Muzart: A Blockchain-Based Digital Museum Platform

Kabir Berger
200024484

Project Supervisor: Alan Miller

School of Computer Science
University of St. Andrews
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Abstract

The shift towards the digital museum reflects a significant change in the cultural sector, moving beyond physical museum spaces to digital platforms accessible worldwide. As preservers of cultural heritage, museums face challenges with traditional collection management methods amid evolving curatorial practices and exhibition. Blockchain technology offers a viable solution, enhancing collection transparency and audience interaction. Muzart, an Ethereum-based blockchain platform, emerges as a comprehensive ecosystem for managing and democratizing museum collections. Allowing users to explore, mint, and own digital NFT artifacts through ERC-1155 tokens which is supported by the IPFS for decentralized storage. This setup ensures transparent, immutable records of artifact ownership, addressing the limitations of physical artifact preservation and traditional record-keeping. Despite the rigidity of smart contracts posing challenges to adaptability, Muzart's approach significantly enhances museum collection management, operational transparency, and audience engagement, marking a progressive step in integrating blockchain technology within museums and cultural heritage. Future efforts aimed at enhancing scalability, integration with decentralized autonomous organizations, and refining content verification procedures will establish Muzart as a leading platform in digitally preserving and making cultural heritage accessible.

Contents

Chapter 1
Introduction

> It is so important that as a museum we continually adapt to new markets and find new ways of reaching people that we may not reach through traditional channels.
>
> Craig Bendle

The exploration of "the digital museum" by educators and scholars marks a pivotal shift in the cultural sector. This concept has seen the traditional idea of "place" evolve and extend beyond the physical confines of museum buildings, finding its way to the desks and pockets of digital visitors. As a result, the museum experience has become as much about the immersive and interactive encounters provided by these digital platforms than the physical institutions themselves [1]. This transition is reflective of broader transformations within the art world, especially with the introduction of blockchain technology. Blockchain platforms are revolutionizing how art provenance and transaction histories are managed and presented, offering indispensable tools for verifying the authenticity of artworks. Moreover, these technologies are essential in maintaining records of art that is stolen, lost, or confiscated, further integrating the digital museum concept into the fabric of the art world's future. Together, these developments signal a significant change in how art and cultural experiences are consumed, valued, and preserved in the digital age [2].

1.1 Problem Statement

Museums serve as vital custodians of cultural heritage and historical knowledge, providing insights into the diverse narratives of human achievement and creativity. Yet, they currently confront several challenges that compromise their capacity for effective collection management, transparency in operations, and the engagement of their audiences. The rapid onset of the digital era, further accelerated by the global COVID-19 pandemic and in the UK the cost-of-living crisis, has accentuated the necessity for museums to evolve and embrace innovative strategies to meet the shifting expectations and demands of their visitors [1].

Collection Management and Financial Viability

Conventional methodologies employed in the management of museum collections are becoming progressively insufficient in addressing the intricacies associated with contemporary curatorial practices and exhibition. Museums bear the essential task of safeguarding artifacts whilst ensuring their accessibility to the public. Financially, the sector faces a precarious situation. Notwithstanding a modest increment in visitor numbers during the 2022-23 period, attendance remained eighteen percent below the levels observed prior to the pandemic. This decrease in visitor engagement has been accompanied by a financial downturn, marked by a three percent reduction in income alongside a staggering ten percent increase in operational costs during this same timeframe. This scenario underscores the imperative for innovative approaches to generating revenue [3].

Digital Transition and Associated Challenges

The digital transformation presents an opportunity for museums to extend their reach and engage with audiences on a global scale[1] through virtual exhibits, social media engagement, livestreams, and the incorporation of virtual and augmented reality technologies. This shift towards a digital presence is crucial for museums aiming to maintain relevance in an era where digital content predominates. Nonetheless, this transition is fraught with challenges. Museums grapple with the task of delivering immersive and captivating online experiences, as many artifacts lose their impact when represented as flat two-dimensional images. Furthermore, the model of offering free online exhibits and collections faces difficulties in sustaining itself as a viable revenue source, highlighting the necessity for more profitable digital engagement models [4, 5].

The Potential of Blockchain Technology

In the face of these challenges, the adoption of blockchain technology offers a novel and promising solution. Blockchain technology proposes a viable method for museum collection management, enhancing operational transparency, and enriching visitor interaction. Through the creation of Non-Fungible Tokens (NFTs) of 3D artifacts, museums can introduce an innovative mode of interaction with digital exhibits. This mechanism not only ensures the preservation of the uniqueness and authenticity of each artifact but also inaugurates new avenues for revenue generation by permitting the sale or exchange of digital recreations. The deployment of blockchain technology harbors the potential to revolutionize the museum experience, rendering it more interactive, accessible, and economically viable. By leveraging this innovative solution, museums can more effectively manage the transition to digital, extending their global reach, ensuring their enduring relevance and ability to inspire and educate forthcoming generations while preserving their cultural and historical significance.

Muzart

This introduces Muzart, a blockchain-based digital museum platform. This project is not merely an online gallery; it is a comprehensive, blockchain-powered ecosystem designed to democratize and manage museum collections and re-engage audiences with cultural artifacts. Muzart enables museums to manage and display art collections, and allows users to explore, mint, and own unique digital tokens of artifacts, thus rethinking ownership and interaction within the digital cultural sphere. Through Muzart, we witness a prospect for enhancing collection management, improving operational transparency and security, and reimagining audience engagement with the arts.

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[1] British Museum's online shop a hit in China [6]

1.2 Methodologies

The development and execution of the Muzart web application was structured through a comprehensive methodology, encompassing four primary stages: literature review, design, implementation, and evaluation. Each phase played a principal role in ensuring the project's objectives were met.

Phase 1: Literature Review

The initial phase involved an extensive literature review, aimed at gathering insights into existing technologies and solutions within the domain of blockchain-based digital artifacts. This review served to benchmark current practices, identify gaps in the available offerings, and understand the technological underpinnings that could be leveraged for Muzart. A focus was placed on exploring advancements in blockchain technology, NFT standards, 3D model rendering, and IPFS storage solutions, laying the groundwork for the subsequent design and development phases.

Phase 2: Design

The design phase involved the architectural planning of both the application's user interface (UI) and the underlying smart contracts. Using Figma, a UI design tool, a comprehensive UI blueprint was created, detailing the user journey and interface layout. Concurrently, the design of the smart contracts and the ERC-1155 token model was formalized, focusing on the integration of metadata and 3D model data storage on IPFS. This stage was fundamental in establishing a cohesive and intuitive user experience while ensuring the technical feasibility and security of the blockchain components.

Phase 3: Implementation

The implementation phase, through an agile methodology, consisted of a series of one week development sprints. This facilitated meticulous sprint planning, regular progress updates through supervisor meetings, and continuous integration and testing to ensure the application's quality and stability. The end of each sprint featured a review and retrospective, enabling the incorporation of feedback and self-reflection on the development process for ongoing improvement. This approach not only enhanced flexibility and adaptability to emerging requirements but also ensured that the final product aligned with user expectations. This phase was instrumental in transforming the project's conceptual designs into a functional web application.

Phase 4: Evaluation

The final phase involved a thorough evaluation of Muzart, assessing its functionality, user experience, and blockchain integration. Feedback from my supervisor to identify areas for improvement and ensure the application's reliability and usability. Additionally, the UI and blockchain technologies underwent thorough integration testing, confirming the viability of Muzart.

1.3 Objectives

The high-level primary objectives of the Muzart project, as set by the initial DOER (Description, Objectives, Ethical Concerns, Resources) proposal, are as follows:

- Develop a blockchain-based platform that integrates with museum collections for transparent and immutable records of artifacts, and ownership.
- Create a digital NFT catalog of museum collections accessible to the public and researchers, including detailed artifact information.
- Implement interactive exhibits within museums to enhance visitor engagement and learning.
- Utilize blockchain to meticulously track the ownership history of museum artifacts, ensuring transparency and authenticity.
- Explore enabling public participation in the curation process through blockchain-based voting and suggestions.

Chapter 2

Context

> I think an NFT should be something that you approach in the same way you approach an exhibition and it’s focused on creating or driving a story, driving impact and doing something that should stand on its own two feet.
>
> Chris Cummings

2.1 Background

2.1.1 Blockchain Technologies

Blockchain technology, first conceptualized by an individual or group known as Satoshi Nakamoto in 2008, serves as the backbone of the digital currency Bitcoin. It's a decentralized digital ledger that records transactions across many computers in such a way that the registered transactions cannot be altered retroactively. This technology offers a secure and transparent method for conducting transactions without the need for a central authority, making it revolutionary in fields beyond cryptocurrency, such as digital art, supply chain management, and secure voting systems. Blockchain's unique properties of decentralization, immutability, and transparency are what make it a promising and transformative technology for various industries, offering new opportunities for authentication, efficiency, and the democratization of data [7].

ERC20 and ERC721 standards offer specialized solutions for fungible and non-fungible tokens, respectively. ERC20 excels in creating and managing fungible tokens (identical and interchangeable), such as cryptocurrencies or utility tokens, with simplicity and widespread compatibility. ERC721 is the first standard designed explicitly for non-fungible tokens (unique), providing a foundational framework for unique digital assets.

The ERC-1155 protocol stands as a highly flexible framework within the Ethereum ecosystem, designed to support the creation and management of both fungible and non-fungible tokens to be managed under a single smart contract. This standard distinguishes itself with features aimed at enhancing security during the transfer of tokens, among other functionalities [8]. This multifaceted approach streamlines the process of creating and managing diverse types of assets on the Ethereum blockchain, significantly enhancing efficiency. One of the pivotal advantages of ERC1155 over its predecessors is its ability to drastically reduce gas costs and storage requirements, owing to its innovative batch transfer capabilities and the consolidation of multiple token types into one contract. This efficiency makes it particularly attractive for projects that require a versatile token framework, such as digital collectibles, gaming items, and various decentralized finance (DeFi) applications [9].

A vital aspect of blockchain technologies are crypto wallets, which are the digital tools that allow users to store, manage, and transact tokens securely. They act as a bridge to the blockchain, enabling individuals to send and receive digital tokens and monitor their balance. MetaMask stands out in the realm of cryptocurrency wallets due to its ease of use, integration capabilities, and widespread acceptance across the decentralized web [10]. As a browser extension and mobile app, MetaMask provides a secure and intuitive interface for interacting with the Ethereum blockchain, supporting a broad array of Ethereum-based tokens and enabling users to manage their digital assets, interact with decentralized applications (dApps), and execute smart contracts [11].

2.1.2 IPFS

The InterPlanetary File System (IPFS) is not merely a protocol but a transformative network architecture that redefines the paradigms of digital content storage. As a decentralized and content-addressable peer-to-peer file-sharing system, IPFS excels in creating a distributed environment for storing and accessing hypermedia files. Its core innovation lies in its ability to provide a robust, efficient, and scalable solution for the web, where digital assets are not stored in centralized servers but are distributed across multiple nodes in the network [12].

IPFS represents a collective file system that amalgamates key elements from prior peer-to-peer systems, incorporating the strengths of DHTs (Distributed Hash Tables), BitTorrent, Git, and SFS (Self-Certified Filesystems). Its major advancement lies in the integration and refinement of these established methods into a unified, powerful system that exceeds the capabilities of its individual components [13]. Operating on a peer-to-peer basis, IPFS does not prioritize any node; each node houses IPFS objects within its local storage. These nodes establish connections amongst themselves to exchange objects, which encapsulate files and various data structures [14].

2.1.3 Sepolia Test Network

A test network (testnet) provides a sandbox environment for developers to trial and refine blockchain applications and smart contracts without risking real funds or assets. This framework offers a secure setting for pre-launch testing on a blockchain main network (mainnet). Within the Ethereum ecosystem, the Sepolia testnet serves as a proof-of-stake (PoS) platform for smart contract experimentation. The PoS consensus mechanism, which underpins this system, validates transactions, and generates new blocks through validators or stakers. These participants are selected based on the amount of cryptocurrency they hold and are willing to 'stake' or secure as a guarantee for the opportunity to validate subsequent blocks. SepoliaETH tokens, which are unlimited in supply, have made Sepolia a preferred choice over other testnets like the Goerli testnet [15].

2.1.4 Smart Contract

Smart contracts, which are self-executing contracts with the agreement terms between buyer and seller embedded within the code, play an important role in the infrastructure of blockchain technology. These contracts streamline the process of enforcing contractual terms, thereby diminishing the necessity for intermediaries, which in turn amplifies transaction efficiency and fortifies security [16]. Acting as programs that operate on the blockchain, smart contracts execute across a network of nodes that may not necessarily trust one another, all without the intervention of an external trusted authority [17]. This intrinsic characteristic of smart contracts to automatically execute and enforce themselves carves out significant potential for applications across various sectors that depend on reliable data to facilitate transactions [18].

2.2 Literature Review

2.2.1 Museum Collection Management

Museums, as defined by the International Council of Museums (ICOM), are "non-profit, permanent institutions in the service of society that researches, collects, conserves, interprets and exhibits tangible and intangible heritage” [19]. With a commitment to serve society, they strive to be open to the public, accessible and inclusive. This foundational purpose, however, faces challenges in the realm of collection management due to outdated and inefficient record-keeping systems.

The critical role of museums in preserving cultural heritage is universally acknowledged. Yet, the sector is confronted with significant management challenges, notably in the domain of collection record-keeping. The following sections examine these challenges, their implications for public accessibility and education, and explores the potential of technological solutions to address these issues.

2.2.1 Challenges in Museum Collections

Museums have traditionally struggled with record-keeping systems for lack of consistency, accuracy, and efficiency. Problems such as missing details, duplicated catalog entries, inconsistent terminology, insufficient cross-referencing, and the loss of records have been prevalent, complicating the access to collections across different curatorial departments. The Smithsonian Institution's early efforts in automation and standardization revealed significant gaps in collections information, underscoring the need for enhanced systems for capturing and retrieving data [20].

A 2011 study by the World Heritage Convention and UNESCO indicated that up to sixty percent of museum collections globally are at risk due to various factors, including storage and budget constraints. Remarkably, 95% of a museum's artifacts are stored out of public view, highlighting the urgent need for solutions to safeguard these collections while also making it accessible to researchers and educators at the same time [13].

The advent of computing technology has been recognized as a potential catalyst for improving museum collection management. As early as 1967, the Smithsonian Institution envisioned automated collections to enhance accessibility to resources for educational and research purposes. This recognition of technology's potential has pushed museums to adopt automation and computing to meet the growing demand for accessible information about their collections [20].

The evolution of societal expectations has placed additional demands on museums. The public increasingly perceives museums as key educators in cultural heritage, beyond mere repositories of objects. This paradigm shift has amplified the need for improved record-keeping practices to enable efficient access and sharing of collection information.

The conventional management of digital collections suffers from security and efficiency deficits. Blockchain technology emerges as a solution, offering secure and traceable data value exchange, which could revolutionize the management and accessibility of digital collections [21].

2.2.2 ArtChain

ArtChain [22], a blockchain solution developed in Australia is one of the first deployed blockchain art trading platforms. Its aim is to use blockchain technology to facilitate secure, consensus-driven transactions within ecosystems traditionally characterized by mistrust. Its inherent design prevents any single entity from altering the ledger without consensus, ensuring data immutability. This technology finds application across various sectors, including food safety and logistics, for tasks such as traceability and workflow management.

Its context is based in the art market, which, with its $200 billion annual turnover, stands as one of the largest unregulated markets globally, second only to drugs and firearms in terms of crime. The market is plagued with challenges including opaque pricing, dubious provenance, authentication difficulties, and inadequate artist recognition and royalty payments. These issues underscore the necessity for a more transparent, secure, and equitable marketplace.

ArtChain emerges as a pioneering blockchain-based art trading system aimed at addressing the art market's endemic challenges. By leveraging the core principles of blockchain, ArtChain proposes a comprehensive ecosystem for the maintenance, trading, and transfer of art assets. The platform's architecture is designed to support commercial-level trading, with a focus on privacy, traceability, irreversibility, and transparency.

ArtChain's architecture was designed following a comprehensive evaluation of several blockchain platforms, ultimately selecting the Ethereum private blockchain coupled with the Proof of Authority (PoA) consensus algorithm. This choice was influenced by Ethereum's capability to meet specific business requirements, including native token support essential for integrating payment and ownership transfer processes within the art trading platform. The system incorporates a microservices architecture to facilitate efficient development, interface reusability, and streamline integration testing, presenting a three-tier structure comprising the user front end, trading back end, and the ArtChain blockchain layer.

PoA, a consensus mechanism that designates approved individuals or entities (authorities or validators) to validate transactions. This mechanism is known for its efficiency and low energy consumption compared to Proof of Work (PoW) [23]. PoA enhances security and efficiency, as validators are likely to be trusted entities within the art market ecosystem, such as reputable galleries, auction houses, or artists themselves. This setup ensures that transactions are quickly validated by parties with a vested interest in maintaining the integrity of the art trading platform.

ArtChain’s trading back-end system is focused on artwork management, this segment facilitates artwork registration, ownership verification, and transfer, enabling artists and collectors to register their works for trading within the ArtChain ecosystem. ArtChain’s blockchain layer is central to the platform, this layer includes a royalty model for artist payments, a Proof of Interaction (POI) model for ecosystem incentives.

To ensure the integrity of the ArtChain network, it aims for collaboration with prominent entities in the art market. Initial ledger nodes, operated by museums, galleries, and auction houses, play a pivotal role in transaction validation and block generation for ArtChain. The Proof of Authority (PoA) model underlies the network's trust architecture, with selected museums and galleries acting as supernodes responsible for authenticity assessments and price evaluations.

2.2.3 Museum Art Exchange Protocol (MAXP)

Blockchain technology not only holds significant promise in the art market, but for museums as well. Particularly in the digitization of artworks, management of collections, and audience engagement. It offers immense capabilities for establishing digital identities. With a system for decentralization and traceability features, blockchain ensures clear value assurance for each item in a collection and provides robust protection for the intellectual property rights of cultural relics and artworks. This ensures that the entire circulation process can be monitored and verified [24].

The Museum Art Exchange Protocol (MAXP) is an innovative encrypted exchange protocol for museum digital collections, addressing the shortcomings of traditional digital collection management systems such as low security and inefficiency. Utilizing blockchain technology, MAXP ensures the secure and traceable exchange of digital collection data, enhancing the protection and regulatory oversight of museum collections. This protocol incorporates the SM2-based dual receiver public key encryption algorithm to establish a regulatory mechanism at the encryption level, creating a blockchain-based NFT trading system for digital museum assets. Through MAXP, museums can cast, exchange, store, and transmit data NFTs within a regulated blockchain environment, ensuring the secure finalization of transactions. The protocol integrates the Diffie-Hellman and SM2 algorithms to construct a double-receiver public key encryption scheme, allowing museums to securely transfer usage rights of digital collection NFTs. This advancement in blockchain applications signifies a major step forward in the secure management and exchange of digital museum collections [25].

Considering the nature of the data, which includes high-definition images, 3D models, and related materials, the MAXP protocol employs the IPFS decentralized storage solution. This strategy guarantees the integrity and precise representation of digital collections within each NFT [26]. To assemble the requisite information accurately, they aligned with established museum collection data standards. Additionally, MAXP implemented content encryption to enhance security measures, ensuring strict control over access and authority. This approach effectively secures permissions, preventing any potential unauthorized access or dissemination of the data.

2.2.4 Blockchain as a Revenue model

The ability of NFTs to create substantial income for artists and museums through the sale of cryptographically authenticated copies of digital images (akin to limited editions in the real world that are signed and numbered) has captured the attention of the financially struggling museum and heritage industry [27].

Unlike traditional NFTS (ERC720), ERC-1155 token introduces a more versatile approach. This flexibility is particularly advantageous for museums and artists looking to monetize their collections without relinquishing ownership of the original pieces [28].

For museums struggling with financial constraints, ERC1155 tokens represent a potential source of relief. By offering authenticated digital replicas of artifacts and artworks, museums can tap into the expanding market of digital collectors without compromising the integrity or availability of the physical collection. This model could generate immediate revenue through the initial sale, or through a royalty model built into the smart contract, that can support the institution's conservation, research, and educational missions.

Beyond the financial benefits, ERC1155 tokens offer a unique opportunity to engage with audiences worldwide. Digital replicas can be integrated into virtual exhibitions, allowing broader access to the museum's collection and fostering global cultural exchange. This democratization of access aligns with the educational goals of museums, expanding their reach and impact far beyond the physical confines of the institution.

2.2.5 Operational Transparency in Supply Chains

In general, transactions carried out by any participant within the supply chain are visible and verifiable by all other participants, guaranteeing transparency throughout the entire network [29].

Visibility refers to the capability to view or exchange information within the supply chain. A supply chain is considered transparent when there is a high level of visibility [30].

Transparency can serve as a unified source of truth for all actors within the supply chain network. The cryptographic linkage of all blocks within a blockchain negates the risk of data tampering, a frequent issue in centralized systems [31].

Blockchain technology has already begun being integrated into numerous supply chains, like real estate, insurance, and healthcare [29, 32]

2.2.6 Audience Engagement

Engagement within the context of museum and cultural heritage experiences is defined through three principal aspects: active participation, storytelling, and the collective experience shared among visitors [33]. As museums evolve to meet the changing landscape of technology and visitor expectations, they increasingly focus on integrating the public into their collections, exhibitions, and programs. This approach is grounded in a human-centric perspective, acknowledging the fluid transition between digital and physical realms without prioritizing one over the other [34].

The application of 3D modeling in cultural heritage preservation and presentation offers innovative opportunities to enhance artifact accessibility and interaction. This technology enables the creation of precise digital copies of cultural items, facilitating in-depth analysis, exploration, and adaptation that physical objects cannot provide. Moreover, 3D models serve as the foundation for virtual reality experiences, revolutionizing educational initiatives, exhibitions, and repatriation efforts by offering virtual access to historical artifacts.

In the realm of digital heritage, 3D models are considered valuable cultural artifacts themselves, capturing the original object's essence while introducing new dimensions of social and scientific significance. The interactive and dynamic capabilities of 3D modeling and virtual reality not only foster unique engagement opportunities but also evoke emotional connections and foster new narratives between individuals and cultural content [35].

The digitization of cultural heritage, which involves converting analog materials into digital formats, is identified as a critical endeavor by cultural institutions globally. Among various digitization methods, 3D modeling stands out, offering digital replicas that enhance the tactile interaction limitations. Such technologies ensure that these digital representations remain discoverable, interpretable, and preserved for future inquiries, thereby broadening digital heritage's reach and safeguarding its longevity [36].

3D modeling marks an advancement in cultural heritage conservation and engagement, bridging the gap between traditional methods and the digital era. By enabling accurate replication, immersive experiences, and greater accessibility, 3D modeling technology is significant in advancing digital heritage conservation practices and deepening public appreciation for cultural artifacts across varied audiences.

2.2.7 Challenges and Considerations

<u>Blockchain Considerations</u>

Integrating blockchain technology into system designs encounters the challenge of its inherent rigidity. While blockchain's security and transparency are unparalleled, its fixed nature poses difficulties in integration with dynamic IT infrastructures or evolving business requirements [37].

Blockchain's reliance on immutable smart contracts means that any adjustments or error corrections necessitate network consensus or, in some instances, contract redeployment. This inflexibility contrasts with the adaptability of conventional IT systems, which can be updated regularly to address new demands.

<u>Environmental Considerations</u>

The discourse surrounding crypto collectibles, predominantly revolves around the significant energy consumption associated with their creation, sale, and exchange. This concern is chiefly attributed to the Bitcoin and Ethereum blockchain, the predominant platform for NFT transactions. Ethereum's proof-of-work (PoW) consensus mechanism, similar to that used by Bitcoin, requires extensive computational efforts — "mining" — to validate transactions and secure the network. This process is energy-intensive, as it involves numerous computers around the world solving complex mathematical problems.

The environmental impact of such high energy consumption has sparked widespread debate within and outside the crypto community. This has raised concerns about the sustainability of NFTs and broader crypto activities, especially in the context of global efforts to reduce carbon emissions and combat climate change [38].

In response, the blockchain community is shifting towards more energy-efficient consensus mechanisms like proof-of-stake (PoS), notably with Ethereum's ongoing transition to Ethereum 2.0, expected to reduce its energy footprint drastically. Apart from Ethereum, there are already energy efficient NFTs in circulation, being traded as usual. For instance, the NFT associated with the Whitworth Gallery is listed and exchanged on the Tezos blockchain, known for its energy efficiency. Additionally, several blockchains employ the Proof-of-Stake method for transaction verification, such as Cardano and Algorand, which have energy requirements akin to traditional centralized server applications. Moreover, Cardano, which is grounded in academic research, has been fully launched at the end of summer 2021. It positions itself as "The Most Environmentally Sustainable Blockchain Protocol" due to its innovative and peer-reviewed Proof-of-Stake system. With its potential for scalability, interoperability, and sustainability, Cardano is seen as a strong competitor to Ethereum's dominance in the blockchain space [27].

2.3 Summary of other Projects

Various platforms and projects have ventured into this space, each contributing unique perspectives and solutions. Here are several notable projects in the realm of digital art and NFTs:

Mirror.xyz

Mirror.xyz leverages the Ethereum blockchain to offer a decentralized platform for writing and publishing. It integrates ERC1155 to monetize written content and articles. While Mirror.xyz innovatively merges blockchain technology with content creation, its primary focus remains on written articles.

NFTArts.co.uk

NFTArts.co.uk positions itself in the museum NFT space, aiming to bridge the gap between traditional art institutions and the digital blockchain world. This platform facilitates the digital representation and sale of museum artworks as NFTs, providing a new revenue stream for these institutions. However, its approach is predominantly focused on 2D digital reproductions of artworks, not fully exploiting the potential of 3D digitalization and interactive viewer engagement that modern audiences might seek.

Northern Heritage Network

The Northern Heritage Network has taken steps towards digitizing heritage by creating 3D representations of historical and cultural objects. This initiative is crucial for preserving and sharing heritage in a digital format. Nevertheless, the project primarily serves as a digital archive, lacking the blockchain integration that would enable secure ownership, provenance tracking, and the potential for creators and owners to engage in a marketplace.

British Museum

The British Museum has entered the NFT space by launching a digital collection of its artifacts as NFTs. This move demonstrates the potential for traditional institutions to embrace blockchain technology for art dissemination. While an initial first step, the British Museum's approach is relatively conventional, focusing on digital reproductions of existing physical artifacts without leveraging the full spectrum of blockchain capabilities, such as interactive experiences or enhanced viewer engagement tools.

Chapter 3

Methodology

Like any development process, the creation of the final prototype went through multiple iterations. This chapter will cover the development methodology, requirement specifications, and ethics.

3.1 Development Methodology

The adoption of an agile methodology was a strategic decision tailored to the dynamic requirements and limited timeframe of the project. Agile methodologies prioritize flexibility, continuous improvement, and customer satisfaction through iterative development. This approach contrasts with traditional, plan-driven project management methodologies by emphasizing adaptability over rigid planning and documentation.

Integration of Agile Methodology

The project’s implementation of agile principles facilitated a more responsive and adaptable development process. Agile's core values—individuals and interactions over processes and tools, working software over comprehensive documentation, customer collaboration over contract negotiation, and responding to change over following a plan—were integral to navigating the project's evolving challenges and requirements.

Key Components Used:

<u>Sprint Planning:</u> At the outset of each one week sprint, a plan was determined for the scope of work to be completed. This involved selecting tasks from the product backlog, a prioritized list of requirements to be done, ensuring that the project was focused on delivering the most valuable features first.

<u>Sprint Reviews and Retrospectives:</u> At the end of each sprint, a review allowed the project to demonstrate the completed, gathering feedback for future iterations. The Sprint Retrospective focused on evaluating the sprints performance and processes, identifying areas for improvement in the next sprint.

Outcomes of Using Agile

The iterative nature of Agile allowed for continuous feedback and adjustment. Regular collaboration with the supervisor, through weekly meetings, ensured that the project direction remained aligned with the objectives and that any issues were promptly addressed. This approach not only improved the quality of the product but also enhanced project management.

3.2 Requirement specification

Functional Requirements:

1. The user must be able to connect their MetaMask wallet for minting transactions.
2. The admin must be able to mint new original tokens of 3D artifacts as ERC-1155 tokens.
3. The admin must be able to manage role permissions and give and revoke admin and user rights.
4. The user must be able to mint a copy of a 3D artifact token to their own wallet.
5. The user must be able to view a gallery or collection view to browse available 3D artifact NFTs.
6. The user must be able to view and interact with a 3D model viewer.
7. The user must be able to view NFT artifact metadata, and blockchain node data for each artifact.
8. The user must be allowed to view a user with validation prompt before they are allowed to mint an artifact token.
9. The user must be given responsive feedback in the minting process.
10. The user must be shown a valid URL to bring the user to etherscan.io to view their NFT token and blockchain node.
11. The user must be able to search for specific NFT artifacts by:
    a. Name
    b. Author
    c. Tags

Non-Functional Requirements:

12. The system must use the OpenZeppelin library for writing secure smart contracts.
13. The system must deploy smart contracts for managing NFTs onto the Sepolia testnet.
14. The system must store NFT data, including metadata and 3D model links, on IPFS and provide a URL for access.
15. The system must provide an intuitive and user-friendly interface compatible with major web browsers (Chrome, Firefox, Safari, Edge).
16. The system's user interface design must be responsive to accommodate various screen sizes.
17. The system must be accessible, adhering to WCAG 2.1 standards for users with disabilities.
18. The system must implement robust security measures to protect user accounts and wallets.
19. The system must ensure data integrity and consistency across all user interactions with the NFTs and smart contracts.
20. The system must ensure the privacy of user data and transactions, complying with GDPR standards.
21. The system must utilize Tailwind CSS for styling, ensuring a responsive and modern design across devices.
22. The application must be developed using Next.js 14 and TypeScript, supporting server-side rendering (SSR) for SEO optimization.

23. The system must utilize the Ethers blockchain library for interacting with the Ethereum blockchain.
24. The system must use hardhat to test and deploy smart contracts.
25. The system must be designed for easy maintenance and updates, allowing for the seamless integration of new features or improvements.

3.3 Ethics

Regarding the ethical considerations with this project and methodology, there was an initial exploration into using user testing feedback for the front-end design and viewing the artifact collection. Thus, an Artifact Evaluation Form was completed. However, as development progressed, it became evident that the web application's simplicity did not justify the need for extensive user testing for its fundamental features. If Muzart would go through further development, engaging in a round of user testing would be advisable. The ethical approvement document can be found in Appendix A.

Chapter 4

Design

This chapter introduces the structure of the museum collection management system, iterations of the user interface, and the design of the smart contract.

4.1 Artifact Collection

The structure of Muzart's artifact collection of 3D NFTs is separated into two parts. The actual unique ERC-1155 token hosted on the Sepolia Testnet and the IPFS storage of its metadata and model. The metadata uses a JSON format where each digital artifact is detailed with essential information, facilitating cataloging similar to traditional methods but with digital advantages.

```json
{
 "id": "0",
 "name": "Artifact Name",
 "description": "Artifact Description.",
 "author": "Artifact Author",
 "model": "ipfs://url-to-3d-model.glb",
 "tags": ["ancient", "digital", "artifact", "3D"],
 "source": "/url-to-artifact-source"
}
```

Figure 1: Metadata.json File Structure

This figure shows an example metatada file that would be used alongside a 3D model file in the tokenization of a digital artifact.

IPFS ensures data integrity and accessibility, assigning unique Content Identifiers (CIDs), included in the IPFS URL, to each artifact for tamper-proof verification This decentralized storage method is critical for maintaining the authenticity and long-term preservation of digital replicas. Each token's data is an IPFS URL pointing to their metadata JSON file. Each metadata file includes the model's IPFS URL. Their unique IDs allow for precise inventory management and global accessibility.

This structure, as a prototype, allows for further development and additional information dependent on the needs of the artifacts themselves. This embodies the future of museum collection management, enabling a seamless integration of traditional practices with the benefits of digital technology. It provides a scalable, cost-effective solution that can adapt to the growing demands of digital archives, ensuring that each artifact is preserved, cataloged, and accessible in perpetuity. The employment of ERC-1155 tokens and IPFS not only marks a departure from conventional methodologies but also sets a new standard for the digital stewardship of cultural heritage, making it an exemplary model for museums transitioning into the digital era.

4.2 Web Application

UI Designs

Iteration 1

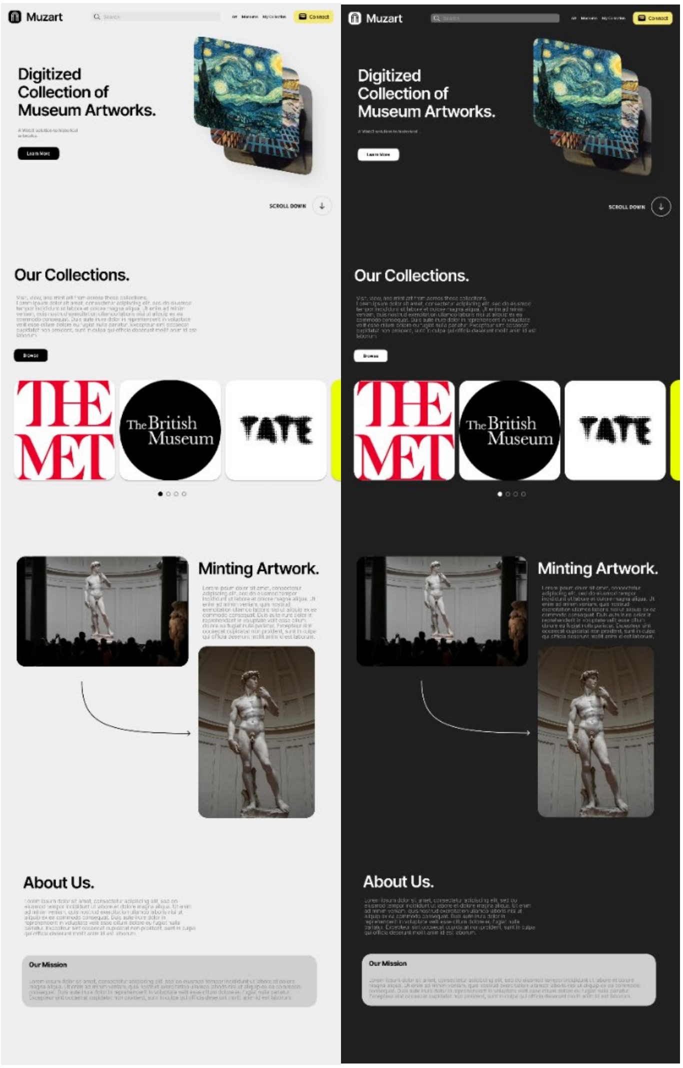

Figure 2: First Iteration Figma Mockup

In the initial design phase, conceptual models for an information-centric user experience were explored. This early stage aimed to present users with knowledge within the application, guiding them on an educational journey. However, this approach encountered difficulties in effectively highlighting the key principle of the projects, the artifacts themselves.

Iteration 2

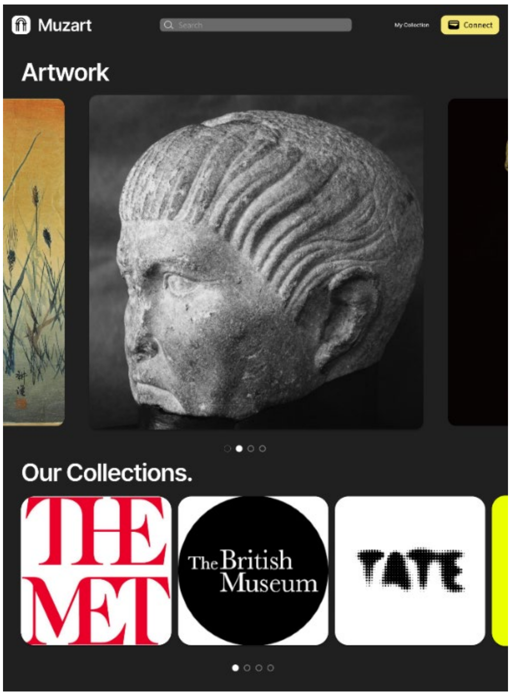

Figure 3: Second Iteration Figma Mockup

The subsequent iteration adopted a new strategy, centering primarily on the direct observation of the artifact collection. This shift aimed at a more straightforward user experience, enabling visitors to start exploring the collection right away upon page load, without the necessity of navigating through multiple pages. Given that the functionality is intended for integration with museums, prioritizing an information page became a secondary consideration.

Final Iteration

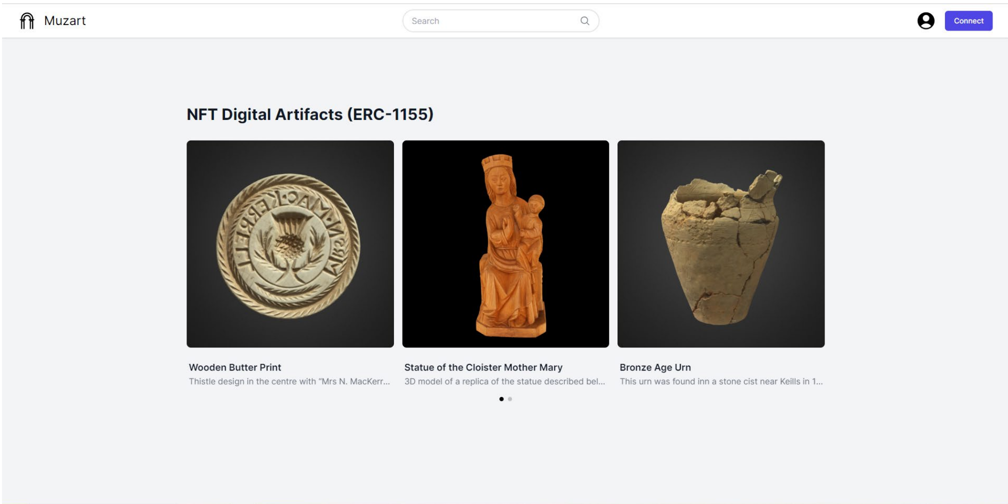

Figure 4 : Muzart App User Interface

This figure presents the final user interface which emphasizes the primary functionality of the application, to display the artifact collection. Throughout the iterations having an accessible search bar and connect wallet button in the navigation bar remained a similar objective.

The Muzart platform showcases its artifact collection using an intuitive and user-friendly interface component known as a swiper, which functions similarly to a carousel. This design choice enhances the user experience by allowing for effortless browsing through the collection, with the ability to swipe between items for a seamless visual exploration. The swiper mechanism is especially conducive to touch-screen devices, aligning with modern web navigation standards and providing an engaging way for users to interact with the digital museum's offerings.

Complementing the swiper, the platform incorporates a robust search functionality, which significantly streamlines the process of locating specific artifacts within the collection. Users can effortlessly search for artifacts by inputting criteria such as the name of the piece, the author's name, or associated tags. This feature is particularly beneficial for educational and research purposes, as it provides a quick and efficient means to access relevant information. The inclusion of a search function reflects Muzart's commitment to enhancing accessibility and user autonomy, ensuring that visitors can navigate the virtual collection with precision and ease.

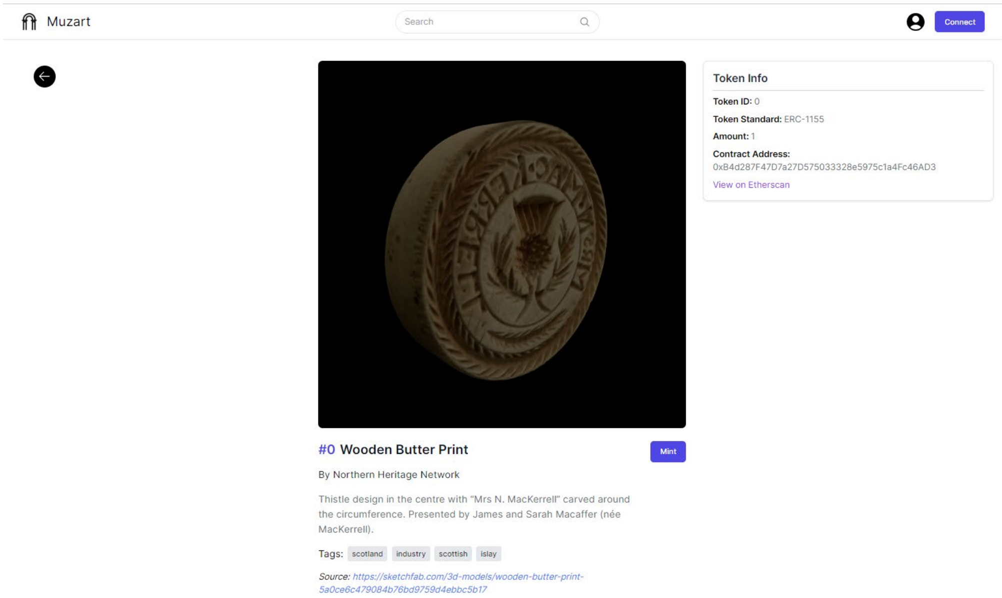

Figure 5: Viewing of an Individual Artifact

This figure shows the page of an artifact upon clicking on its thumbnail in the main screen's collection page. The 3D mode viewer window is the black square in the middle of the screen. Alongside the artifacts information below which includes, its name, author, description, tags, and source. On the right side is the blockchain token information, which includes the token ID, token standard, amount minted, and smart contact address, as well as a hyperlink to view the artifact token on etherscan.io. Etherscan is an Ethereum blockchain explorer, where you can view all the blockchain transactions on the network, including transaction history, address information, block information, token information, smart contracts, and more. This is used for validation of the artifact's provenance and authenticity.

Web Framework

Building upon the robust foundation provided by React, front-end JavaScript library is widely used for building modern user interfaces, Next.js emerges as powerful frontend framework. It offers a range of features designed to enhance the development of web applications. Developed by Vercel, Next.js aims to solve some of the common challenges associated with React development, particularly in areas like routing, server-side rendering (SSR), static site generation (SSG), and building optimized production-ready applications. Next.js enhances the React ecosystem by providing a standardized structure for projects, automatic code splitting, easy-to-use page routing, and pre-rendering capabilities, which are essential for improving the performance and SEO of web applications. Next.js enables developers to build fast, scalable, and highly performant web applications with ease, making it a preferred choice for modern web development projects. Tailwind CSS and Typescript, which is built into the Next JS framework, is favored for its utility-first approach to styling, which significantly reduces the time and effort required for customizing UI designs as well as enhances code maintainability and scalability. [39, 40].

4.3 Smart Contract Design

This section outlines the *MuzartArtifact* smart contract's architecture and its implementation details, emphasizing the use of the ERC1155 multi-token standard for handling NFTs of 3D models. Utilizing OpenZeppelin contracts for ERC1155 and AccessControl, it presents a secure and standardized approach to managing blockchain assets. The discussion covers the contract's structure, functionalities, development process, and deployment advantages, aligning with Muzart's overall goals.

By adopting OpenZeppelin's ERC1155 and AccessControl, the smart contract gains a layer of security and standardization essential for its foundation. This includes role-based access control for precise permission management.

The MuzartArtifact contract incorporates specific elements like token ID tracking and role-specific minting functions, enhancing its operational context. Functions such as mintOriginal and mintCopy showcase the contract's adaptability in token management. These two separate functionalities require different sets of access control roles. For museums the role of admin would allow them to create new original tokens of their existing or recreated digital artifacts. While for the common user their permissions would only allow them to make unique copies of the artifacts already in the Muzart collection.

For the development and deployment of the smart contract, the project utilizes Hardhat, a development environment for compiling, deploying, testing, and debugging Ethereum software. Hardhat allows for the local simulation of the Ethereum network, providing a convenient testing ground for smart contracts before they are deployed to a live blockchain.

The combination of OpenZeppelin contracts, the Hardhat environment, and custom functionalities results in a secure, scalable, and flexible architecture. It supports effective asset management and aligns with Muzart's aim to offer a secure platform for digital heritage.

Chapter 5

Architecture and Implementation

This section delves into the system architecture of Muzart, providing an in-depth analysis of each component and its implementation, including Smart Contracts, Blockchain Integration, 3D Model Rendering and Interaction, IPFS for Storage, and the Next.js Application.

5.1 System Architecture

The system architecture of the Muzart app consists of four main components: the Next JS App, the IPFS storage, the crypto wallet, and the Sepolia Testnet. These components connect and function using two JSON-RCP Providers, Alchemy API and Infura API, as well as an IFPS Gateway. This implementation specifically revolves around using the Metamask wallet chrome extension. However any Ethereum crypto wallet that uses the functionality window.ethereum will work with this application, however all functionality was only tested with Metamask. Other possible wallets that use the window.ethereum functionality include Trust wallet and Coinbase wallet.

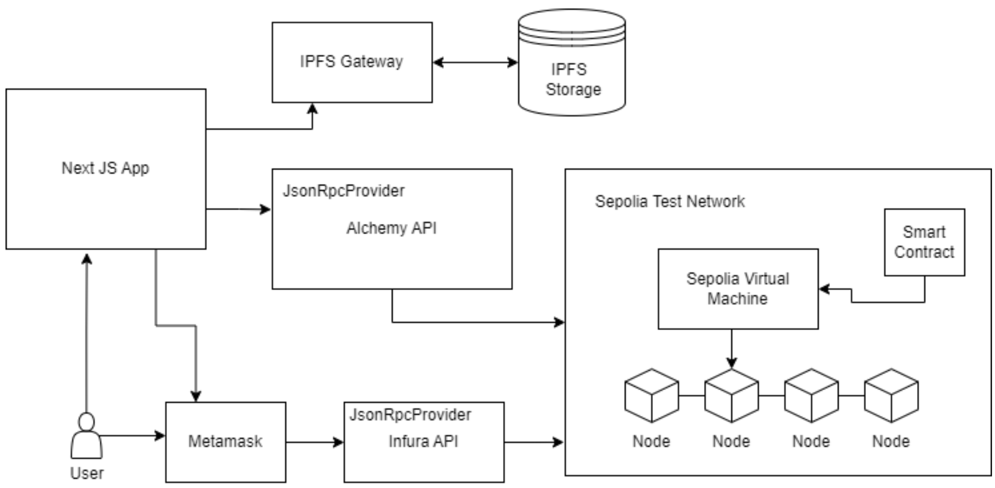

Figure 6: System Architecture Diagram

The system architecture diagram illustrates the intricate interactions between various components of the system. This architecture is foundational to understanding how users engage with the application, particularly through their interactions with Next.js App and their MetaMask wallet. The Next app architecture will be discussed further in detail in section 5.1.6.

Artifact Fetching

Upon initiating the application, users are greeted by the homepage, which prominently features a collection of artifact NFTs. This initial interaction leverages the Alchemy API to communicate with a smart contract hosted on a node within the Sepolia test network. The contract, upon execution, returns Uniform Resource Identifiers (URIs) corresponding to each token. Subsequently, for the retrieval of JSON metadata associated with these artifacts, the client dispatches HTTP GET requests to the IPFS storage, specifically utilizing NFT.Storage, via an IPFS gateway. This process is replicated on individual artifact pages, where HTTP GET requests target the specific IPFS URL of each artifact's 3D model found in their metadata JSON file.

MetaMask and Infura API

User interaction with the MetaMask wallet is twofold, encompassing both direct user engagement and client-mediated transactions. User activities within the application, barring those undertaken by administrators, necessitate confirmations via the MetaMask wallet prior to the execution of any blockchain transactions. MetaMask, which conventionally employs the Infura API as its Remote Procedure Call (RPC) provider, facilitates interaction with the Sepolia test network.

For the Muzart application, the use of the Infura API for NFT token retrieval and administrative functionalities presented limitations, particularly due to Infura's stipulations regarding the ownership of Ethereum. This constraint underscored the necessity for an alternative approach to managing NFT tokens and administering application-specific functionalities, thereby shaping the architectural decisions to use the Alchemy API.

In summary, the system architecture integrates the Next.js framework, MetaMask wallet, Alchemy and Infura APIs, and IPFS storage solutions to create a cohesive and functional application. This architecture not only facilitates user interaction with digital artifacts but also addresses the complexities associated with blockchain transactions and data retrieval from decentralized storage. An in-depth analysis into the blockchain functionalities can be found in section 5.3.

5.2 Smart Contract

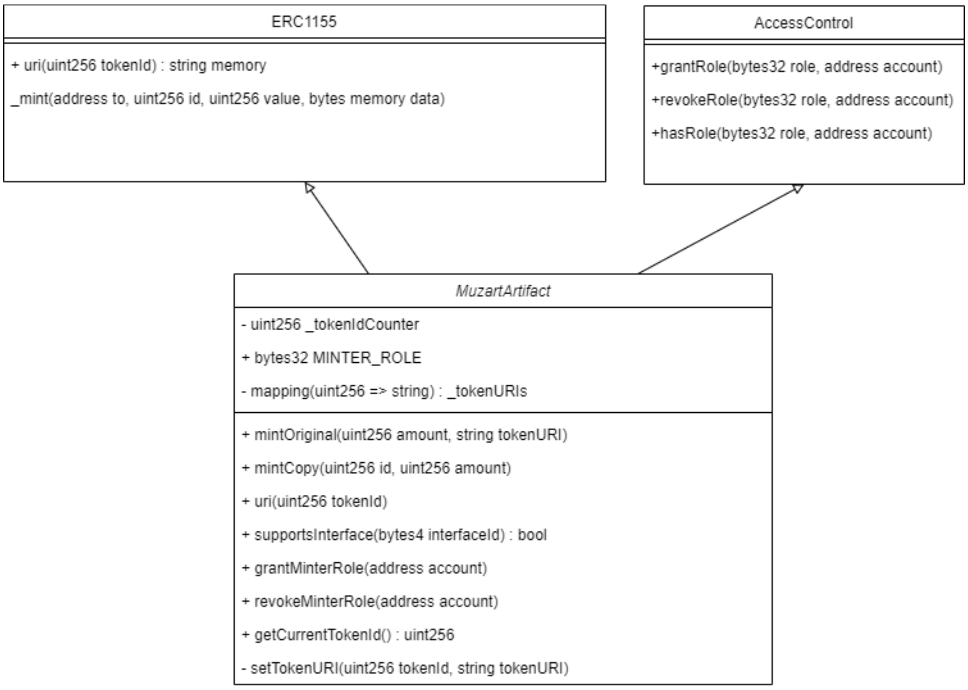

Figure 7: UML Class Diagram of MuzartArtifact Smart Contract

The smart contract, MuzartArtifact, as depicted in the provided diagram, is structured to inherit functionalities from both the ERC1155 and AccessControl contracts, components of the OpenZeppelin contracts library.

Smart Contract Architecture

OpenZeppelin's ERC1155 standard includes two primary functions:

`uri(uint256 tokenId)`

This function overrides the ERC1155 base to return the URI of the token metadata, which is an IPFS URL to the metadata JSON file containing details about the token, such as the 3D model information.

`_mint(address to, uint256 id, uint256 amount, bytes memory data)`

This protected function facilitates the minting of tokens to a specified address.

The AccessControl module is used to manage permissions across the contract, using role-based access control to restrict the execution of certain functions to accounts that have been granted specific roles. These functions include: `grantRole()`, `revokeRole()`, and `hasRole()`.

Contract Specifics

The MuzartArtifact contract includes several custom elements and functions:

`uint256 _tokenIdCounter:` A private variable to track the current token ID incrementally.

`bytes32 MINTER_ROLE:` A public constant that represents a unique identifier for the minter role.

`mapping(uint256 => string) _tokenURIs`: A private mapping to store token URIs against token IDs.

`mintOriginal(uint256 amount, string tokenURI)`: A public function that allows users with the minter role to mint new original tokens, assigning the provided URI to these tokens. This uses the _mint function defined in ERC1155.

`mintCopy(uint256 id, uint256 amount):` This function enables the minting of copies of existing tokens, provided that the user has the required role. This also uses the _mint function defined in ERC1155.

`getCurrentTokenId():` A public view function that returns the current value of the `_tokenIdCounter`, which is useful to determine the number of minted tokens.

`setTokenURI(uint256 tokenId, string tokenURI)`: A private function used to set the URI for a specific token ID on creation. It is private so it's only allowed to be called within the contract, barring it from being called by outside scripts and updating existing minted tokens.

Benefits of the Architecture

The utilization of OpenZeppelin's ERC1155 and AccessControl contracts provides a secure foundation for the MuzartArtifact, benefiting from the robustness and standardization of these well-established contracts. The modularity of the architecture allows for seamless upgrades and integration with other systems and services. Moreover, the role-based access control ensures that administrative actions, such as minting original tokens, are securely managed, with permissions that can be tailored as the project's requirements evolve.

5.3 Blockchain Integration

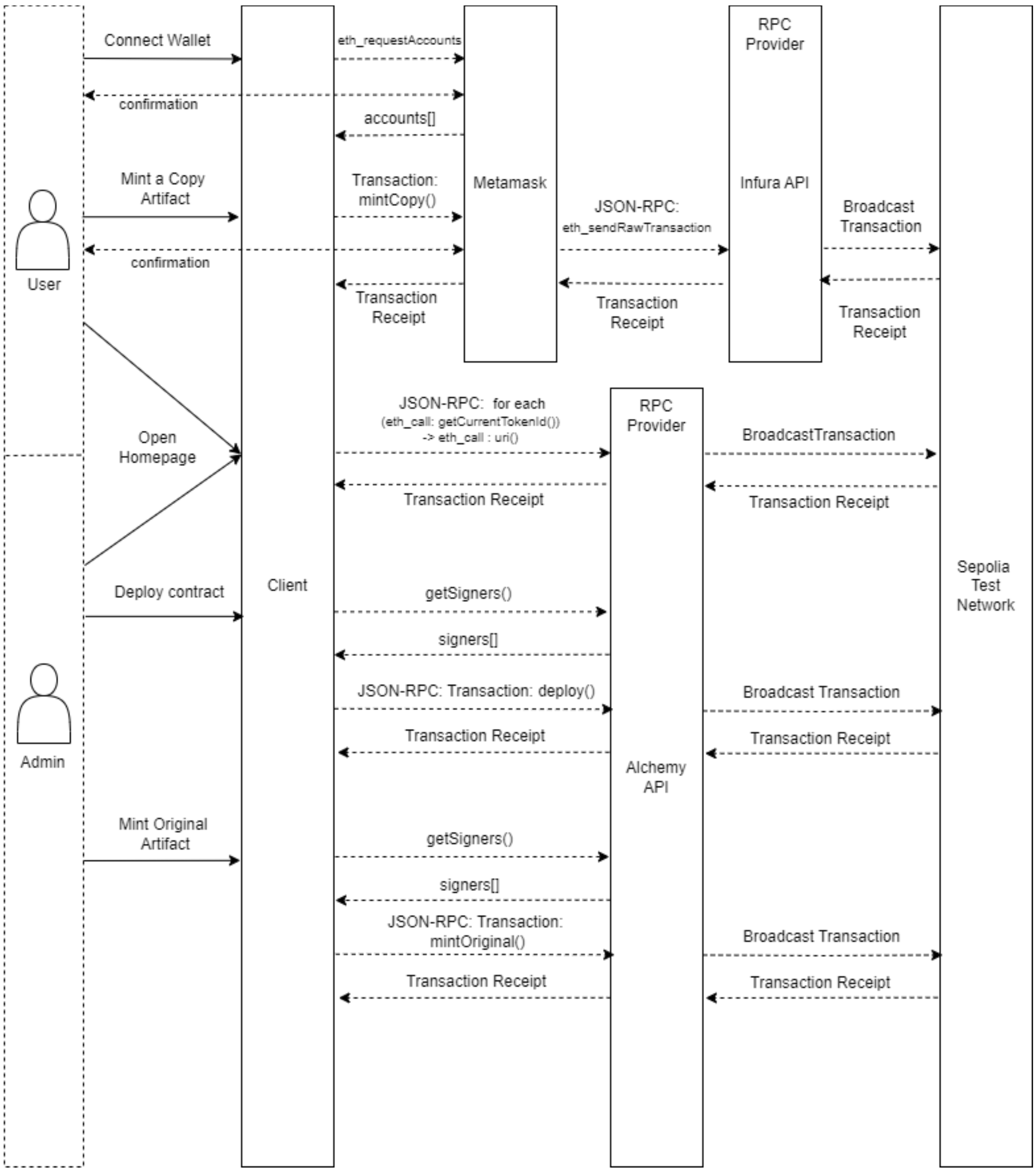

Figure 8: Blockchain System Interaction and Communication

This diagram displays the communication pathways and methods used by users or administrators to interact with the Sepolia Testnet. It provides a comprehensive overview of the end-to-end system interactions, detailing how the blockchain components of Muzart function.

How it Works

The Alchemy API is a blockchain developer platform and node service, it acts as a Remote Procedure Call (RPC) provider. It offers a scalable and reliable connection to the Ethereum network without the need to run your own node. This provider is responsible for sending and receiving JSON-RPC messages over HTTP to an Ethereum node hosted by Alchemy.

The JSON-RPC protocol is a stateless, light-weight RPC protocol. It is used to send commands to an Ethereum node, such as querying the blockchain, sending transactions, or executing smart contract calls. The commands are encoded as JSON objects and sent via HTTP.

When you use Alchemy, you don’t need to run your own Ethereum node. Instead, you are given an endpoint URL, which is used to send JSON-RPC requests. This URL serves as the gateway to Alchemy’s Ethereum nodes. Alchemy’s Ethereum node processes the request. If it's a transaction, the node will broadcast it to the Ethereum network where it can be included in a block by miners. If it's a query, the node will read from the blockchain and return the result.

Once the Ethereum node receives the signed transaction, it validates it and propagates it across the Ethereum network. Miners then pick up the transaction, and if it's valid and has an appropriate gas price, they include it in a block. Once included in a block and appended to the blockchain, the transaction is considered confirmed. After the transaction is confirmed, the Ethereum node can return the result of the smart contract function call. For read operations, this would be the return value of the function. For transactions that change the state, the result is the transaction receipt, which includes information like the transaction hash, logs, and whether the transaction was successful. Alchemy sends the response back to client over the same HTTPS connection.

Wallet Connection

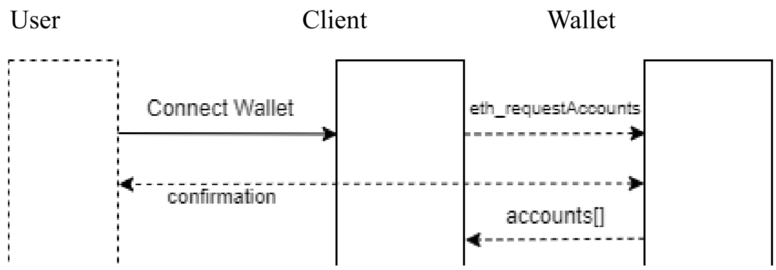

Figure 9: Wallet and Application Communication

Connecting the users Metamask wallet using the Ethereum Provider API (`eth_requestAccounts`). This is an inter-process communication between the Muzart application and Metamask wallet. If the user clicks on the connect wallet button, they are then prompted to agree to this connection within their wallet. Metamask will then return an array of account addresses that the user has allowed back to the application.

Smart Contract deployment

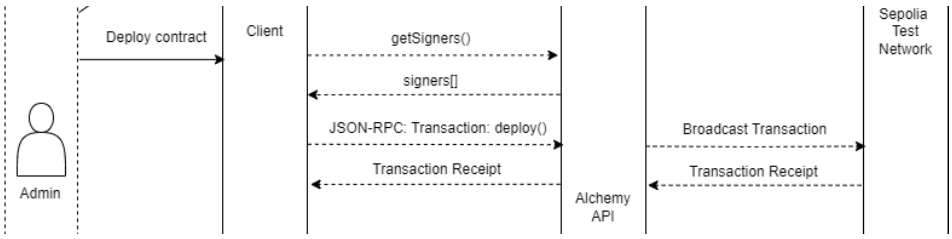

Figure 10: Blockchain Deployment Interaction

To deploy the smart contract on the Sepolia Testnet, we utilize Hardhat, an Ethereum development environment, in conjunction with the ethers.js library for configuring the blockchain network, specifying wallet private keys, and setting Alchemy API keys. By employing the Alchemy API, `getSigners()` method is used to obtain a list of accounts available from the connected Ethereum node. Utilizing the first account from this list, the smart contract is deployed using Alchemy's `deploy()` function. This action sends a transaction to the Ethereum network to instantiate the smart contract, effectively treating the smart contract's methods as JavaScript functions for ease of interaction, particularly for retrieving NFT metadata.

During the deployment process or when executing a transaction, Hardhat leverages ethers.js to issue a JSON-RPC request to Alchemy's nodes on the designated network, in this instance, Sepolia. This request encompasses the smart contract's compiled bytecode and any constructor arguments. The deployer's account signs off on this transaction, which then awaits the mining and deployment of the contract on the blockchain. Upon successful deployment, the smart contract is allocated an address within the network and a transaction receipt is returned.

Fetching Artifact Tokens

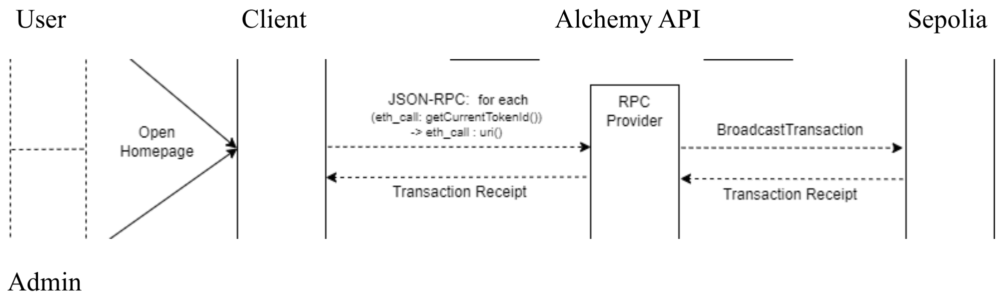

Figure 11: Artifact Fetching Communication

When the user loads the Next app for the first time, it will call the smart contracts functions and fetch the metadata from all the original Muzart artifact tokens, then cache it into local storage for quick retrieval. This is done by first defining a smart contract instance. This instance is made up of the ABI (Application Binary Interface) and the address of the smart contract. The ABI is a JSON representation that tells Ethers.js how to encode and decode data to call the contract's methods correctly. The contract address is the unique identifier of the smart contract deployed on the blockchain. Then an instance of JSON-RPC Provider is created with a URL to the Sepolia Testnet via Alchemy. It first calls the `getCurrentTokenId` method of the smart contract to determine the total number of tokens. It then iterates over each token ID, calls the `uri` method of the smart contract to get the metadata URI for each token, and uses the `fetchMetadata` function to retrieve the metadata from IPFS. It collects all metadata into an array using `Promise.all` for concurrent execution and returns this array after filtering out any undefined results. These calls are read operations, so they don't require a gas fee. The provider sends these calls as JSON-RPC requests to the Ethereum node specified by the Alchemy URL. The asynchronous `fetchMetadata` function accepts a URI pointing to metadata stored on IPFS. It replaces the ipfs:// scheme with an HTTP URL to an IPFS gateway (https://ipfs.io/ipfs/). Then, it performs an HTTP fetch request to retrieve the metadata and parses it as JSON. This is necessary because web browsers cannot directly access IPFS content using the ipfs:// scheme.

Mint a Copy Artifact Token

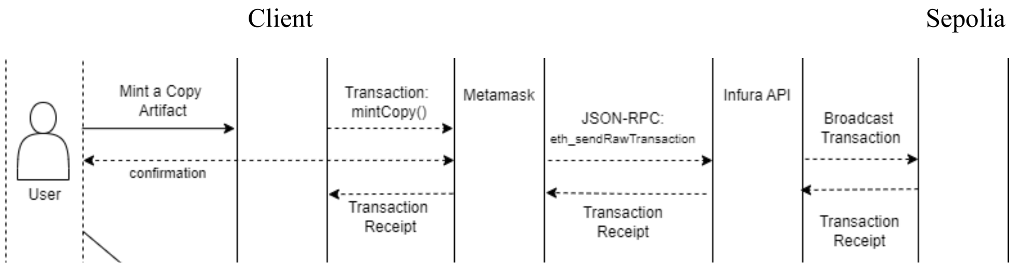

Figure 12: Mint Copy Blockchain Communication

If the user tries to mint an artifact (after connecting their wallet), it will make a transaction request to Metamask. The transaction includes all the necessary information for the smart contract function call. This transaction includes details such as the target smart contract's address, the function's signature and encoded arguments, the nonce (a number that represents the transaction count for your account), gas limit, gas price, and any Sepolia test ether to be sent along with the call. Metamask will prompt the user for confirmation, if the user agrees, Metamask uses the private key stored securely in the user's wallet to sign the transaction. Signing the transaction is a cryptographic operation that generates a signature proving that the sender (the user) has authorized the transaction. This will act as a bridge between the Next app and the Infura API. MetaMask packages this action into a JSON-RPC request format, and uses one of these methods: `eth_sendRawTransaction` for sending a transaction, or `eth_call` for a smart contract query. Infura provides a remote Ethereum node as a service. It acts as an entry point to the Ethereum network. For transactions that change the state, the result is the transaction receipt, which includes information like the transaction hash, logs, and whether the transaction was successful. Infura sends the response back to MetaMask over the same HTTPS connection. This response is the transaction receipt after the transaction is mined. MetaMask then passes the result back to the web application, which initiated the request. The web application then handles information to update the user interface letting them know they have successfully minted the token.

Minting an Original Artifact Token

Admin Client Alchemy API Sepolia

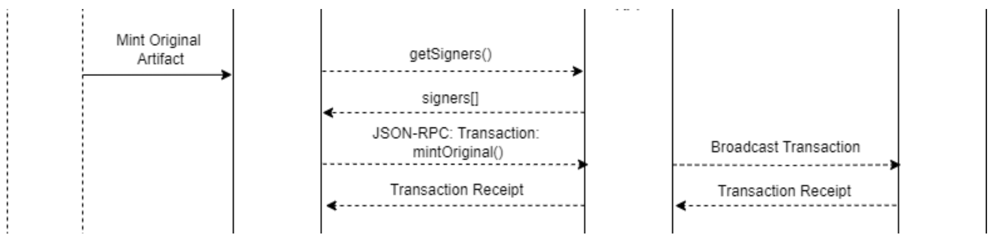

Figure 13: Mint Original Token Interaction

For minting an original, the same process as mint copy is used however, without Metamask as a bridge and signer for the transaction. Instead, like the contract deployment or fetching the token URI, Alchemy API is directly used. This functionality, however, can only be done by an admin role.

JSON-RCP Provider and Signer

The two approaches undertook in this project:

1. Using Metamask as an intermediary signer and Infura API
2. Self-signing and directly using Alchemy API

1. For the user (using Metamask):

MetaMask operates as a trusted wallet extension that gives users direct control over their transactions, including minting operations. Users can review transaction details, such as gas fees and the destination address, before confirming. This transparency builds trust and enhances user experience. By leveraging MetaMask, the private keys used for signing transactions never leave the user's browser, minimizing the risk of key compromise that could occur if keys were handled server-side. Using MetaMask supports the decentralized ethos of the blockchain ecosystem, as transactions are signed and initiated by the user, not centrally processed on the server. Users can adjust gas prices and gas limits directly within MetaMask, giving them flexibility based on their priorities for transaction speed versus cost.

2. For admin (directly using Alchemy API):

Server-side transaction management allows the admin to maintain control over the minting of original NFTs. This is useful for ensuring compliance with specific rules or standards you've set for original content. When transactions are managed via Alchemy on the server-side, you can optimize gas fees across multiple transactions, potentially batching them or choosing times when gas prices are lower to execute minting operations. Server-side management of minting operations can be more easily scaled and automated, particularly if you're dealing with a high volume of originals that need to be minted. This approach can lead to more efficient processing and reduced overall costs. For actions that require heightened security and control, such as minting of original NFTs, server-side processing can provide an additional layer of security. You can implement rigorous server-side checks and balances that might be more challenging to enforce in a client-side environment.

5.4 3D Model Rendering and Interaction

Figure 14: 3D Rendering of NFT Token inside Muzart App

The three-dimensional models used within the application, sourced from Sketchfab, were contributed by the Northern Heritage Network. These models adhere to the .glb file format, which encapsulates both the .gltf model and its associated texture images into a singular comprehensive file. This consolidation facilitates the application of DRACO compression, significantly reducing the file sizes—transforming models originally exceeding fifty megabytes to approximately five megabytes, thereby achieving a substantial reduction to nearly one-tenth of their initial size. Notably, the resolution of all downloaded models was standardized to 1K.

Libraries

For the purpose of rendering these models, the Muzart application incorporates a combination of libraries, specifically three.js, react-three/fiber, and react-three/drei. Each library fulfills a pivotal role in the rendering process of the 3D model artifact tokens.

At the core of the application's 3D rendering capabilities lies Three.js, a JavaScript library that provides an abstracted, high-level API for WebGL. It simplifies the creation and manipulation of 3D scenes, cameras, lights, materials, and geometries, thereby enabling developers to focus on the creative aspects of 3D visualization without delving into the complexities of WebGL.

The react-three/fiber library acts as a React renderer for Three.js. It enables the declaration of Three.js scenes directly within the React component hierarchy, facilitating a more intuitive and React-centric development experience. React-three/fiber harnesses the React reconciliation algorithm, optimizing scene updates and rendering cycles based on state changes and props, thus ensuring efficient rendering performance.

```
<Canvas >
  <Suspense >
    <PerspectiveCamera />
    <ambientLight />
    <spotLight/>
    <pointLight />
    <Model />
    <OrbitControls />
  </Suspense>
</Canvas>
```

Figure 15: React-three/drei Componentization

The react-three/drei library serves as a companion library to react-three/fiber, react-three/drei. It provides a collection of reusable React components that abstract common patterns and functionalities in Three.js development, such as cameras, lights, and controls. This library significantly accelerated development by reducing boilerplate and focusing on composition.

Model and Canvas

To ensure a consistent rendering of all models, a dedicated Model component was developed. This component leverages the model reference to uniformly position and scale the models, maintaining consistency across the application.

The perspective camera defines the viewpoint from which the scene is observed, simulating a real-world camera perspective. This camera supports depth perception, allowing for a more natural and immersive viewing experience. The lighting, which is essential for revealing the shapes, textures, and materials of 3D models. Various types of lights can be used, such as ambient, point, and directional, to achieve desired visual effects. The orbit controls enhanced user interaction by enabling the rotation, zooming, and panning of the scene through mouse and touch inputs. This feature is instrumental in allowing users to explore models from different angles and distances.

User Experience

By enabling interactive and visually appealing 3D representations of artifacts, users can engage with the content in a more meaningful and immersive manner. The abstraction and components provided by react-three/fiber and react-three/drei reduce the complexity and amount of code needed to implement sophisticated 3D visuals, speeding up the development process. React-three/fiber's integration with React's reconciliation algorithm ensures that 3D scenes are updated in an efficient manner, optimizing rendering performance and providing a smooth user experience. This amalgamation of interactive elements substantially enhances the user experience, granting users the flexibility to explore different facets of the artifacts from various perspectives, thereby enriching their comprehension and engagement with the content.

5.5 IPFS for Storage

The retrieval of metadata from the IPFS storage through an IPFS gateway involves a series of HTTP communication protocols that facilitated the exchange of data between the client application and the IPFS network. This process is underpinned by a decentralized storage solution, IPFS, which allows for the storing and sharing of files in a distributed file system.

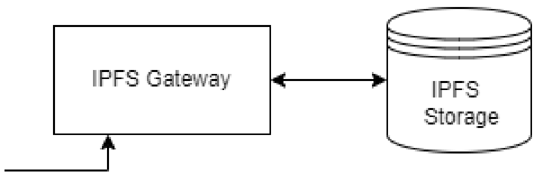

Figure 16: IPFS Gateway and Storage

Upon the initiation of a request for metadata associated with a particular digital asset, the client application constructs an HTTP GET request targeting the IPFS gateway's URL. This URL is typically structured to include the base address of the gateway followed by the unique content identifier (CID) of the metadata file stored on IPFS. The CID is a hash of the file's content, ensuring immutability and content-addressability within the IPFS network. The HTTP request is then dispatched to the IPFS gateway, which acts as an intermediary between the client application and the IPFS network. The gateway resolves the CID to locate the corresponding metadata file within the distributed network. This resolution process involves querying the IPFS network to identify the nodes that store the requested content.

Upon successful location of the content, the IPFS gateway retrieves the metadata file and transmits it back to the client application via the HTTP protocol. This response is encapsulated within an HTTP response message, which includes the status code indicating the outcome of the request (e.g. 200 OK for success), headers with metadata about the response, and the body containing the requested file content.

The client application, upon receipt of the HTTP response from the IPFS gateway, parses the response to extract the metadata content. This content is then processed and displayed according to the application's functionality, providing the client with the retrieved metadata and 3D model.

5.6 Next App

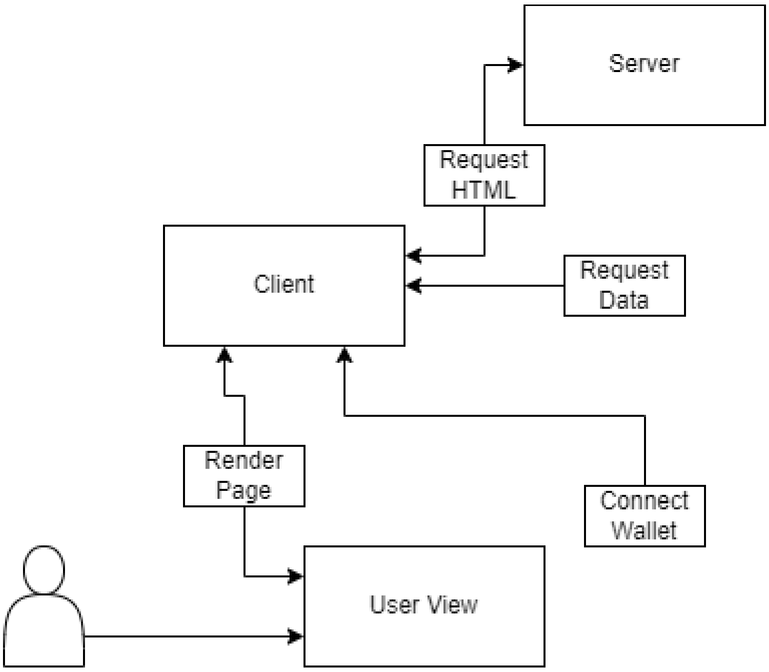

Figure 17: Next App System Architecture [41]

In the development of the Next.js application, user interaction with the user view initiates a sequence of events facilitating the dynamic rendering of content. Upon navigating to various pages within the application, the client makes requests to the server for the corresponding HTML documents. These documents are then rendered within the user's viewport, presenting the requested content in an interactive format. Specifically, when users access the collection or artifact pages, the client employs data query requests directed towards the Sepolia test network and IPFS.

Furthermore, the application is architecturally designed to embrace modularity and componentization. This design philosophy promotes the development of reusable components, such as buttons and modals, enhancing the application's codebase structure. The modular approach not only facilitates a more organized and readable code but also streamlines the update process. Modifications to individual components are propagated throughout the application, reflecting changes universally and ensuring coherence in the application's functionality and presentation.

Chapter 6

Testing

Muzart's testing strategy encompasses three core aspects: Unit Testing, Integration Testing, and Accessibility Testing. Unit Testing verifies each smart contract function in isolation, focusing on code integrity and logic correctness. Integration Testing assesses the interactions between smart contract components and their collective operation, such as token transactions and IPFS metadata handling. Accessibility Testing ensures the application's user interface complies with accessibility standards, optimizing usability for all users, including those with disabilities. This approach ensures Muzart's functionality, interoperability, and user accessibility are thoroughly vetted for an optimal platform experience.

6.1 Unit Testing

```
Role Management
  ✓ should only allow MINTER_ROLE to mint original artifacts
  ✓ Dynamic Role Assignment (65ms)
  ✓ Unauthorized Role Actions

Minting Functionality
  ✓ should allow minting copies of existing tokens (64ms)
  ✓ should revert when minting copies of non-existent tokens
  ✓ Mint With Zero Amount
  ✓ Minting the Same Token URI Multiple Times (75ms)

URI Management
  ✓ should correctly generate token URIs
  ✓ Token URI Immutability (63ms)
  ✓ Fetching Nonexistent Token URI

Interface Support
  ✓ should support ERC1155 and AccessControl interfaces

Event Emissions
  ✓ should emit events for key actions

Copy Minting Specifics
  ✓ Minting Copies Before Originals

MuzartArtifact
  ✓ Should mint and transfer an NFT to someone (79ms)


14 passing (2s)
```

Figure 18: Smart Contract Unit Testing

This figure shows the successful passing of the comprehensive unit test suite for the 'MuzartArtifact' smart contract using Hardhat, Chai, and ethereum-waffle libraries. The tests are organized into categories that verify the contract's functionality, security roles, event emissions, and ERC1155 standard compliance. All testing was done in a hardhat local environment which does not require gas fees.

Setup: Before running the tests, signers are initialized, and the 'MuzartArtifact' contract is deployed.

Role Management: Tests ensure that only users with the MINTER_ROLE can mint original artifacts. It verifies dynamic role assignment by granting and revoking roles and confirms that unauthorized users cannot perform actions restricted to certain roles.

Minting Functionality: This suite checks that minting is only allowed for existing tokens and reverts for non-existent tokens or when attempting to mint with zero amount. It also ensures that the contract can handle minting the same token URI multiple times, testing the idempotency of minting.

URI Management: Tests confirm that token URIs are generated correctly and remain immutable, providing reliability in token metadata. It also checks the contract's behavior when querying a URI for a non-existent token, expecting the call to revert.

Interface Support: The contract's support for ERC1155 and AccessControl interfaces is verified, ensuring compliance with the necessary Ethereum token standards for a multi-token smart contract with role-based permissions.

Event Emissions: Key contract actions, such as minting originals, are tested to ensure they emit the correct events. This provides transparency and allows applications to react to contract state changes.

Copy Minting Specifics: A specific test checks the logical sequence of minting operations to prevent copies from being minted before the original.

MuzartArtifact Functionality: The final test confirms the contract can mint an original artifact and transfer it to an owner, encapsulating the fundamental purpose of the MuzartArtifact smart contract.

The tests make use of expect assertions to validate contract functionality against the expected outcomes, employing calls such as `to.be.revertedWith` for error handling and `to.emit` for event verification. Overall, the testing code aims to cover the critical functionalities of the MuzartArtifact smart contract, ensuring it operates as intended and adheres to security and ERC standards.

6.2 Integration Testing

Integration testing was done on both wallet connection and user minting of an artifact on Muzart. A second Metamask wallet (Account 2) was used for this.

Wallet Connection Testing

The following screenshots demonstrate the user connecting to their Metamask wallet.

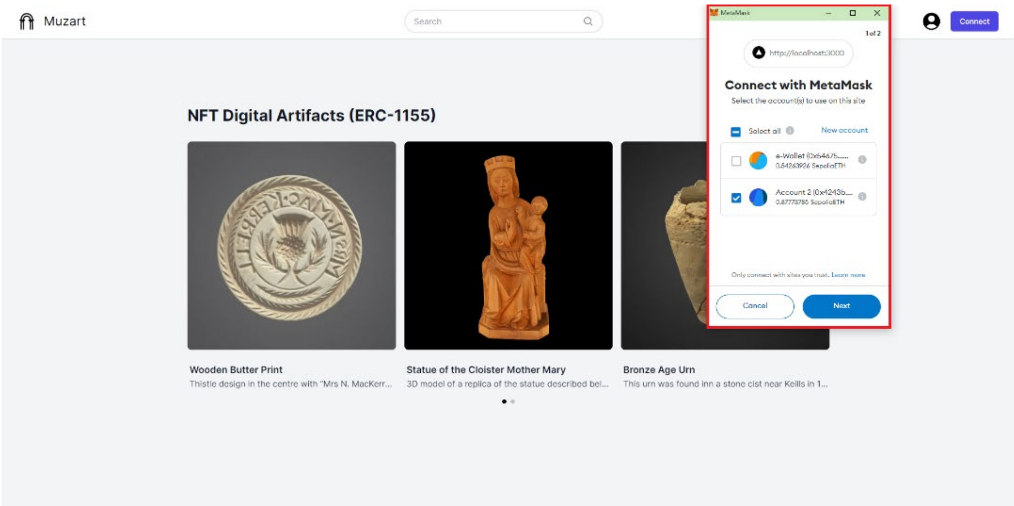

Figure 19: Connect Wallet Selection

The first step to connecting the users Metamask wallet is to make sure the wallet is logged in and ready to use in the browser. Here the figure shows the user having clicked the purple Connect button in the top right corner. This will initiate the connection and Metamask will prompt the user to select which wallet accounts to allow to connect.

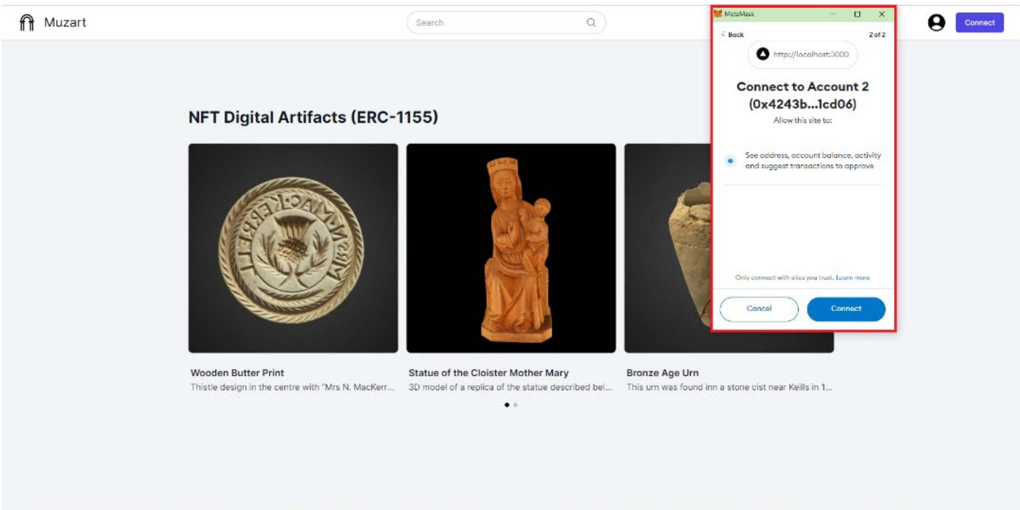

Figure 20: Connect Wallet Confirmation

This figure shows Metamask's confirmation window to allow the Muzart app to access the wallet address.

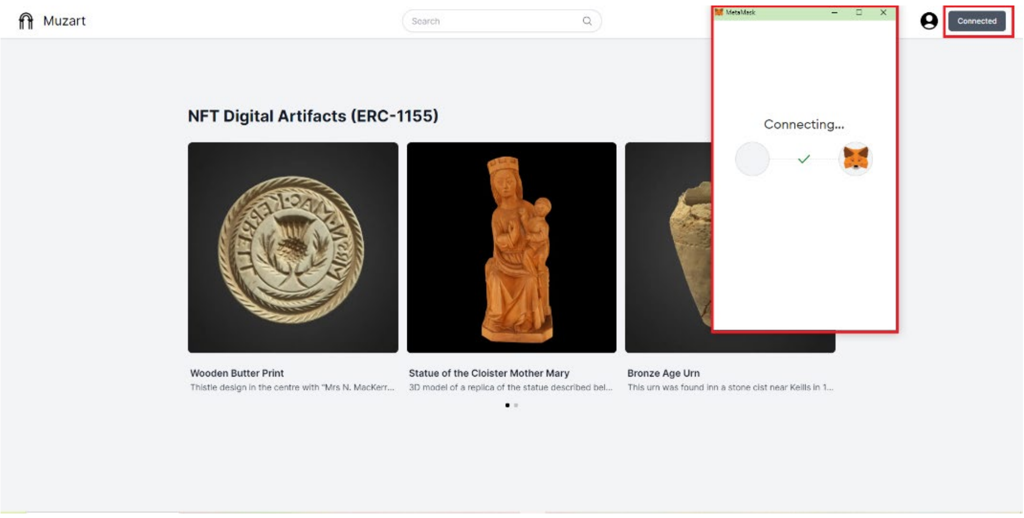

Figure 21: Connect Wallet Success

This figure shows the successful connection in both the Metamask wallet and within the Muzart app. In the top right the “Connected” button in grey shows that a wallet has been connected.

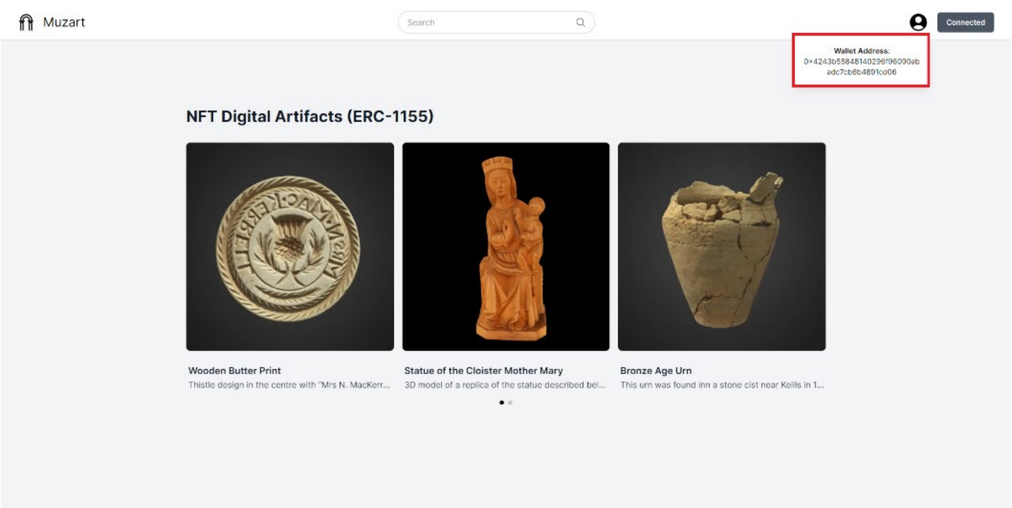

Figure 22: View Connected Wallet Address

Here the user has clicked on the user icon which displays their wallet address. This is to confirm that they have the right wallet connected to Muzart.

Minting Testing

The following screenshots demonstrate the user minting functionality using Metamask wallet Account 2.

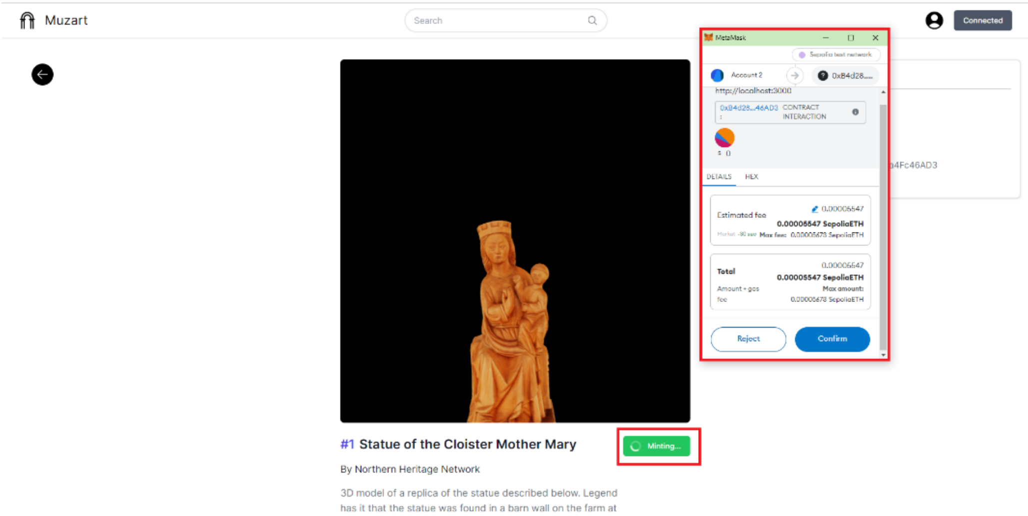

Figure 23: Minting Artifact Confirmation

This figure shows the initial minting process of clicking on the "Mint" button which then changes to "Minting…" to let the user know that the minting process has commenced. Alongside this Metamask will display a confirmation window with all the details of the wallet account and blockchain gas fees needed to process this transaction.

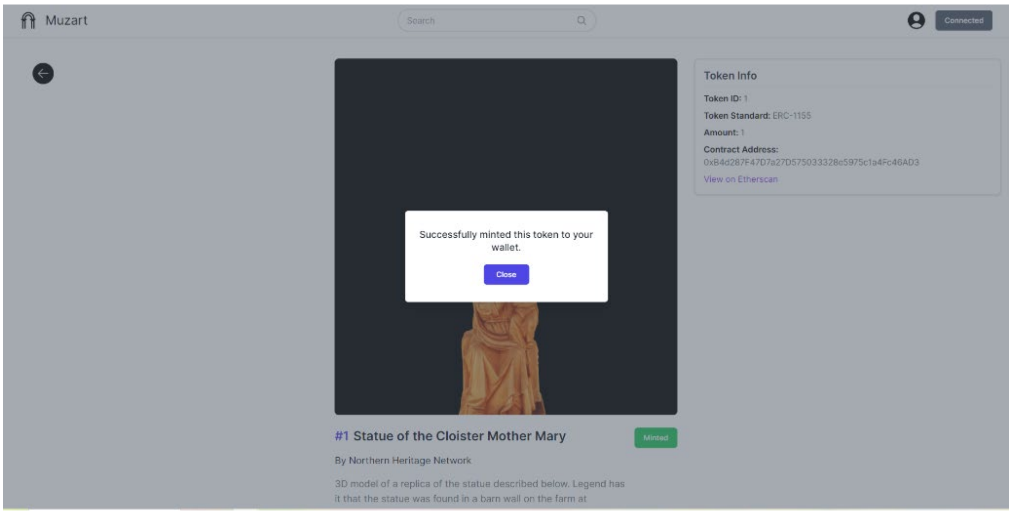

Figure 24: Minting Artifact Completed

This figure shows the successful minting of the artifact token to the user's wallet. The user is presented with the "Successfully minted this token to your wallet" dialog for confirmation.

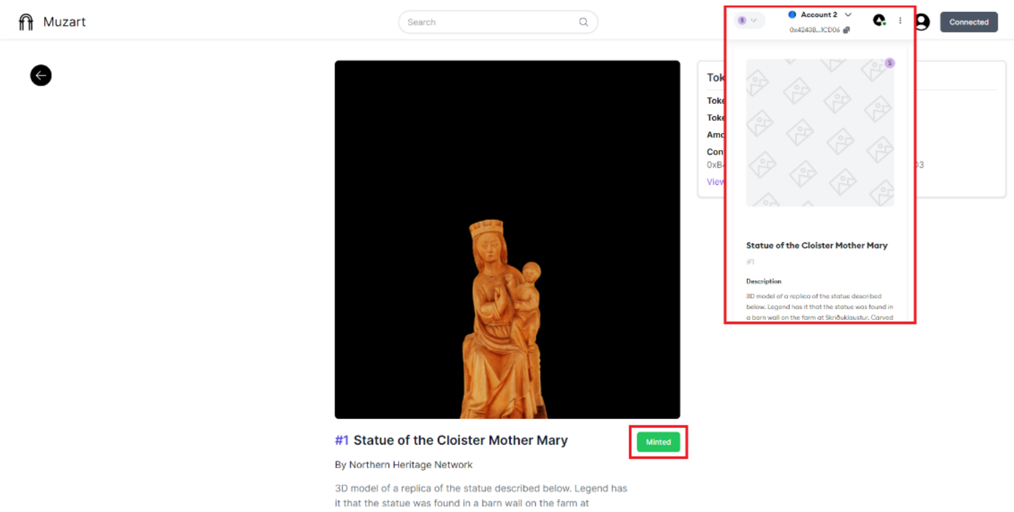

Figure 25: Artifact Viewed in Wallet

This figure shows the Artifact token in their Metamask wallet. This can be done by selecting the NFT tab within their wallet and importing the contract address of the token. The Muzart app will also let the user know the process has completed with the mint button now displaying “Minted”.

6.3 Accessibility Testing

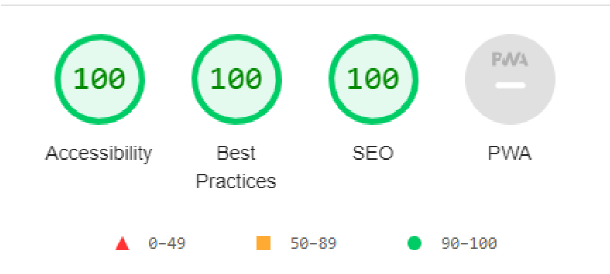

Figure 26: Google Lighthouse Analysis

The provided figure displays a web application's performance in various accessibility and optimization metrics:

The application has achieved a perfect score in accessibility, indicating comprehensive compliance with web accessibility guidelines. This suggests the application is well designed for users with disabilities, with features like keyboard navigability, screen reader compatibility, and adherence to proper semantic HTML and ARIA standards.

The best practices have also achieved a perfect score because of the application's strict adherence to current web development best practices. This typically covers a range of considerations from secure browsing protocols to correct image handling and the use of up-to-date web APIs.

The application also boasts a perfect score in SEO, signifying that it's optimized for visibility on search engines. This high SEO rating suggests effective use of meta tags, alt attributes for images, structured data, and mobile-friendliness, among other factors.

Chapter 7

Evaluation and Critical Appraisal

This chapter evaluates Muzart to its original objectives and makes a comparative evaluation of the related works reviewed in section 2.2.

7.1 Original Objectives

The original objectives were to:

1. Develop a blockchain-based platform that integrates with museum collections for transparent and immutable records of artifacts, and ownership.
2. Create a digital NFT catalog of museum collections accessible to the public and researchers, including detailed artifact information.
3. Implement interactive exhibits within museums to enhance visitor engagement and learning.
4. Utilize blockchain to meticulously track the ownership history of museum artifacts, ensuring transparency and authenticity.
5. Explore enabling public participation in the curation process through blockchain-based voting and suggestions.

Muzart successfully achieved all its goals, with the exception of Objective 5, which, upon exploration, was determined not to be crucial for the primary aims of collection management and transparency. Nonetheless, this objective had the potential to further enhance audience engagement in the curation process within the museum space. However, it could have been a distinct project since it would have required a completely different implementation of Ethereum token standards and smart contracts.

For Objectives 1 and 2, the effective creation and deployment of the MuzartArtifact smart contract facilitated the establishment of a digital NFT catalog and a publicly accessible collection. Through its integration with the Sepolia test network, the Muzart platform ensured the collection remained transparent and immutable on the blockchain. It also maintained comprehensive records of the artifacts, including their provenance and ownership, as metadata on the IPFS and Sepolia blockchain data.

Objective 3 saw successful realization through the adoption of the ERC-1155 token standard, which enabled the interactive minting of unique digital copies of the original NFT museum artifacts. Moreover, the incorporation of 3D formatting for these artifacts significantly enriched interactive learning and engagement opportunities.

Overall Muzart met its significant objectives, effectively establishing and validating an innovative and successful blockchain-based platform for museum artifact collections.

7.2 Comparison to Related Works

Collection Management

In summary, traditional museums face significant hurdles in collection management, including outdated and inefficient record-keeping systems, inconsistent terminology, and the loss of records. These issues not only pose a risk to the preservation of cultural heritage but also limit public access and educational opportunities. The fact that a vast majority of museum artifacts are stored out of public view underscores a pressing need for more accessible and inclusive solutions.

Muzart addresses these challenges head-on by leveraging blockchain technology to create a digital NFT catalog of museum collections. This approach not only facilitates transparent and immutable records of artifacts and their ownership but also enhances trust in the museum's collection. The concerns about the risk to physical artifacts due to storage and budget constraints are addressed by Muzart through digital preservation. The blockchain-based platform ensures the longevity and integrity of digital records, mitigating risks associated with physical storage. The inefficiencies and inaccuracies plaguing traditional record-keeping systems are resolved in Muzart through the use of blockchain and IPFS for storing artifact data. This ensures consistency, accuracy, and ease of access, enhancing the educational value of the collections.

While traditional museums often struggle with making their vast collections accessible to the public, Muzart's digital platform ensures that anyone with an internet connection can explore and learn about cultural artifacts. By digitizing artifacts as ERC-1155 tokens and storing them on IPFS, Muzart ensures that the data is secure, traceable, and permanently accessible to the public. This democratizes access to cultural heritage, aligning with the evolving societal expectations of museums as key educators.

Furthermore, the interactive exhibits within Muzart that utilize blockchain technology provide a more engaging and educational experience than traditional static displays. Muzart's use of three.js for 3D model rendering and interactive exhibits surpasses traditional methods by providing a dynamic and immersive learning environment. This aligns with the public's increasing desire for educational experiences that are engaging and informative.

While traditional museum collection management plays a crucial role in cultural preservation, the advent of technologies like those employed by Muzart represents a significant advancement in making cultural heritage more accessible, secure, and engaging for the public. Muzart exemplifies how technology can revolutionize the way we interact with and preserve our collective history, addressing the limitations faced by traditional museums and setting a new standard for cultural education and preservation.

ArtChain and MAXP

ArtChain and MAXP serve distinct niches within the cultural sector, with ArtChain targeting the art trading market to introduce transparency and equity, and MAXP focusing on enhancing the security and efficiency of digital collection management in museums. In contrast, Muzart aims to democratize access to museum collections, providing an interactive platform for users to explore and own unique digital replicas of artifacts, thus catering to a broader audience interested in cultural heritage.

ArtChain employs a private Ethereum blockchain with a Proof of Authority mechanism, focusing on privacy and traceability in art trading. MAXP utilizes SM2-based encryption for secure data exchange among museums, emphasizing regulatory compliance and intellectual property protection. Both contrast with Muzart's use of the public Sepolia Testnet, an Ethereum mainnet mirror image, which, like ArtChain, also includes a PoA consensus mechanism.

Public vs. Private Blockchain

By opting for a private Ethereum blockchain, ArtChain prioritizes control and privacy in art trading. Private blockchains are accessible only to authorized participants, offering a secure environment where transactions and data are visible only to members of the network. This controlled access is vital in a market sensitive to provenance and ownership details, allowing ArtChain to ensure that transaction data remain confidential and protected from unauthorized access. The choice of a private blockchain aligns with the need for trust and discretion in high-value art transactions, where participants demand robust protection of their privacy.

In contrast, Muzart's decision to use the Sepolia Testnet demonstrates a commitment to openness and inclusivity. Public blockchains offer transparency and are accessible to anyone, which aligns with Muzart's goal to democratize access to cultural artifacts. This approach enables Muzart to balance innovation with stability, providing a secure yet open platform for users to explore and interact with digital replicas of artifacts.

SM2 Encryption in MAXP

MAXP's use of SM2-based dual receiver public key encryption complements its blockchain framework by adding an additional layer of security. This cryptographic standard, is crucial in securely transferring digital assets and ensuring that only authorized users can access or transfer ownership of digital collections. This focus on encryption demonstrates MAXP's emphasis on regulatory compliance and intellectual property protection, essential in the museum context where digital replicas of artifacts require stringent security measures to prevent unauthorized distribution and use. This could potentially be a possible avenue for Muzart to pursue in the future to improve security and management of artifacts on the transfer of ownership between museums.

Comparison

The targeted stakeholders of ArtChain and MAXP are distinct yet complementary; ArtChain aims to provide a transparent ecosystem for artists and collectors, while MAXP focuses on the secure management of digital collections for museums. Muzart, however, has a broader impact, engaging museum administrators, educators, and the general public by enhancing access to and interaction with cultural artifacts through digital means.

The technological frameworks of ArtChain, MAXP, and Muzart demonstrates the diverse applications of blockchain within the cultural sector. While ArtChain and MAXP emphasize security, traceability, and regulatory compliance within their specific domains, Muzart leverages similar blockchain benefits to create an immersive and educational platform, thus fulfilling the evolving demands of digital-native audiences for interactive cultural experiences.

Chapter 8

Conclusion

While Muzart has laid a solid foundation for integrating blockchain technology with cultural heritage, its evolution will necessitate overcoming current limitations and embracing future technological advancements. This continuous improvement will ensure that Muzart remains at the forefront of digital heritage preservation, offering an increasingly secure, accessible, and engaging platform for users worldwide.

8.1 Summary of Outcomes

The Muzart application represents a step forward in the integration of blockchain technology within the museum and cultural heritage sectors. By successfully achieving its primary objectives, Muzart has established a robust and innovative platform that not only enhances the accessibility and interaction with museum collections but also introduces a new paradigm for collection management, transparency, and audience engagement. The following are some of the key outcomes of the project:

Digital Transformation of Museum Collections: Muzart's development and deployment of the MuzartArtifact smart contract have facilitated the creation of a digital NFT catalog, making museum collections accessible to a global audience. This digital transformation allows for the preservation of cultural heritage in a format that is both immutable and transparent, thanks to blockchain technology.

Innovative Revenue Model: The utilization of ERC-1155 tokens has opened up new financial avenues for museums and artists. By enabling the monetization of digital replicas of artworks and artifacts, Muzart offers a sustainable revenue model that supports the ongoing missions of cultural institutions without compromising the integrity or ownership of the original pieces.

Enhanced Operational Transparency: The blockchain's inherent transparency on the public Sepolia Testnet, ensures that all transactions within the Muzart platform are visible and verifiable, fostering trust and security among users, artists, and institutions. This level of operational transparency is critical in maintaining the authenticity and provenance of cultural artifacts.

Revolutionized Audience Engagement: Through the integration of 3D modeling technologies, Muzart has significantly enhanced the way audiences interact with and experience cultural heritage. The platform provides immersive virtual experiences that transcend the limitations of virtual museum visits, promoting active participation and collective experiences among audiences worldwide.

Muzart's application of blockchain and 3D modeling technologies has not only set a new standard for digital heritage preservation and accessibility but also highlighted the transformative potential of these technologies in redefining the cultural sector. As Muzart continues to evolve, it promises to further unlock the value of museum collections for the digital age, ensuring that cultural heritage remains a vibrant and accessible part of our collective human experience.

8.2 Limitations and Future Work

While Muzart has achieved significant milestones in harnessing blockchain technology for cultural heritage preservation and accessibility, it is not without its limitations. Addressing these limitations not only highlights areas for improvement but also outlines a pathway for future work to enhance the platform's functionality and impact.

Limitations

The platform's use of smart contracts ensures a high degree of security and trust due to their immutable nature once deployed. However, this same rigidity can limit adaptability and responsiveness to evolving user needs or unforeseen issues, highlighting a broader challenge of user accessibility and adoption. The technical complexities of blockchain and NFTs might deter users unfamiliar with these technologies, potentially narrowing Muzart's reach and impact.

Additionally, the lack of advanced encryption for NFT data, unlike the SM2-based encryption utilized by MAXP for secure data exchanges, might compromise the ability to protect sensitive information associated with digital replicas. This raises data privacy concerns and limits the platform's capability to offer robust security features for sensitive metadata.

Operating on the Sepolia Testnet has provided an invaluable testing ground for Muzart. However, this environment doesn't capitalize on the enhanced security and broader network effects of the Ethereum Mainnet, potentially affecting the platform's long-term reliability. Moreover, Muzart's scalability could be challenged by the inherent issues of blockchain networks, such as slow transaction times and high gas fees during network congestion.

The platform also navigates the complex regulatory and legal landscape of blockchain and NFT regulation, with copyright and intellectual property rights presenting potential legal challenges. The digital divide further complicates accessibility, as those without adequate technological resources or internet access may find themselves excluded.

Integrating Muzart with existing museum systems poses its own set of challenges, from compatibility issues to data migration and the need for staff training. Environmental concerns, particularly related to the energy-intensive nature of blockchain technologies, and the importance of content verification to maintain the credibility of digital collections, underscore the platform's responsibility to ensure ethical and sustainable practices.

Future Work

By exploring advanced blockchain solutions like upgradable smart contracts or proxy patterns, Muzart can introduce the necessary flexibility to update and adapt its operations without compromising the existing data integrity. This move is critical in addressing the rigidity of smart contracts and ensuring the platform can evolve in response to user feedback and emerging technological advancements.

Incorporating advanced encryption methods, akin to those employed by MAXP, stands as a pivotal enhancement to Muzart's data security measures. Such encryption would ensure the protection of sensitive information associated with digital artifacts, addressing concerns over data privacy and securing the transmission of sensitive metadata.

Transitioning to the Ethereum Mainnet from the Sepolia Testnet marks a strategic evolution for Muzart, aiming to leverage the Mainnet's enhanced security features and wider network benefits. This transition requires meticulous planning, extensive testing, and effective cost management strategies to ensure that Muzart remains a secure and trusted platform for its users.

To address the challenges of user accessibility and adoption, Muzart can invest in user education and interface simplification, making the technology more approachable for individuals unfamiliar with blockchain and NFTs. Bridging the digital divide is also paramount, necessitating initiatives to make Muzart accessible across diverse technological landscapes, particularly in regions with limited internet connectivity.

Integrating Muzart with existing museum management systems poses another area for future development, necessitating solutions that ensure compatibility and ease of data integration. This will enable a seamless fusion of digital and physical collections, enhancing the operational efficiency of museum partners.

Environmental sustainability remains a concern with the use of blockchain technology. Future iterations of Muzart could explore more energy-efficient blockchain protocols, which offer a greener alternative to the traditional Ethereum proof-of-work (PoW) mechanisms, thus minimizing the platform's ecological footprint.

Looking ahead, Muzart could further innovate by exploring decentralized autonomous organizations (DAOs) for community governance, integrating artificial intelligence to refine curation processes, and employing augmented reality (AR) for creating immersive museum experiences. These advancements would not only enhance user engagement but also foster a deeper connection between audiences and cultural heritage.

By addressing these limitations and exploring new technological frontiers, Muzart is positioned to improve its offering significantly. Future work focused on improving scalability, legal compliance, and content verification processes will further establish Muzart as a leading platform in the digital preservation and accessibility of cultural heritage.

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User Manual

Running the Next App

To install all the required packages run:

```
npm i
```

Then to start the app run:

```
npm run build

npm run start
```

Minting a New Original Token

Make sure the .env has the correct private key of a Wallet that has been given ADMIN and MINTER role privileges in the smart contract.

Have a DRACO compressed .glb 3D model file ready.

Upload the file to IPFS, NFT.storage, and save its IPFS URL.

Create metadata JSON file for token data with its model attribute being the model file's IPFS URL.

Upload the metadata file to the IPFS storage.

Update the mintOriginalToken.js url variable to the new matadata IPFS URL.

Then run the command:

```
npx hardhat run src/ethereum/deployment/mintOriginalToken.js -network sepolia
```

For Running Smart Contract Tests

```
npx hardhat test
```

Appendices

Appendix A

Ethics Form

UNIVERSITY OF ST ANDREWS
TEACHING AND RESEARCH ETHICS COMMITTEE (UTREC)
SCHOOL OF COMPUTER SCIENCE
ARTIFACT EVALUATION FORM

Title of project

Blockchain based Museum NFT collections

Name of researcher(s)

Kabir Berger

Name of supervisor

Alan Miller

Self audit has been conducted **YES** ☒ **NO** ☐

This project is covered by the ethical application CS15727.

Signature Student or Researcher

Kabir Berger

Print Name

Kabir Berger

Date

29/9/23

Signature Lead Researcher or Supervisor

Print Name

Alan Miller

Date

29/9/23