present a synthesis of all the above, identifying common themes that are in focus in certain areas of the GLAM sector and those that are presented as the biggest challenge, also mentioning those that are not present at all or have received little attention.

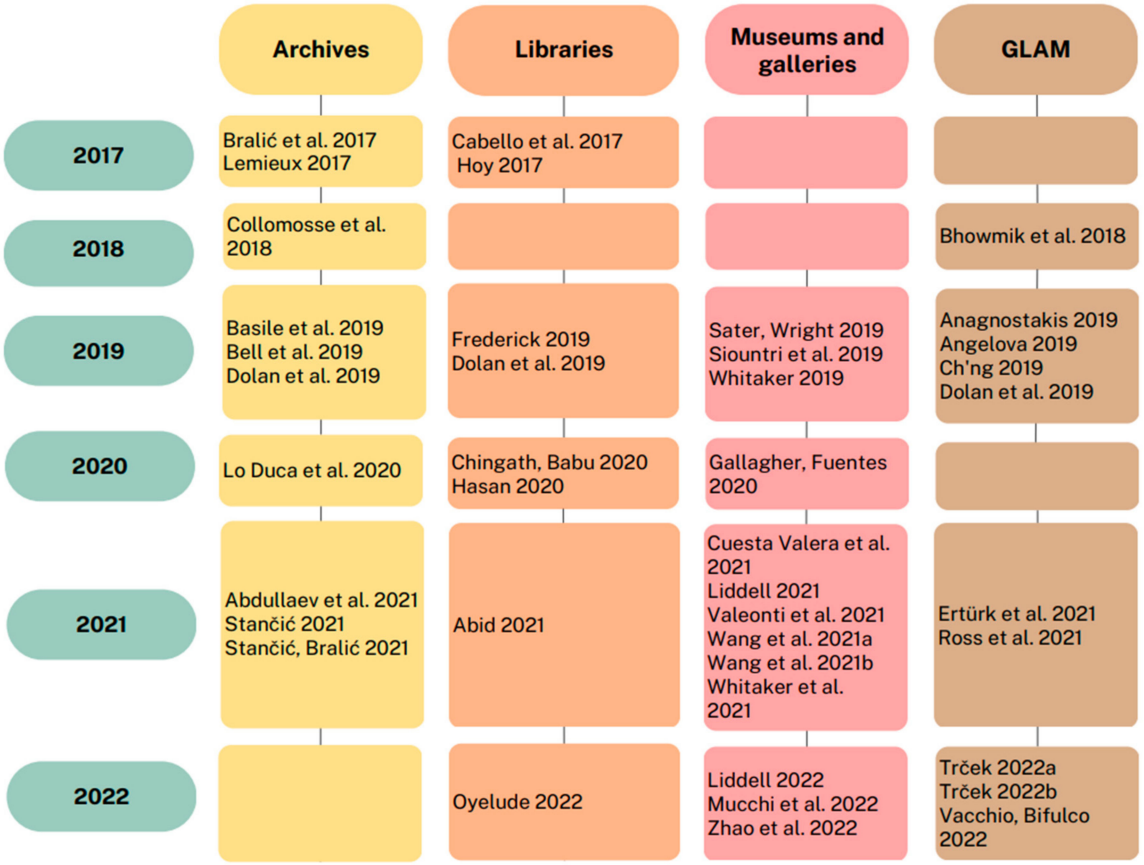

Figure 2. Articles sorted by publication year and GLAM sectors.

3.1. Archives

In the archives domain, 10 articles were selected from the period from 2017 to 2022 (Figure 3). The focus of most papers was the problem of long-term storage of digital documents, security, and credibility. Long-term storage of digital documents and ensuring document integrity using blockchain technology has been identified as one of the primary research topics in the field of archives. Basile et al. [19] suggest "a blockchain-based architecture for that digital archive that guarantees security and availability in a decentralised, efficient and cost-effective way". Abdullaev et al. [20] believe that the application of blockchain technology contributes to greater reliability and completeness of archival information and a shorter delivery time of archival data. The article presents an information model of the use of blockchain technology in archival science (for obtaining archival data) and an algorithm for double control of archival data exchange.

Articles that present the decentralized platform ARCHANGEL, which ensures the long-term integrity of digital documents kept in public archives, were highlighted [21–23]. Using distributed ledger technology (DLT), the provenance, immutability, and integrity of archived documents is ensured. Blockchain technology is used to create digital signatures (content evidence) of scanned physical or originally digital documents in order to preserve their integrity over a long period of time. In addition to archives, they consider the potential of applying this technology in libraries and museums for related and common tasks such as authentication and provenance and sharing of digital objects, materials, and documents (e.g., interlibrary loan).

In addition to the ARCHANGEL platform, the problem of long-term storage of digitally signed documents using blockchain technology is being solved by the development of the TrustChain model [24–26]. It is a semi-open system in which only certain institutions can create new entries, but anyone interested can review the records and confirm their authenticity. The goal of TrustChain is to enable archival (and similar) institutions to

avoid periodic re-signing or re-timestamping of all the archived, digitally signed records. Although TrustChain cannot extend the lifetime of a digital certificate, it would provide assurance that the document and its signature have remained unchanged since the TrustChain entry was created. The authors propose a database support system that allows metadata to be changed as needed, but also significantly simplifies the search compared to the information search in the chain, keeping the immutability characteristic of the blockchain.

Valuable research that questions the storage of tangible heritage contained in digital archives was conducted by Lo Duca et al. [27]. In the article, they compare two different blockchains, Ethereum and Hyperledger, through several different criteria and determine the advantage of Hyperledger. At this point it is worth mentioning the early paper by Lemieux [28] that brings "a typology of blockchain solutions for managing current records representing three distinct design patterns".

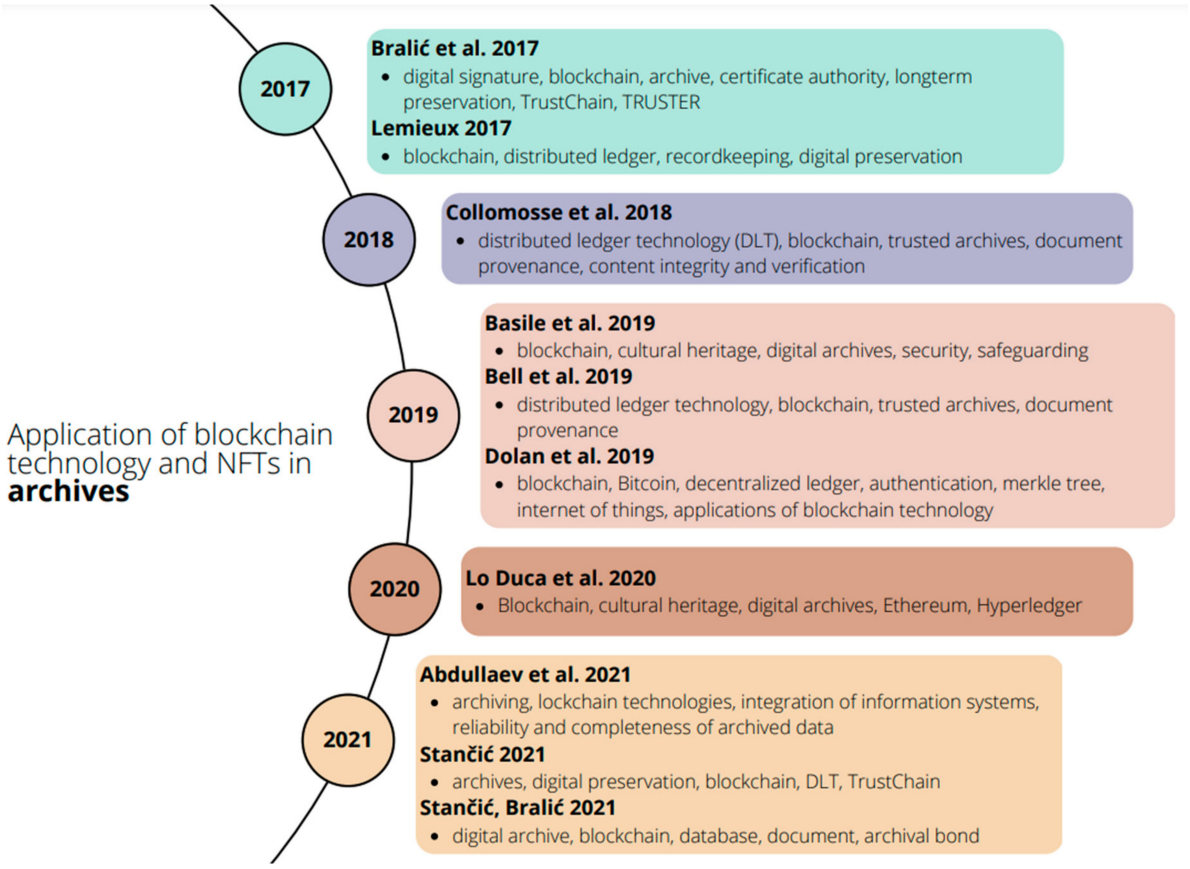

Figure 3. Application of blockchain technology and NFTs in archives.

3.2. Libraries

For the libraries domain, eight articles were selected from the period from 2017 to 2022 (Figure 4). Three articles were identified that make up the literature review [29] and an overview of the possible areas of application of blockchain technology in libraries [30,31]. The authors state the advantages of implementing systems based on this technology with the aim of improving digital storage, borrowing and tracking, improving collection and catalogue management, improving interlibrary loans, sharing materials, tools and services between institutions and users themselves, checking credibility, etc. Already at the very beginning, some authors [32] saw the potential of blockchain technology to solve a large amount of administrative tasks and improve one of the main functions of modern libraries, which is to speed up and simplify the lending system between institutions and users using a decentralized lending system that is transparent, and the record of the process itself is immutable and verifiable at any time. Cabello et al. [32] propose the development and

implementation of the LibChain system that embodies the best aspects of this technology using smart contracts on the Ethereum blockchain and the Whisper protocol. In her research, Frederick [33] expresses a certain level of caution when it comes to the application of these concepts in practice, but she certainly points out the potential in achieving access to electronic sources on a subscription basis. Service providers would have the ability to set stricter conditions for their use and a powerful tool to prevent abuse.

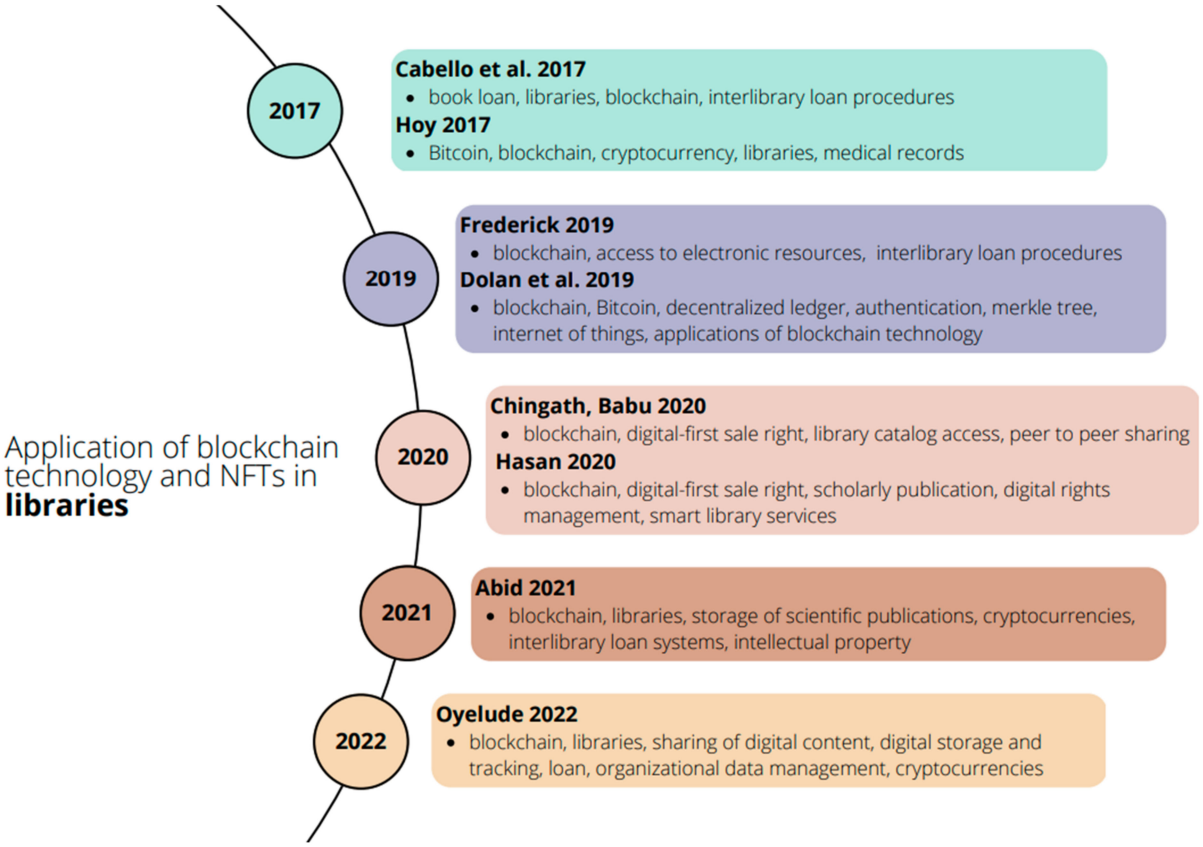

Figure 4. Application of blockchain technology and NFTs in libraries.

Hoy [34] also sees potential by focusing on the collecting, preservation, and sharing of scientific publications in the field of medicine where the speed, availability of new research and discoveries, and the credibility of the results are of great importance. Although this article was published two years before the COVID-19 pandemic, it would be interesting to investigate how the circumstances of the pandemic helped to make the potential of such solutions visible. Hasan [35] states similarly, emphasizing the advantages of private networks among institutions for sharing parts of research that have not yet been published, so that all network users have access to data, but also that the author and time of entry of published results is visible for the purpose of their protection. For academic publishing and digital rights management, he proposes the Orvium platform, which allows authors to bypass publishers and publish their work on the platform using blockchain. The platform has also enabled a system of tokens that are obtained with each publication on the platform, and which can then be used to pay for reviews of articles. In addition, the author points out the advantage of blockchain technology for the publication of e-books and the protection of digital first sale rights. The author himself determines the terms of use of the book through a smart contract, and the book can be purchased with special book tokens (Publica platform).

The third topic identified during the literature research refers to the improvement of the online catalogue and the design and management of collections on the blockchain [23,35]. In addition to the online catalogue system, the authors also propose the use of univer-

sal membership cards that would make it easier for users to access numerous services, subscriptions, and licences, while also enabling increased user privacy.

3.3. Museums and Galleries

When it comes to museums and related heritage institutions, 13 relevant articles were selected (Figure 5). Experts in the field of museums and cultural heritage see the potential in the application of blockchain technology in simplifying and improving some existing tasks in the professional area, such as managing collections and material objects, and managing operations. The potential related to new forms of artistic creation such as digital and virtual art is particularly visible, for which new and more efficient solutions are sought for the purpose of storage and protection and display. The main themes identified in this context concern rights and ownership, management of museum documentation, display of objects and collections, and their sharing and sale.

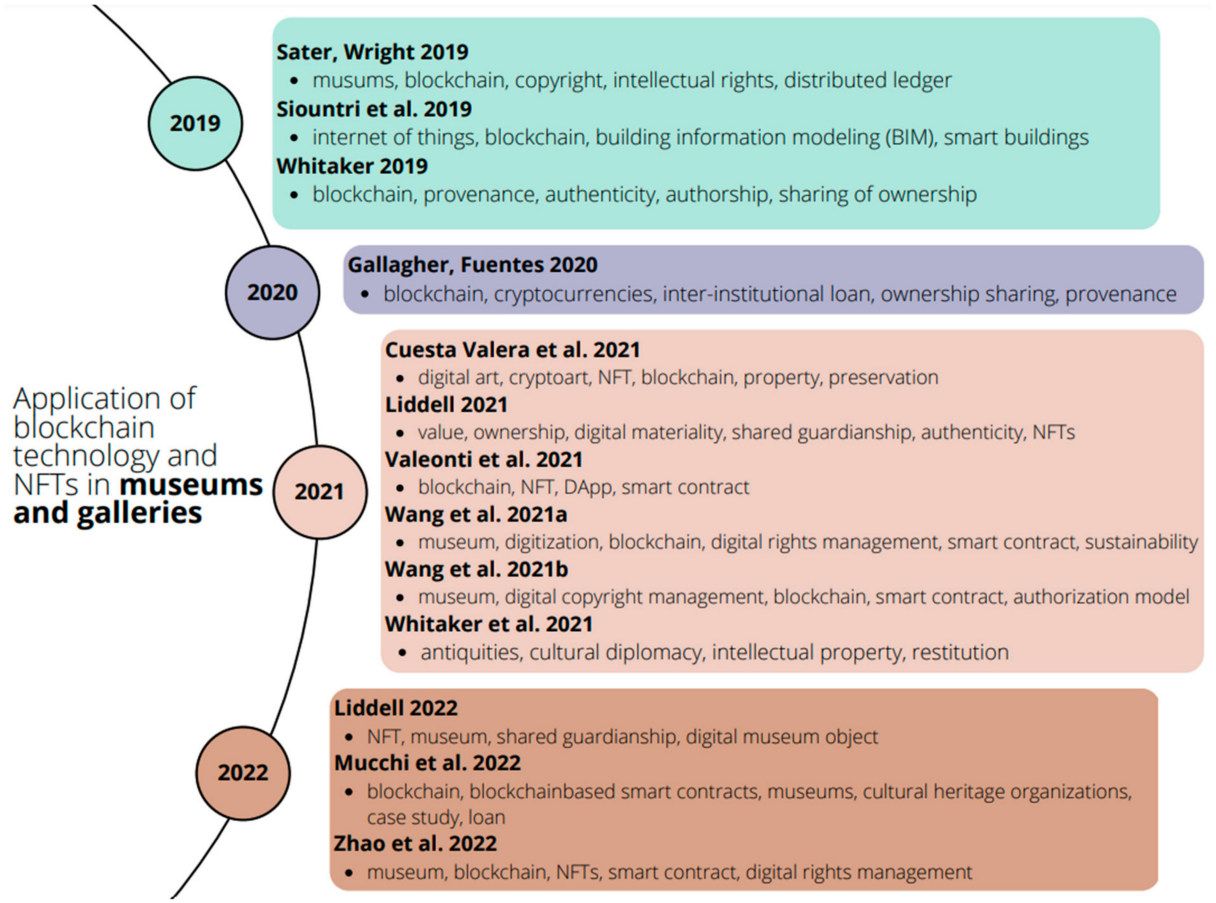

Figure 5. Application of blockchain technology and NFTs in museums and galleries.

The verification of provenance, authorship, authenticity, and ownership of works of art and museum objects is the most extensive topic in this field [11,36,37]. This is not surprising if we consider the main characteristics of blockchain technology, which is the immutability of records in the chain that can be retrieved and verified at any time and where transparency is of utmost importance.

Whitaker et al. [11,38] give examples of using blockchain in the art field and verifying the provenance and authorship of art works, creating a registry to verify the authenticity and share ownership of works of art. The advantage of an art register with data on provenance, ownership, and every transaction of an art work would facilitate the work of museums and auction houses and provide collectors with security when acquiring art and other cultural objects. The authors believe that the blockchain could be used to

clearly establish certain rights to cultural heritage items, especially those that were taken from a nation during war or colonization. Using blockchain technology, ownership rights, exhibition rights, various forms of income or share in cash flow and dividends can be separated from investment structures. This technology enables the so-called tokenization of the object, i.e., allows recording of partial ownership with certain rights assigned to separate parties (e.g., a museum retains the right to display the object, but returns ownership rights to the country from which the object originated). In this context, the improvement of documentation management during archaeological excavations with greater transparency in terms of ownership and provenance of objects is unavoidable.

Gallagher and Fuentes [36] also mention the research of the provenance of art and the possibilities of borrowing objects from the collection, and the use of blockchain technology for the loan of art objects on the example of loans between museums and theatres by Mucchi et al. [39]. The latter state that they see the advantages in simplifying the process, solving organizational problems, and reducing borrowing costs, and the disadvantages in the costs of creating a private blockchain or fees on already existing blockchains, the possibility of human error when writing a smart contract, and high energy consumption.

Siountri et al. [40] write about the use of BIM (building information model), IoT, blockchain technology, and other advanced technologies in the context of smart museums. Blockchain enables data security and is introduced as a system for monitoring, gathering information about the activity of sensors and security systems, and for monitoring the activities of people participating in the process. BIM and blockchain would prevent unauthorized access to data and ensure its secure storage and management.

With the digitization of museum work and the display of objects online, there is a need for a system of authorizing the use of copyrights over digital objects in order to prevent their abuse [41]. Wang et al. [42] proposed a "digital authorization" model for museums using blockchain technology, and Zhao et al. [43] proposed a digital rights management model based on blockchain and NFTs. It is a distributed digital rights management and authorization system using non-fungible tokens (NFTs) and smart contracts. Museums can create NFTs of museum objects and other cultural objects in order to highlight their ownership, and the applicant buys NFTs with cryptocurrency (or museum tokens) with the purpose of obtaining a certificate of authorization for the use of the specified content.

Sater and Wright [44] write about the licensing of digital intellectual property using smart contracts. Museums would put their historical records on the distributed ledger. In this way, ownership and copyright information would be complete and shared among cultural institutions and with the public, which would enable greater accessibility, the possibility of research, and the connection of cultural objects and works of art. The use of NFTs to prevent the illegal reproduction of digital art is also mentioned in their work by Valeonti et al. [37].

In addition to the legal aspect, another important topic is certainly the long-term and more efficient storage and preservation of digital art using NFTs and blockchain and accompanying documentation [45]. The formation of an art registry on the blockchain [11] is a logical step in this direction, as is the design of different models and systems for sharing data and documentation among museums and with the public using Distributed Ledger Technology—DLT [44].

In this context, the concept of joint (or shared) custody of digital museum objects using blockchain technology and NFTs, which Liddell [46,47] writes about, is certainly interesting. She explores how blockchain technology could create new connections between museums, collections and audiences by connecting personalised experiences about museum objects to NFT versions of those objects. The process of creating NFTs from the museum collection is a process of pseudo-fragmentation of art works or other museum objects that simulates the effect of shared ownership and authenticity. The owner of an NFT has control over his token, and can trade or sell it, challenging the traditional institutional authority over their digital collections. Liddell also critically analyses how NFTs could embody different perspectives of a certain object and function as personal and independent publication of a

digital collection. The potential for the creation of a new relationship between participants and museums that can be understood as shared guardianship or a sense of enchantment that can create social value for museums is highlighted. Guardianship in this context is seen as a means of connecting the individual with the museum object and the museum, and not only as a form of protection and preservation of the object. Liddell describes a project with the National Museums Liverpool and the University of Manchester, where blockchain technology was found to have a positive impact on creating a connection between the participants, the museum object and the museum. By owning a digital token, the participants felt a moral obligation towards the object and the museum, which is one of the prerequisites for shared guardianship.

The sale of the digital art on the blockchain, NFTs, and the use of cryptocurrencies to purchase tickets are certainly an inevitable topic [36,37]. In this context, the authors state the improvement of the experience of visiting museums for certain visitors and the potential sharing of ownership of museum objects.

3.4. GLAM (in General)

A number of authors have identified GLAM as a possible area of application for blockchain technology. The analysis of the articles shows that the authors mention some related problems and solutions that exist in the entire GLAM sector. Nevertheless, we decided to present them separately and as an introduction to the second part of the paper, which will deal with a kind of synthesis of all the above and concluding considerations. Additionally, in this research we focused on the GLAM sector as whole, in order to emphasize the importance of joint development of shared methods related to using blockchain technology to improve long-term preservation of digital objects—their development separately for individual heritage sectors (archives, libraries, museums) would be a redundant effort. We find confirmation of this, on the one hand, in the convergence of metadata standards, especially those related to digitized and digital-born materials (such as the application of METS, PREMIS, and similar standards for long-term management and preservation of digital materials) and, on the other hand, in harmonization processes among metadata standards and models (EDM, CIDOC-CRM, LRM, RiC, etc.).

In this part of the literature research, 10 articles were identified (Figure 6). The authors highlight the possibility of using blockchain technology to improve systems and procedures for long-term storage of documentation on cultural heritage objects and authentication, provenance verification and sharing of digital objects [12,14,48–50]. Ch'ng [50] states that original works of art or cultural heritage objects can be reproduced in a number of ways (digital copies, 3D copies, photographs, casts, etc.), and that their copies are used to make the works accessible to a wider audience. However, he sees the problem in the very nature of digital copies, which can be further shared without authorization and cannot be distinguished from the original copy. On the other hand, blockchain makes it possible to determine the ownership and identity of the first original copy, and can be used for permanent storage of digital documentation of cultural heritage, especially if the original material is in danger of decay. Trček [12], like some previously mentioned authors, proposes a digital register of cultural objects on blockchain, and the use of blockchain on the mobile network. The proposed business model is based on blockchain on a mobile network to make mining easier, and the target miners are tourists and other visitors. This includes a system of rewards for mining in the form of digital tokens (reward points) that could be exchanged for a ticket, exhibition catalogue, etc. He sees the advantage in reducing costs for heritage management.

Ertürk et al. [51] propose a blockchain-based cultural heritage protection system called Heirloom, which facilitates revenue collection for cultural heritage preservation and raising awareness of its importance. The system uses blockchain, IPFS (InterPlanetary File System), and smart contracts, and allows organizations to raise money for heritage protection without intermediaries. Assets (heritage objects and similar) are converted into

NFTs and sold through platforms, and metadata is stored on IPFS, whereby donors receive a share in the rights of maintenance and protection.

Angelova [52] sees the potential of applying blockchain technology in the area of heritage management with an effect on internal procedures within the institution, management of funds, special policy management and maintenance of specific cultural heritage registers. The recent research by Trček [53], which proposes an innovative ledger solution called HeriLedger, is also valuable. In this paper a new ledger solution for cultural heritage preservation was presented and compared to the traditional blockchain architectures. It shows substantial improvements in terms of computational resource consumption, resistance to quantum computing, and privacy with optional accountability. Additionally, having in mind the business context, the core business model was developed.

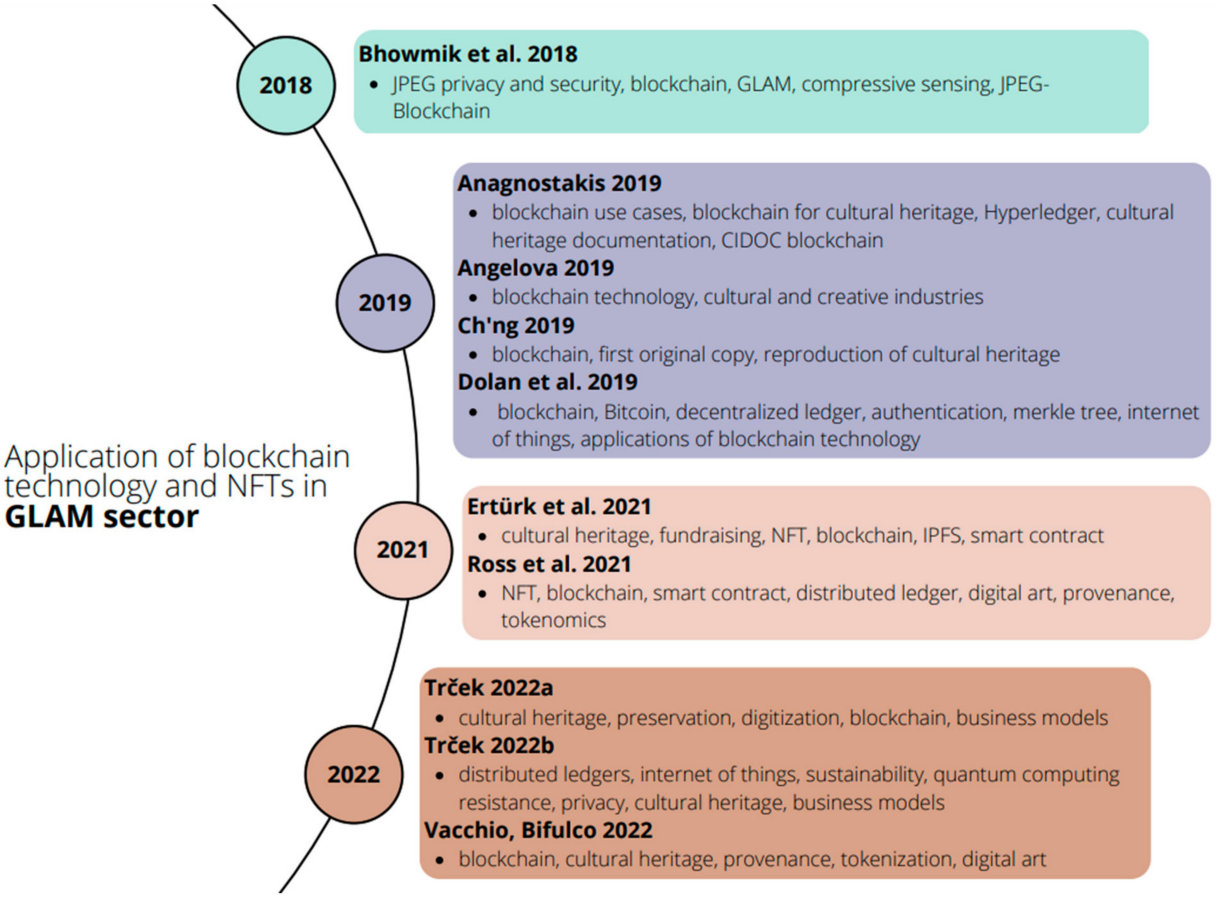

Figure 6. Application of blockchain technology and NFTs in GLAM sector.

4. Discussion

After a thorough analysis of selected articles from the fields of archives, libraries, museums, and galleries, it is possible to abstract several key points, including advantages, challenges, and proposed solutions and possible implementations for using blockchain technology and NFTs in the cultural heritage domain. In most of the articles, the authors consider the good sides of blockchain and the advantages of implementing solutions in the heritage environment rather than their challenges or threats. If there are mentions of certain challenges or threats, more often the focus is on existing weaknesses of the blockchain itself. Many of these aspects are related and applicable throughout the GLAM field and will be presented and summarized below.

4.1. Advantages of Using Blockchain Technology and NFTs in the Cultural Heritage Domain

A big challenge for archives is the credibility of records and documents and solving the problem of certificate expiration. In this context, the possibility of using a **smart contract** stands out. Another topic is definitely **the longevity of digital records and their permanent storage**. We can see a similar thing with libraries and museums, which also try to store documentation about objects and collections for a long time, especially due to potential loss in material (e.g., inventory books) or immaterial forms, i.e., digital form (library catalogues, online object inventory books, etc.).

When we talk about documentation and smart contracts, the inevitable topic is certainly **the regulation of legal aspects** in the operations of these institutions. The authors cited numerous possibilities of using blockchain to regulate legal relations between institutions when concluding contracts, loans, sales, donations, etc. The perspective certainly exists in terms of **simplifying and speeding up the process** and **greater transparency** with the aim of protecting all participants. In this context, the always controversial issue of **provenance of heritage items and restitution** was mentioned. Mention is made of the improvement of this aspect in terms of keeping documentation during archaeological excavations, registering the origin of objects on the blockchain, helping to identify alienated heritage objects, etc.

An interesting, albeit somewhat idealistic, proposal is also **the joint sharing of the right to exhibit and the right to own individual heritage objects** that are part of disputes in the context of requests for return (restitution) to the countries where they were originally found or formed.

Another aspect of work that many institutions certainly want to simplify or make safer is **the communication/promotional aspect** (in the broadest sense), such as the display of digital art, borrowing books and other materials from libraries, selling items or services, and promoting collections, services and values that are in the intangible and tangible sense found in all of the GLAM institutions as guardians of cultural heritage. If the previously mentioned areas of documentation and legal aspects are a kind of *internal domain*, then the presentation, lending, sale, etc. mentioned here form the communication aspect of institutions towards their users and other external stakeholders, and we can list them as an *external domain* for application of blockchain technology (Figure 7).

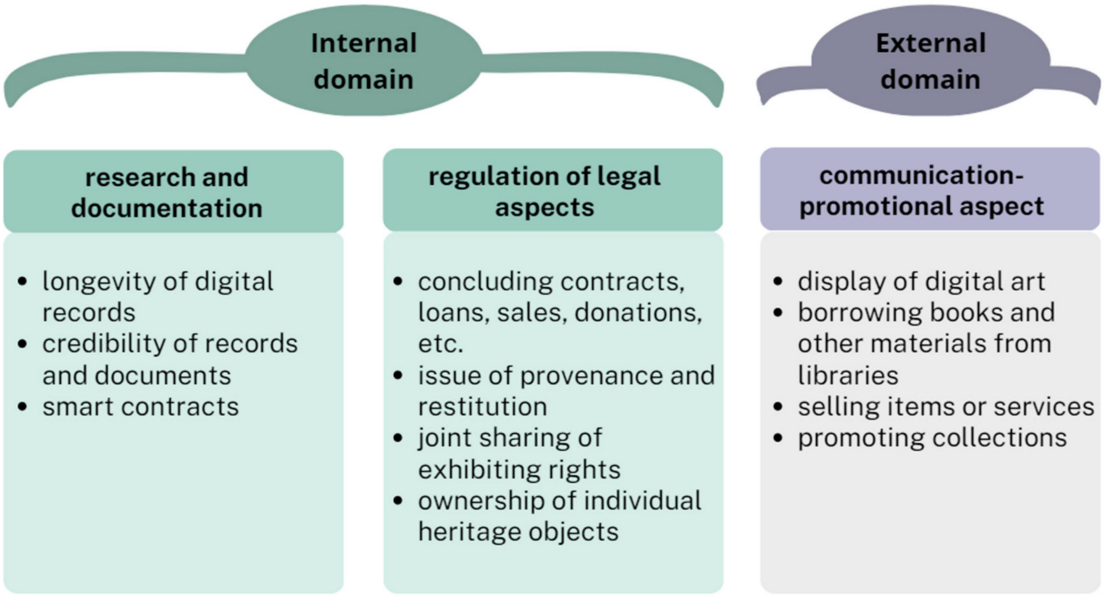

Figure 7. Internal and external domain of application of blockchain technology in GLMA sector.

To summarize, the identified advantages are:

- Improved and enhanced long-term storage of digital documents;
- Ensuring integrity, immutability, authentication, and provenance of digital objects, materials, and documents;
- Greater reliability and completeness of archival information and a shorter delivery time of archival data;
- Improved and more transparent administrative tasks by speeding up and simplifying loans (e.g., interlibrary loan, art objects loan), sharing materials, tools and services between institutions and users themselves;
- Improved access to electronic sources on a subscription basis, stricter conditions for their use and prevention of abuse;
- Improved and enhanced publication of e-books and the protection of digital first sale rights;
- Greater reliability and completeness of the online catalogue, and the design and management of collections on the blockchain;
- Improved and enhanced storage, protection, and display of digital and virtual art;
- Improved and enhanced verification of provenance, authorship, authenticity, and ownership of works of art and cultural objects;
- Possibility of shared ownership of cultural objects (between several participants or owners, institutional or private individuals);
- Improved and transparent legal process (e.g., copyrights over digital objects, licensing of digital intellectual property and sale issues.

4.2. Challenges of Using Blockchain Technology and NFTs in the Cultural Heritage Domain

The presented scientific articles and conducted research indicate a great potential for the application of blockchain technology and NFTs in the heritage sector. Although the potential is great, there are still many doubts about the possibilities of their application in practice. In this context, the technical aspect of the application of this technology and its still close **connection with cryptocurrencies** should certainly be taken into account.

For now, many authors are researching and mentioning numerous advantages of using this technology, but only a few consider **the technical demands of its application**. For example, the question of connecting digital or, even more so, physical objects with a record on the blockchain remains open. Especially with e.g., provenance verification or a digital art register, where the content is actually stored on a server (e.g., IPFS). Digital objects could be linked to the blockchain by a hash code, but while the blockchain is "eternal", what about these storage systems? Are these documents also stored there long-term? Furthermore, how can physical objects, such as paintings, be connected to the blockchain in a way that ensures durability and resistance to counterfeiting? While there are already several elaborate models for using blockchain for digital rights management or long-term storage of digitally signed documents, these issues are not yet fully worked out technically, at least not in the literature dealing with cultural heritage and blockchain technology.

The main challenges still concern the **application of blockchain technology in practice**. What are the implementation costs of blockchain-based systems, and are there maintenance costs? Should GLAM institutions develop their own blockchains or use existing public ones such as Bitcoin Blockchain, Ethereum Blockchain, etc.? Application on existing blockchains means the necessity of using existing cryptocurrencies, which are still not regulated in every country in a legal and economic sense. This is particularly in contradiction with the original idea of blockchain, starting with Bitcoin and other cryptocurrencies, as decentralized and deregulated systems.

Establishing and maintaining your own blockchain is not a simple undertaking, and the use of existing private companies that are specialized for this goes against the idea of autonomy and rights that GLAM institutions currently possess. The authors state that the use of blockchain technology can bypass existing "middlemen" such as art galleries, publishing houses or, in the case of music, record companies. Yet, many still use **private platforms** such as OpenSea or laCollection (which makes and sells NFTs for some of the

world's most prominent museums) to design their own NFTs, which are nothing more than the "middleman" of the NFT world. Who is the owner of the digital record on the blockchain in that case (do we read the fine print on contracts)? In the context of heritage institutions, the existence of a "middleman", i.e., a private company that would design, implement, and maintain a blockchain-based system, seems like an unavoidable necessity. The establishment of state agencies that would provide such services to public institutions would be ideal, but at the present moment it does not seem highly realistic.

Because it is necessary and legitimate to ask the question of the **level of knowledge about blockchain technology** among heritage experts and the general population, we should mention here the Guggenheim Museum, which opened a workplace in March 2021 for a person who will be exploring NFTs. They recognized the importance of new technologies and the employment of educated experts in that field. Unfortunately, this was the exception rather than the rule in the heritage sector. So, the importance of the constant **education** of professionals in the heritage field about new technologies and their use should be emphasized and further encouraged.

To summarize, the identified challenges are:

- Association and reputation of the blockchain technology and NFTs with extralegal cryptocurrencies;
- Government restrictions and legal issues for using crypto wallets and cryptocurrencies;
- Dilemma about the level of applicability of public blockchain vs. private blockchain in the heritage sector;
- Issue of scalability and speed of different blockchains within the cultural heritage sector;
- Lack of knowledge base and educational programs about the blockchain technology, DLT, NFTs (or any new technology for that matter);
- Cost of design, implementation, and maintenance of blockchain infrastructure (especially in a relation to publicly funded cultural heritage institutions);
- Security issue concerning the possibility of losing the private key and wallet security;
- Ecology issues and high energy consumption.

4.3. Solutions and Possible Implementations for Using Blockchain Technology and NFTs in the Cultural Heritage Domain

Below are some identified solutions and proposals that are certainly worth further research. Much more research and practical solutions are needed, along with the continued development of new and improved models and applications. This is certainly an important aspect considering that blockchain technology itself has not yet become part of the mainstream, i.e., it is still very unknown to end users.

Proposed solutions and possible implementations:

- ARCHANGEL—a decentralized platform that ensures the long-term integrity of digital documents kept in public archives;
- TrustChain model— long-term storage of digitally signed documents using blockchain technology;
- LibChain system—a decentralized lending system between users and institutions using smart contracts on the Ethereum blockchain and the Whisper protocol;
- Orvium platform—for academic publishing and digital rights management (allows authors to bypass publishers);
- Publica platform—publication of e-books and the protection of digital first sale rights;
- Heirloom—a blockchain-based cultural heritage protection system which facilitates revenue collection for cultural heritage preservation and raising awareness of its importance;
- HeriLedger—an innovative ledger solution for cultural heritage preservation linked to the tourism sector.

5. Conclusions

This literature review shows, through the detected increase in research and application of blockchain technology and NFTs in the field of cultural heritage, a strong momentum and great potential for the application of blockchain technology and NFTs in the GLAM sector. Building trust (accuracy, reliability, authenticity, and related concepts) connected with powerful blockchain technologies will certainly contribute to and strengthen the position of archives, libraries, museums and other heritage institutions as trusted information providers in the global information environment.

However, most of the papers presented here consisted of theory-based research. Much more empirical research needs to be carried out, especially bearing in mind the specifics of the heritage sector. Additionally, the education of scientists and professionals in the heritage field about blockchain technology is necessary in order to create adequate conditions for the design of quality and comprehensive scientific projects and research that will provide concrete results and guidelines.

The GLAM sector and other heritage institutions need to keep up with the growing and rapid changes, as the world we are living in is ever-changing and developing in an unpredictable way. The huge challenge to understanding and adopting blockchain technology is the lack of a knowledge base, and this paper aims to shed light on the most recent topics discussed within the GLAM and heritage field considering blockchain technology.

6. Future Directions

The authors propose solutions taking into account the main characteristics of blockchain technology such as credibility, immutability of records, availability, and transparency in the areas of activity of GLAM institutions where these characteristics are of the greatest importance and, accordingly, of maximum applicability. This therefore refers to the area of research and documentation that is present in all GLAM institutions and is part of every institutional collection management, scientific research, and description.

If we consider "cultural heritage data is humanities research data" [54] (p. 1), it is of vital importance for the credibility of the research process to "be able to trace the provenance of knowledge back to the source micro-level (with its original context and perspective intact)" [55] (p. 260). The cited article refers to the field of heritage but does not mention blockchain technology (therefore it is not included in the literature review) and here is highlighted to warn of the need for further research in the area of establishing interoperability between blockchain-based methods and existing conceptual models, metadata structure, value, content, and exchange standards. For example, conceptual models, such as The IFLA Library Reference Model (IFLA LRM), could provide foundations for the precise identification of potential complex relationships in the application of NFTs among cultural heritage works and their physical and digital manifestations, expressions and instances. Conceptual reference models, such as CIDOC-CRM, can provide shared understanding of cultural heritage information by providing a common semantic framework that any cultural heritage information can be mapped to, for the purpose of information integration, machine reasoning, and creation of new knowledge. Furthermore, in a linked open data environment, the use of Semantic web building blocks such as URIs for identifiers, XML for syntax, and RDF for data exchange, is inevitable.

Valuable insights can be adapted from research based on ontology-driven blockchain designs that can be adapted to the application of smart contracts in cultural heritage. Kim and Laskowski [56] presented a modelling approach based on formal ontologies that can aid in the development of smart contracts that execute on the blockchain, and as a proof-of-concept, they translated TOVE Traceability Ontology axioms (expressed in first-order logic) into smart contracts that could execute a provenance trace and enforce traceability constraints on the blockchain. Ontological smart contracts (OSC) represent further developments by which formal ontologies can provide an opportunity to tackle the interoperability challenge in the digital environment by ontological modelling of agents and their interactions in the context of smart contracts [57]. The latter two articles describe

the application of smart contracts outside the field of heritage (therefore they are not included in the literature review) and are singled out here to highlight the potential of such functionalities in the heritage sector.

The presented future directions indicate the need for heritage experts and researchers to study the technologies and applications of blockchain and NFT outside the heritage field in order to recognize possible future applications in the GLAM sector. This certainly presupposes great and systematic efforts of researchers and experts in the field of heritage and once again points to the necessity of their further education in the field of blockchain, NFTs and related technologies.

Author Contributions: Conceptualisation, H.S., M.B. and G.Z.; methodology, H.S., M.B. and G.Z.; formal analysis, H.S., M.B. and G.Z.; investigation, H.S. and M.B.; resources, H.S., M.B. and G.Z.; data curation, H.S., M.B. and G.Z.; writing—original draft preparation, H.S. and M.B.; writing—review and editing, H.S., M.B. and G.Z.; visualisation, H.S. and M.B.; supervision, H.S., M.B. and G.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research is part of the project Application of blockchain technology in heritage environment and was funded by an institutional grant 11-931-1073 (Faculty of Humanities and Social Sciences Zagreb) supported by University of Zagreb.

Data Availability Statement: Data can be obtained upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Haber, S.; Stornetta, W.S. How to time-stamp a digital document. *J. Cryptol.* **1991**, *3*, 99–111. [CrossRef]
2. Sherman, A.T.; Javani, F.; Zhang, H.; Golaszewski, E. On the Origins and Variations of Blockchain Technologies. *IEEE Secur. Priv.* **2019**, *17*, 72–77. [CrossRef]
3. Number of Internet and Social Media Users Worldwide as of January 2023. Available online: https://www.statista.com/statistics/617136/digital-population-worldwide/ (accessed on 11 April 2023).
4. Market Capitalization of Transactions Globally Involving a Non-Fungible Token (NFT) from 2018 to 2021. Available online: https://www.statista.com/statistics/1221742/nft-market-capitalization-worldwide/ (accessed on 11 April 2023).
5. Number of Transactions Involving a Non-Fungible Token (NFT) in Gaming, Art, Sports and Other Segments from 2018 to 2020. Available online: https://www.statista.com/statistics/1221487/nft-sales-volume-by-segment/ (accessed on 11 April 2023).
6. How Museums Are Interacting with NFTs in 2022. Available online: https://cuseum.com/blog/2022/4/26/how-museums-are-interacting-with-nfts-in-2022 (accessed on 11 April 2023).
7. How 21 Museums & Cultural Organizations Engaged with NFTs in 2021. Available online: https://cuseum.com/blog/2021/11/16/how-21-museums-amp-cultural-organizations-engaged-with-nfts-in-2021 (accessed on 7 April 2023).
8. NFTs, on the Decline Elsewhere, Are Embraced by Some Museums. Available online: https://www.nytimes.com/2022/11/30/arts/design/nfts-museums.html (accessed on 7 April 2023).
9. Del Vacchio, E.; Bifulco, F. Blockchain in Cultural Heritage: Insights from Literature Review. *Sustainability* **2022**, *14*, 2324. [CrossRef]
10. NFT Beats Cheugy to be Collins Dictionary's Word of the Year. Available online: https://www.theguardian.com/books/2021/nov/24/nft-is-collins-dictionary-word-of-the-year (accessed on 7 April 2023).
11. 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]
12. Trček, D. Cultural heritage preservation by using blockchain technologies. *Herit. Sci.* **2022**, *10*, 1–11. [CrossRef]
13. Yaga, D.; Mell, P.; Roby, N.; Scarfone, K. *Blockchain Technology Overview*; National Institute of Standards and Technology: Gaithersburg, MD, USA, 2018.
14. Ross, D.; Cretu, E.; Lemieux, V. NFTs: Tulip Mania or Digital Renaissance? In Proceedings of the 2021 IEEE International Conference on Big Data (Big Data), Orlando, FL, USA, 15–18 December 2021; pp. 2262–2272. [CrossRef]
15. Ethereum Whitepaper. Available online: https://ethereum.org/en/whitepaper/#a-next-generation-smart-contract-and-decentralized-application-platform (accessed on 21 August 2022).
16. Non-Fungible Tokens (NFT). Available online: https://ethereum.org/en/nft/#:~:text=NFTs%20are%20tokens%20that%20we,a%20new%20NFT%20into%20existence (accessed on 23 August 2022).
17. Wang, Q.; Li, R.; Wang, Q.; Chen, S. Non-Fungible Token (NFT): Overview, Evaluation, Opportunities and Challenges. *arXiv* **2021**, arXiv:2105.07447. [CrossRef]
18. Pinto-Gutiérrez, C.; Gaitán, S.; Jaramillo, D.; Velasquez, S. The NFT Hype: What Draws Attention to Non-Fungible Tokens? *Mathematics* **2022**, *10*, 335. [CrossRef]

19. Basile, M.; Dini, G.; Marchetti, A.; Bacciu, C.; Lo Duca, A. A blockchain-based support to safeguarding the Cultural Heritage. In Proceedings of the 28th International Conference on Electronic Imaging & the Visual Arts (EVA), Florence, Italy, 8–9 May 2019; pp. 64–71. [CrossRef]
20. Abdullaev, A.; Saidov, A.; Aliev, A. Problematic Issues of Providing Validity and Optimization of the Exchange of Archival Information Based on Blockchain Technology. In Proceedings of the 17th International Asian School-Seminar Optimization Problems of Complex Systems (OPCS), Novosibirsk, Russia, 13–17 September 2021; pp. 4–8. [CrossRef]
21. Collomosse, J.; Bui, T.; Brown, A.; Sheridan, J.; Green, A.; Bell, M.; Fawcett, J.; Higgins, J.; Thereaux, O. ARCHANGEL: Trusted archives of digital public documents. *arXiv* **2018**, arXiv:1804.08342. [CrossRef]
22. Bell, M.; Green, A.; Sheridan, J.; Collomosse, J.; Cooper, D.; Bui, T.; Thereaux, O.; Higgins, J. Underscoring archival authenticity with blockchain technology. *Insights* **2021**, *32*, 21. [CrossRef]
23. Dolan, L.; Kavanaugh, B.; Korinek, K.; Sandler, B. Off the Chain: Blockchain Technology—An Information Organization System. *Tech. Serv. Q.* **2019**, *36*, 281–295. [CrossRef]
24. Bralić, V.; Kuleš, M.; Stančić, H. A Model for Long-term Preservation of Digital Signature Validity: TrustChain. In *Integrating ICT in Society*; Atanassova, I., Zaghouani, W., Kragić, B., Aas, K., Stančić, H., Seljan, S., Eds.; University of Zagreb: Zagreb, Croatia, 2017; pp. 89–113.
25. Stančić, H. Blockchain in digital preservation. In *Trust and Records in an Open Digital Environment*; Stančić, H., Ed.; Routledge: Abingdon, NY, USA, 2021; pp. 13–226.
26. Stančić, H.; Bralić, V. Digital Archives Relying on Blockchain: Overcoming the Limitations of Data Immutability. *Computers* **2021**, *10*, 91. [CrossRef]
27. Lo Duca, A.; Bacciu, C.; Marchetti, A. The Use of Blockchain for Digital Archives: A comparison between Ethereum and Hy-perledger (AIUCD 2019). *Um. Digit.* **2020**, *4*. [CrossRef]
28. Lemieux, V.L. A typology of blockchain recordkeeping solutions and some reflections on their implications for the future of archival preservation. In Proceedings of the 2017 IEEE International Conference on Big Data (Big Data), Boston, MA, USA, 11–14 December 2017; pp. 2271–2278. [CrossRef]
29. Chingath, V.; Babu, H.R. Advantage Blockchain Technology for the Libraries. In Proceedings of the International Conference on Digital Transformation: A Cognitive Learning towards Artificial Intelligence, Patiala, India, 6–8 September 2019; pp. 127–134. Available online: https://www.researchgate.net/publication/341725555_Advantage_Blockchain_Technology_for_the_Libraries (accessed on 17 March 2023).
30. Abid, H. Uses of blockchain technologies in library services. *Libr. Hi Tech. News* **2021**, *38*, 9–11. [CrossRef]
31. Oyelude, A.A. Trending issues in advancing blockchain technology in libraries, archives and museums. *Libr. Hi Tech. News* **2022**, *39*, 6–7. [CrossRef]
32. Cabello, J.; Janßen, G.; Mühle, A. *Distributed Library Management System Based on the Blockchain Technology*; Atos IT Challenge; Technische Universität Berlin: Berlin, Germany, 2017.
33. Frederick, D.E. Blockchain, libraries and the data deluge. *Libr. Hi Tech. News* **2019**, *36*, 1–7. [CrossRef]
34. Hoy, M.B. An Introduction to the Blockchain and Its Implications for Libraries and Medicine. *Med. Ref. Serv. Q.* **2017**, *36*, 273–279. [CrossRef]
35. Hasan, N. Blockchain Technology and Its Application in Libraries. *Libr. Her.* **2020**, *58*, 118–125. Available online: https://www.researchgate.net/publication/348602358_Blockchain_Technology_and_its_Application_in_Libraries (accessed on 17 March 2023).
36. Gallagher, M.; Fuentes, M.G. Key Blockchain Projects to Improve Performance at the British Museum. *UCL School of Menagement*. 2020. Available online: https://www.mgmt.ucl.ac.uk/sites/default/files/upload/pdfs/British%20Museum%20-%20Blockchain%20.pdf (accessed on 9 May 2022).
37. 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]
38. 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]
39. Mucchi, L.; Milanesi, M.; Becagli, C. Blockchain technologies for museum management. The case of the loan of cultural objects. *Curr. Issues Tour.* **2022**, *25*, 3042–3056. [CrossRef]
40. Siountri, K.; Skondras, E.; Vergados, D.D. Towards a Smart Museum using BIM, IoT, Blockchain and Advanced Digital Technologies. In Proceedings of the ICVISP 2019: 3rd International Conference on Vision, Image and Signal Processing, Vancouver, BC, Canada, 26–28 August 2019. [CrossRef]
41. Wang, Y.-C.; Chen, C.-L.; Deng, Y.-Y. Museum-Authorization of Digital Rights: A Sustainable and Traceable Cultural Relics Exhibition Mechanism. *Sustainability* **2021**, *13*, 2046. [CrossRef]
42. Wang, Y.-C.; Chen, C.-L.; Deng, Y.-Y. Authorization Mechanism Based on Blockchain Technology for Protecting Museum-Digital Property Rights. *Appl. Sci.* **2021**, *11*, 1085. [CrossRef]
43. Zhao, L.; Zhang, J.; Jing, H. Blockchain-Enabled Digital Rights Management for Museum-Digital Property Rights. *Intell. Autom. Soft Comput.* **2022**, *34*, 1785–1801. [CrossRef]
44. Sater, S.; Wright, R. Conversation on Art, Museums, and Blockchain. *Tulane J. Technol. Intellect. Prop.* **2019**, *21*, 35–52. Available online: https://ssrn.com/abstract=3406841 (accessed on 15 December 2022).

45. Cuesta Valera, S.; Fernández Valdés, P.; Muñoz Viñas, S. NFT y arte digital: Nuevas posibilidades para el consumo, la difusión y preservación de obras de arte contemporáneo. *Artnodes* **2021**, *28*. [CrossRef]
46. Liddell, F. Building Shared Guardianship through Blockchain Technology and Digital Museum Objects. *Mus. Soc.* **2021**, *19*, 220–236. [CrossRef]
47. Liddell, V.F. The Crypto-Museum: Investigating the Impact of Blockchain and NFTs on Digital Ownership, Authority, and Authenticity in Museums. Ph.D. Thesis, School of Arts, Languages & Cultures, University of Manchester, Manchester, UK, 2022.
48. Bhowmik, D.; Natu, A.; Ishikawa, T.; Feng, T.; Abhayaratne, C. The Jpeg-Blockchain Framework for GLAM Services. In Proceedings of the 2018 IEEE International Conference on Multimedia and Expo, San Diego, CA, USA, 23–27 July 2018. [CrossRef]
49. Anagnostakis, A. Towards a Blockchain Architecture for Cultural Heritage Tokens. In *Transdisciplinary Multispectral Modeling and Cooperation for the Preservation of Cultural Heritage. TMM_CH 2018. Communications in Computer and Information Science*; Moropoulou, A., Korres, M., Georgopoulos, A., Spyrakos, C., Mouzakis, C., Eds.; Springer: Berlin/Heidelberg, Germany, 2019; Volume 961, pp. 541–551. [CrossRef]
50. Ch'Ng, E. The First Original Copy and the Role of Blockchain in the Reproduction of Cultural Heritage. *PRESENCE Virtual Augment. Real.* **2019**, *27*, 151–162. [CrossRef]
51. Ertürk, E.; Doğan, M.; Kadiroğlu, Ü.; Karaarslan, E. 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]
52. Angelova, M. Application of Blockchain Technology in the Cultural and Creative Industries. In Proceedings of the II International Conference on High Technology for Sustainable Development (HiTech), Sofia, Bulgaria, 10–11 October 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 1–4. [CrossRef]
53. Trček, D. HeriLedger—A New Generation of Blockchains for Cultural Heritage Preservation. *Sensors* **2022**, *22*, 8913. [CrossRef]
54. Tasovac, T.; Chambers, S.; Tóth-Czifra, E. Cultural Heritage Data from a Humanities Research Perspective: A DARIAH Position Paper. 2020. Available online: https://hal.science/hal-02961317 (accessed on 15 March 2023).
55. Oldman, D.; Doerr, M.; Gradmann, S. Zen and the Art of Linked Data: New Strategies for a Semantic Web of Humanist Knowledge. In *A New Companion to Digital Humanities*, 1st ed.; Schreibman, S., Siemens, R., Unsworth, J., Eds.; Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2016; pp. 251–273. [CrossRef]
56. Kim, H.M.; Laskowski, M. Toward an ontology-driven blockchain design for supply-chain provenance. *Intell. Syst. Account. Finance Manag.* **2018**, *25*, 18–27. [CrossRef]
57. Cantone, D.; Longo, C.F.; Nicolosi Asmundo, M.; Santamaria, D.F.; Santoro, C. Ontological Smart Contracts in OASIS: Ontology for Agents, Systems, and Integration of Services. In *Intelligent Distributed Computing XIV. IDC 2021. Studies in Computational Intelligence*; Camacho, D., Rosaci, D., Sarné, G.M.L., Versaci, M., Eds.; Springer: Cham, Switzerland, 2022; Volume 1026, pp. 237–247. [CrossRef]