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A Blockchain-Enabled NFT Marketplace for Transparent and Immutable Digital Asset Ownership

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Abstract— Non-Fungible Tokens (NFTs) represent distinct digital assets recorded on a blockchain, enabling reliable verification of ownership, authenticity, and uniqueness. This work presents the design and implementation of a decentralized NFT marketplace that allows users to create, trade, and transfer digital assets without relying on centralized intermediaries. The proposed system applies cryptographic techniques, including SHA-256 hashing, to maintain the integrity and uniqueness of NFT metadata, while Elliptic Curve Cryptography (ECC) is used to ensure secure wallet authentication and transaction authorization. Smart contracts deployed on the Ethereum Virtual Machine (EVM) automate core operations such as NFT minting, ownership transfer, and validation. In addition, blockchain consensus mechanisms such as Proof of Stake (PoS) and Proof of Work (PoW) are utilized to validate transactions and maintain network reliability. The workflow begins with user input through an Ethereum wallet, where digital asset details are securely processed using cryptographic methods. A Solidity-based smart contract then generates the NFT and records its ownership on the blockchain. Once created, users can seamlessly perform buying, selling, and transfer operations through verified blockchain transactions. The final output is a uniquely identifiable NFT with securely maintained and transparent ownership information.

Keywords: Blockchain Technology, NFT Marketplace, Ethereum, Smart Contracts, Decentralized Systems, Digital Assets, Wallet Authentication

I.INTRODUCTION

The rapid expansion of digital content creation and online asset trading has created a growing need for reliable methods to verify the ownership and authenticity of digital assets. In conventional digital marketplaces, ownership information is typically maintained within centralized systems, where records are stored in private databases. This centralized approach introduces several limitations, including susceptibility to data manipulation, duplication of assets, and unauthorized distribution [1], [2]. Moreover, users are required to rely on intermediaries for validating transactions and managing ownership, which often leads to reduced transparency and increased operational costs [3].

To address these challenges, blockchain technology offers a decentralized alternative by maintaining a distributed ledger that records transactions in a secure and tamper-resistant manner. Unlike traditional systems, blockchain eliminates the need for trusted third parties, as all transactions are validated and stored across multiple nodes in the network [4], [5]. Building on this concept, Ethereum enhances blockchain functionality by enabling programmable smart contracts, which automatically execute predefined rules for asset ownership and transaction management within decentralized applications (DApps) [6], [7]. This approach allows direct peer-to-peer exchange of digital assets while maintaining a transparent and verifiable ownership history.

In this context, Non-Fungible Tokens (NFTs) have emerged as an effective way to represent unique digital assets, including artwork, collectibles, and virtual items. Unlike cryptocurrencies, which are interchangeable, NFTs are indivisible and contain distinct metadata that differentiates each asset, thereby ensuring uniqueness and traceability [10], [11]. The increasing adoption of NFTs has further encouraged the development of decentralized marketplaces, where creators can directly tokenize and monetize their digital content without depending on centralized platforms [12], [13].

Another essential aspect of NFT-based systems is secure user authentication and data storage. Blockchain wallets, which operate using public-key cryptography, allow users to sign transactions and verify ownership without exposing their private keys, ensuring secure identity management in decentralized environments [14], [15]. In addition, due to the high cost of storing large data directly on-chain, decentralized storage solutions such as IPFS, along with off-chain databases, are commonly used to store NFT metadata efficiently while maintaining ownership records on the blockchain [16], [17].

The main contributions of this work are as follows:

- Design and development of a decentralized NFT marketplace that enables users to create, trade, and transfer digital assets with transparent ownership verification.
- Implementation of Ethereum-based smart contracts to automate NFT minting, ownership transfer, and transaction validation without relying on

- Integration of blockchain wallets and cryptographic authentication mechanisms to ensure secure user interaction and efficient management of NFT assets.

II. RELATED WORK

Early studies on blockchain technology highlighted its potential to maintain decentralized and tamper-resistant transaction records without depending on centralized authorities. The foundational work by Nakamoto [18] introduced the concept of distributed consensus and immutable ledgers, which later researchers such as Wood
[19] and Crosby et al. [20] expanded toward broader applications in digital asset management. These contributions established blockchain as a dependable platform for recording ownership and reducing the risk of data manipulation. However, initial blockchain implementations were largely limited to cryptocurrency transactions and did not provide effective support for representing unique digital assets such as artwork or collectibles. In addition, these systems were constrained by practical challenges including limited scalability, high energy consumption, and slow transaction speeds. Concerns related to regulatory uncertainty, inefficient storage mechanisms, restricted flexibility, and privacy issues further hindered their widespread adoption.

The emergence of Ethereum marked a significant advancement by introducing programmable blockchain functionality through smart contracts. Buterin [21] proposed the concept of decentralized applications (DApps), enabling systems to operate without centralized control, while Antonopoulos and Wood [8] demonstrated how smart contracts could be used to facilitate secure digital asset exchange. Further, Christidis and Devetsikiotis [22] emphasized the importance of smart contracts in enabling trustless interactions across distributed networks. Despite these advancements, existing studies mainly focused on the technical capabilities of decentralized computation and did not adequately address the design of NFT-based marketplaces or user-centric trading platforms. Moreover, Ethereum-based systems introduced new challenges, including high transaction fees (gas costs), scalability limitations, and increased complexity in smart contract development. Security vulnerabilities in smart contracts, along with the lack of intuitive user interfaces, also posed barriers to broader adoption.

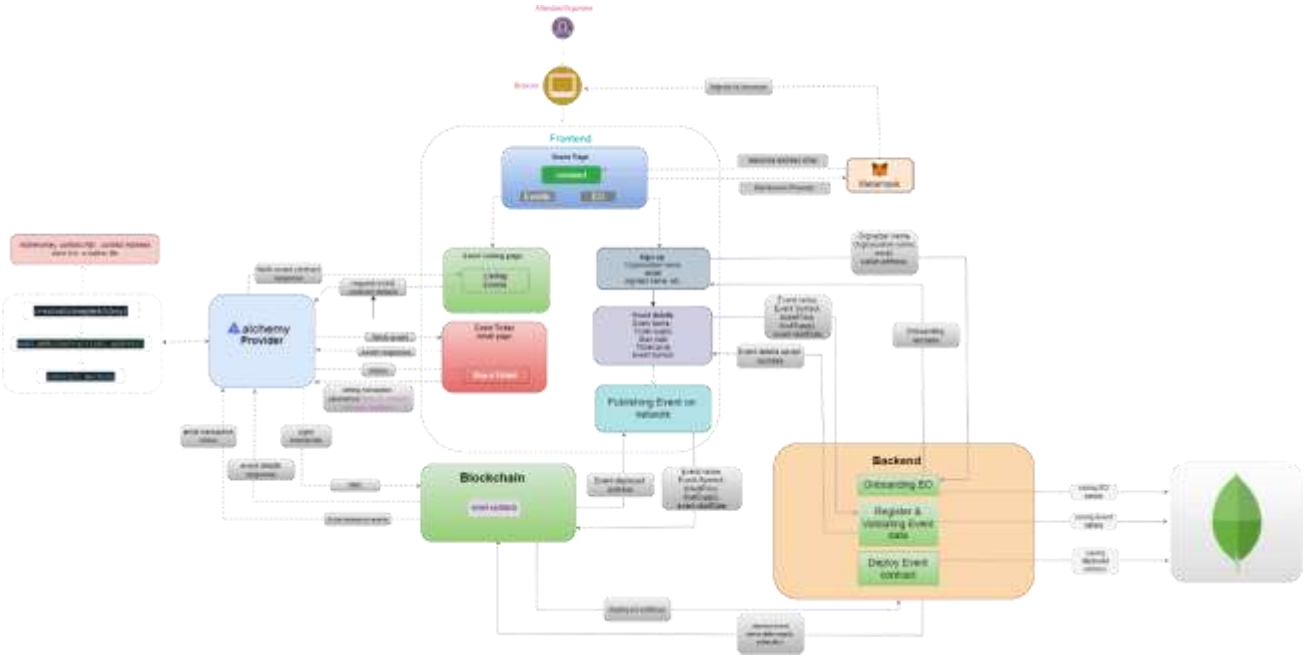
The introduction of the ERC-721 standard by Entriken et al. [23] provided a structured approach for representing unique and non-interchangeable digital assets on the blockchain. Building on this, Wang et al. [24] and Nadini et al. [25] examined NFT ecosystems and trading patterns, demonstrating how NFTs enable verifiable ownership and scarcity of digital content. Dowling [26] further explored the economic dynamics of NFT pricing within decentralized markets. While these studies confirmed the growing importance of NFTs in digital ownership, they primarily focused on market behavior and theoretical analysis rather than the development of complete and practical marketplace architectures. Additionally, NFTs face several real-world challenges, including high transaction costs, environmental concerns associated with blockchain operations, and market volatility. Issues such as copyright violations, regulatory uncertainty, and security risks also continue to limit their practical implementation.

Given the high cost and inefficiency of storing large files directly on-chain, researchers have proposed hybrid storage architectures that combine blockchain-based ownership records with off-chain data storage. Benet [27] introduced the InterPlanetary File System (IPFS) as a decentralized solution for content addressing, while Chen et al. [28] explored the integration of blockchain with distributed storage systems to enable secure data sharing. These approaches improve scalability by offloading large data from the blockchain while preserving essential ownership information on-chain. However, integrating such hybrid models into real-world web-based NFT marketplaces remains a complex task. Challenges such as dependency on off-chain storage availability, synchronization issues between on-chain and off-chain data, and increased system complexity continue to affect their reliability and efficiency.

III. PROPOSED METHODOLOGY

The proposed methodology focuses on designing and implementing a decentralized NFT marketplace that supports the secure creation, listing, and trading of digital assets using blockchain technology . The system combines multiple components, including smart contracts, cryptographic wallet authentication, and off-chain storage, to ensure reliable data handling and efficient operation. The overall workflow begins with user authentication through a blockchain wallet, followed by NFT creation, listing in the marketplace, and transaction processing on the blockchain network. In addition, backend services and database support are incorporated to manage metadata and improve system scalability. This approach provides a decentralized environment where digital asset ownership and transactions can be handled in a secure and transparent manner.

3.1. Proposed System Architecture



The system architecture represents how different components interact to enable a fully functional decentralized NFT marketplace . It is composed of several layers that work together to support asset creation, storage, and trading.

The **frontend serves** as the user interface, allowing users to interact with the platform through a web application. Users can connect their wallets, view NFTs, create listings, and perform transactions through this interface.

The **wallet layer** integrates blockchain wallets such as MetaMask, which act as a secure gateway for user authentication and transaction signing. These wallets function as the user's identity within the decentralized ecosystem.

The **blockchain layer** consists of smart contracts deployed on networks such as Ethereum or Polygon. These contracts handle essential operations such as NFT creation, ownership verification, and transfer of assets while ensuring data integrity.

To enable smooth communication between the application and the blockchain, an API service like **Alchemy** is used. This allows the system to fetch blockchain data and submit transactions efficiently.

Backend services manage supporting operations such as event validation, onboarding processes, and smart contract deployment. Finally, the database layer uses MongoDB to store off-chain data such as metadata and user information. This hybrid design reduces blockchain storage costs while maintaining critical ownership data on-chain. Overall, the architecture supports scalable and efficient NFT marketplace functionality.

3.2 User Wallet Authentication Module

This module handles user authentication through blockchain wallets like MetaMask . Instead of traditional login systems, users connect their wallets to access the platform and perform transactions.

Authentication is achieved using Elliptic Curve Cryptography (ECC), which allows secure identity verification and transaction signing without exposing private keys. Once the user connects their wallet, the system retrieves and verifies the public address through the blockchain network.

Fig1: MetaMask Wallet Authentication and Connection Flow

Fig. 1 illustrates the wallet connection process in the proposed NFT marketplace system. Initially, the user accesses the web application and selects the *Connect Wallet* option available on the interface. The application then sends a connection request to the MetaMask wallet, where the user must grant permission to proceed. Once the request is approved, the wallet shares the user's public address with the application. This address is then validated through the Alchemy provider to ensure authenticity. After successful verification, the user is connected to the platform and can interact with the blockchain to perform operations such as NFT minting, listing, and purchasing.

Key functionalities include:

- Establishing wallet connectivity through Web3 providers
- Verifying user identity using the public wallet address
- Enabling secure transaction signing via private keys stored within the wallet
- Allowing safe interaction with blockchain-based smart contracts

This module replaces traditional authentication mechanisms by providing a decentralized and more secure alternative to username-password systems.

3.3. NFT Minting Module

The NFT minting module enables users to convert digital content such as images or videos into blockchain-based tokens . Each NFT is assigned a unique identifier that confirms ownership and authenticity.

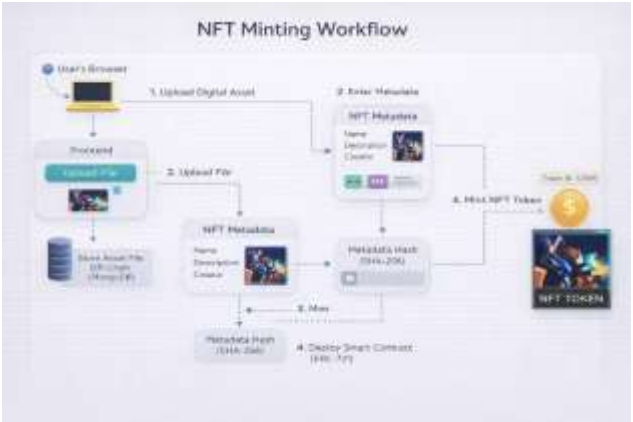


Fig2: NFT Creation and Minting Process

Fig. 2 represents the NFT minting workflow within the proposed decentralized marketplace system. The process

begins when a user uploads a digital asset, such as an image or video, through the frontend interface. Once the asset is submitted, the system gathers relevant metadata, including the asset name, description, and creator details. The actual file is stored off-chain using a database such as MongoDB, while a SHA-256 hash of the metadata is generated to maintain data integrity and prevent tampering.

This generated hash is then transmitted to the blockchain, where a smart contract compliant with the ERC-721 standard executes the minting operation. Upon successful execution, a unique token ID is created and linked to the user's wallet address. This step finalizes the NFT creation process, ensuring that ownership information is permanently recorded on the blockchain.

The minting process involves:

- Uploading the digital asset through the user interface
- Creating and storing metadata (name, description, creator details)
- Generating a SHA-256 hash to ensure metadata integrity
- Deploying the NFT on the blockchain using smart contracts

3.4. Marketplace Module

The marketplace module provides an interface for users to explore and trade NFTs in a decentralized environment . Users can browse listings, view detailed information about assets, and perform transactions.

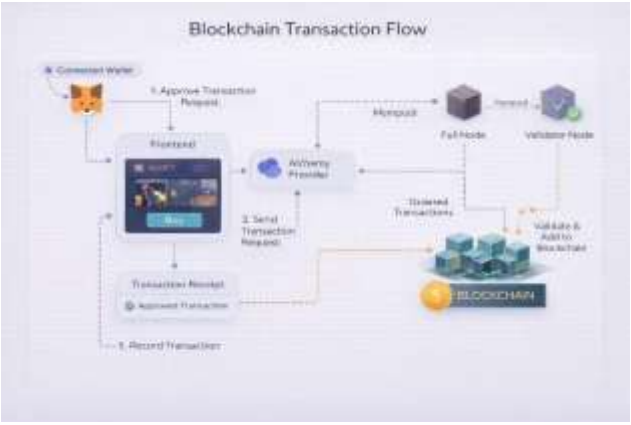
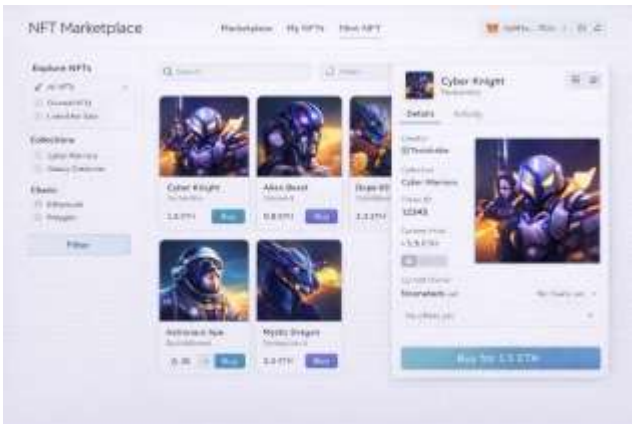


Fig3: User Interface of the Proposed NFT Marketplace

Fig. 3 illustrates the user interface of the proposed NFT marketplace system. The interface is designed to provide an intuitive environment where users can browse available NFTs, view essential details such as creator information and pricing, and perform actions like purchasing or listing assets. It also offers navigation across different sections, including the marketplace, owned



NFTs, and minting options, allowing users to manage their digital assets efficiently.

When a user selects a specific NFT, the platform presents comprehensive information such as the token ID, current ownership details, and transaction history. Through this interface, users can seamlessly interact with the blockchain by initiating transactions like buying, selling, or transferring NFTs using their connected wallet.

Main features include:

- Displaying NFT listings along with relevant metadata and pricing
- Allowing users to list their NFTs for sale
- Providing search and filtering capabilities for easy asset discovery
- Supporting peer-to-peer transactions without intermediaries

This module acts as a bridge between the frontend application and blockchain smart contracts, enabling real-time retrieval and display of NFT-related data.

3.5. Transaction Module

This module is responsible for handling NFT transactions, including buying, selling, and transferring ownership . When a user initiates a transaction, it is signed using their wallet and sent to the blockchain network.

The transaction is validated through consensus mechanisms such as Proof of Stake (PoS). Once verified, it is added to the blockchain, and ownership records are updated accordingly.

Fig. 4 illustrates the transaction flow within the proposedNFT marketplace system. The process begins when a user connects their crypto wallet and confirms a transaction request through the frontend interface. Once approved, the request is forwarded to the blockchain network via the Alchemy provider, which acts as an intermediary for communication between the application and the blockchain.

After submission, the transaction enters the mempool, where it is temporarily held before being processed by network nodes. Validator nodes then verify the transaction and, upon successful validation, include it in a newly created block. Once the block is added to the blockchain, the transaction becomes permanent and cannot be altered. A transaction receipt is subsequently generated and returned to the application, confirming completion.

Key processes include:

- Execution of smart contracts for NFT purchase or transfer
- Validation of transactions by blockchain nodes
- Generation of a unique transaction hash for verification
- Updating ownership details on the blockchain

This workflow ensures that NFT transactions are processed in a secure, verifiable, and tamper-resistant manner, maintaining accurate ownership records throughout the system.

3.6 Database Module

Since storing large files directly on the blockchain is costly, the system adopts a hybrid storage approach . Critical ownership data is stored on-chain, while large files and metadata are stored off-chain.

Fig5: Hybrid Storage Architecture for NFT Data Management

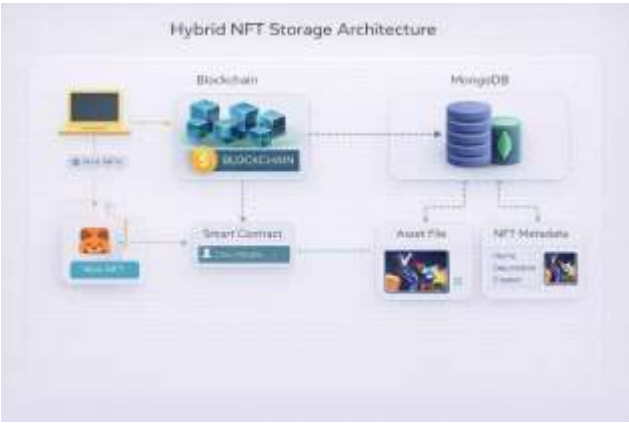


Fig. 5 illustrates the hybrid storage architecture adopted in the proposed NFT marketplace system. In this design, the minting process begins at the frontend, where the user uploads a digital asset along with its associated metadata. The smart contract deployed on the blockchain records only essential details, such as the token ID, owner's address, and a hash of the metadata, ensuring data integrity and traceability.

To avoid the high cost of on-chain storage, larger components such as asset files and detailed metadata are stored off-chain using systems like MongoDB or IPFS. This separation allows the blockchain to handle ownership verification, while the database manages storage of bulk data. As a result, the system achieves a balance between security, scalability, and cost efficiency.

The database module stores:

- NFT metadata
- References to asset files
- Marketplace listing information
- User activity records

In this approach, only critical data—such as token ID, ownership details, and metadata hash—is maintained on the blockchain, while the remaining data is handled off-chain. This significantly reduces transaction costs (gas fees) while preserving data reliability and authenticity.

IV. RESULT AND DISCUSSION

This section presents the outcomes obtained from the implementation and evaluation of the proposed decentralized NFT marketplace system. The system was assessed in terms of functionality, performance, and transaction reliability. Key operations—including wallet connection, NFT minting, listing, purchasing, and ownership transfer—were analyzed to measure execution time and overall efficiency. The results indicate that the proposed architecture effectively supports decentralized digital asset trading while maintaining reliable system performance and consistent transaction handling.

4.1 Software and Hardware Environment

The system was developed and tested within a standard web-based development environment. The frontend application operates on commonly used browsers such as Google Chrome and Mozilla Firefox, while backend services run on a Node.js runtime. Blockchain interactions are handled using the MetaMask wallet along with the Alchemy provider, enabling efficient communication with the Ethereum network. [28], [29], [30].

Table I. Software Tools

Component	Technology Used
Frontend	React + Vite
Backend	Node.js, Express.js
Blockchain	Ethereum
Smart Contracts	Solidity(ERC-721 Standard)
Wallet Integration	MetaMask
Blockchain API	Alchemy Provider
Database	MongoDB

Table I summarizes the technologies used across different layers of the system. React with Vite is used to build the frontend interface, while Node.js and Express.js handle backend operations. Smart contracts are developed using Solidity and deployed on the Ethereum blockchain. Wallet authentication is managed through MetaMask, and the Alchemy provider facilitates interaction with the blockchain network. Additionally, MongoDB is used for storing off-chain metadata. Together, these components form a scalable and efficient architecture for decentralized NFT trading.

4.2.System Functional Evaluation

The performance of the system was evaluated by measuring the execution time of key NFT operations.

Operation	Average Time (seconds)
Wallet Connection	2
NFT Minting	15
NFT Listing	5
NFT Purchase	18
NFT Transfer	12

Table II: Average Execution Time of NFT Marketplace Operations

Table II presents the average time required to complete core operations within the system. Basic tasks such as wallet connection and NFT listing are completed quickly, whereas blockchain-dependent operations like minting and purchasing require more time due to transaction validation and block confirmation processes. Despite these delays, the results demonstrate that the system maintains a balance between performance and security. The observed execution times confirm that the proposed architecture is capable of supporting efficient and reliable NFT transactions in a decentralized environment.

V. CONCLUSION & FUTURE SCOPE

The development of the blockchain-enabled NFT marketplace demonstrates how distributed ledger technology and smart contracts can be effectively utilized to manage digital asset ownership in a secure and transparent manner. The system leverages Ethereum-based smart contracts to handle NFT minting and ownership transfer, while cryptographic hashing techniques ensure the integrity of associated metadata. In addition, wallet-based authentication mechanisms provide a reliable way to verify user identity without exposing sensitive information. By eliminating intermediaries and maintaining tamper-resistant ownership records on the blockchain, the platform improves trust and transparency in digital transactions. The use of off-chain storage combined with on-chain references further enhances scalability by reducing transaction costs. Overall, the system successfully supports key marketplace operations such as minting, listing, purchasing, and transferring NFTs, offering a more efficient alternative to traditional digital marketplaces.

Future improvements can enhance both functionality and user adoption of the proposed system. Integrating decentralized storage solutions such as IPFS or Filecoin can provide more reliable and permanent storage for NFT metadata, reducing reliance on centralized databases. Expanding the platform to support multiple blockchain networks—including Ethereum, Polygon, and Solana—can improve transaction speed and lower operational costs while increasing interoperability across ecosystems. Additionally, introducing mobile wallet compatibility and cross-platform interfaces can make the system more accessible to a wider range of users, supporting broader adoption of Web3 technologies.

In summary, the proposed NFT marketplace provides a practical implementation of decentralized digital asset management using blockchain and cryptographic techniques. It addresses several limitations of existing centralized platforms and establishes a scalable foundation for future developments in Web3-based digital economies.

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