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Technological Framework of NFTs and Smart Contracts for Preserving Malaysian Arts and Cultural Heritage

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ABSTRACT

Non-Fungible Tokens (NFTs) have been developed over the past few years as an impactful new digital asset class that allows both artists and cultural institutions to securely generate revenue from their digital creations while protecting them. However, limited research exists that fully addresses the integration of NFTs and smart contracts as a technological framework for preserving and promoting artistic and cultural heritage in Malaysia. While there has been much discussion about the economic advantages of NFTs paired with smart contracts, the technical backbone infrastructure remains largely unexplored in many ways for cultural preservation. The research explores NFTs and smart contracts to offer automated royalties and an unprecedented transfer of ownership system with cultural impact. This research, through a mixed-method approach-including a literature review, interviews with experts, and the formulation of relevant mathematical models-conducted an analysis of how smart contracts automate the NFT transaction and royalty distribution. The results have so far shown that, underpinned by blockchain technology, NFTs can offer a promising solution to present and future Malaysian artists and cultural institutions in ensuring the authenticity and financial viability of traditional and modern forms of art. Besides that, scalability, environmental concerns, and legal frameworks are several sober challenges to widespread adoption. Finally, this research concludes that NFTs and smart contracts have the potential to revolutionize Malaysia's cultural economy by offering a sustainable model for heritage preservation and a supporter of the arts in general.

1. Introduction

Non-Fungible Tokens (NFT) have been among the most significant classes of digital assets over recent years. They allow new ways for artists and cultural institutions to monetize and protect their digital creations securely. NFTs on blockchain technology maintain authenticity while managing

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provenance through a decentralized, immutable ledger system [1,2]. Smart contracts form one of the key building blocks in this environment. These self-executing contracts automate activities such as transactions, ownership transfers, and royalty distributions without the need for intermediaries, ensuring transparency and security [1-3]. For instance, Ethereum, one of the main platforms for NFTs, utilizes smart contracts through programming in Solidity for the aforementioned activities to take place [4]. Section 2.2 discusses in more detail how smart contracts work.

Applications of NFTs have been discussed to the sale and ownership of digital art, where it allows artists to retain ownership and residual royalties after the first sale [5]. However, beyond the economic benefits, there is increasing interest in exploring how NFTs can be applied to the preservation and promotion of cultural heritage, which traditionally faces challenges related to ownership rights, financial sustainability, and accessibility. Blockchain's ability to tokenize cultural assets and create immutable records offers a unique opportunity for cultural institutions to preserve and promote both traditional and modern forms of art [6].

Despite the growing discourse on NFTs, there is a significant gap in the literature regarding the technological framework supporting these innovations, brilliant contracts, in the context of cultural heritage preservation. Most of the available literature studies economic benefits only, without going into the technical mechanisms that make NFTs suitable tools for this purpose [7]. Additionally, within the Malaysian context, the potential of NFTs to safeguard the nation's rich cultural heritage - ranging from batik to wayang kulit–remains underexplored. There is limited understanding of how blockchain technology and NFTs can be employed to not only commercialize these art forms but also ensure their long-term preservation and global visibility.

Given this gap, the significance of this research lies in its exploration of the technological underpinnings of NFTs and smart contracts, specifically within the framework of cultural heritage preservation. It contributes to the deficiency in present literature, which is a technical insight into how NFTs can be applied and utilized beyond their popular use in the domain of digital art toward safeguarding traditional cultural assets. This research also contributes to policymakers, cultural institutions, and artists in Malaysia by providing a framework that could enhance the visibility and financial sustainability of cultural heritage in the digital age. The basis of this paper is to discuss the technological underpinnings of NFTs, focusing on smart contracts within blockchain systems, while showing how these technologies can help advance and preserve Malaysian arts and cultural heritage. Later in the study, a comprehensive technical analysis with mathematical models explaining the automation of royalties and the sale of ownership in the transactions will be shown.

2. Background of NFTs Technology

2.1 Blockchain Architecture for NFTs

Blockchain is a distributed ledger technology (DLT) that operates on a decentralized network of nodes, where each node stores a complete copy of the blockchain. Each transaction is stored in a "block," and blocks are linked together in a chain, providing a secure and transparent way to manage digital assets [3,8]. Transactions are grouped into blocks and verified by a consensus mechanism. Proof of Work (PoW) and Proof of Stake (PoS) are two common consensus algorithms used to validate and add new blocks to the chain [9]. NFTs typically operate on Ethereum, a blockchain that utilizes PoW but is transitioning to Ethereum 2.0, which adopts PoS to reduce the environmental impact of blockchain mining. These consensus mechanisms ensure that transactions are validated securely and fairly. Each NFT is a unique token recorded on the blockchain with smart contracts [3]. Smart contracts enable self-executing agreements that facilitate the token creation, sale, royalties, and

ownership transfer [5,8]. The immutability of the blockchain ensures that once an NFT is minted, it cannot be altered, providing security against forgery or modification [4].

2.2 Smart Contracts: Mechanisms and Cryptography

Smart contracts are the backbone of NFT technology. These self-executing pieces of code, deployed on blockchain networks like Ethereum, automatically enforce and execute terms when predefined conditions are met. This eliminates the need for intermediaries, offering automation, transparency, and security. The robustness of smart contracts lies in their reliance on cryptographic algorithms, such as Elliptic Curve Cryptography (ECC) and SHA-256 hashing, which ensure that all transactions are secure and tamper-proof [10-13]. This section consolidates their mechanisms, cryptographic foundations, and advantages.

2.2.1 Mechanisms of smart contracts

A smart contract operates through encoded conditions that trigger actions on the blockchain [14]. For instance: Royalty Payments (smart contracts ensure automatic distribution of royalties to artists each time an NFT is resold) and Ownership Transfers (these contracts securely transfer NFT ownership upon payment). Here is a Solidity example for royalty automation (Table 1).

Table 1
Example of Solidity

```
pragma solidity ^0.8.0;

contract NFT {
    address payable public artist;
    uint256 public royaltyPercentage;

    constructor(address payable _artist, uint256 _royaltyPercentage) {
        artist = _artist;
        royaltyPercentage = _royaltyPercentage;
    }

    function distributeRoyalty(uint256 salePrice) public payable {
        uint256 royalty = (salePrice * royaltyPercentage) / 100;
        artist.transfer(royalty);
    }
}
```

Once deployed, the contract resides on the blockchain. Once finalized, it can neither be changed nor deleted. What this means is that when a smart contract is deployed, executed, or perhaps used, everything will remain tamper-proof [10-13]. A smart contract contains an agreement with embedded conditions and rules. These conditions are continuously tracked by the blockchain network, which executes mutually agreed actions once these conditions are met. Smart contracts in an NFT marketplace, for example, could include stipulations like ownership transfer from the seller to the buyer, provided the payment is made, as well as royalty payments to the natural creator of the artwork automatically whenever the NFT changes hands. A smart contract becomes immutable; no party involved in that contract–even the creator–can alter its terms. In such a way, transparency and trust between parties are ensured. The blockchain forms a secure, immutable record of each execution of the contract. Additionally, smart contracts remove intermediaries and automate

processes; hence, no intermediaries are involved, meaning there are no middlemen like lawyers or brokers, which reduces costs and potential human error.

2.2.2 Cryptographic security

The security of smart contracts is deeply reliant on cryptographic principles, which guarantee that transactions are both secure and transparent. In symmetric encryption methods as applied in smart contract applications, the key cryptographic techniques include Elliptic Curve Cryptography and SHA-256 hashing [10-12]. ECC is used in generating and managing a user's private-public key pair. In blockchain, the public key of a user is associated with his or her digital wallet, while his or her private key signs the transactions. ECC allows a smart contract to interact with the users and ensures that only the owner of the corresponding private key can approve any such transaction that involves transferring ownership of an NFT or issuing a royalty payment. SHA-256, on the other hand, is a cryptographic hash function that takes any input and produces a one-way, fixed-size 256-bit hash. It is a one-way function, meaning the original input cannot be derived from the hash; hence, it provides integrity and security to data. In smart contracts, every block of transactions is hashed using SHA-256. The result is an immutable, timestamped record of every transaction. That ensures the execution of the smart contract is recorded forever, with the integrity of the execution of the contract maintained.

The use of smart contracts in execution would involve an NFT artist selling his or her digital artwork through blockchain-based platforms such as Ethereum. First, the artist will create an NFT by uploading his or her artwork into the marketplace and then setting an overall sale price for the work, along with a royalty rate for any future sales of the work, for example, 10%. This information gets encoded into a smart contract. The buyer comes in and decides to buy the NFT; the buyer transfers the sale amount to this smart contract. The contract automatically takes over, transferring the ownership of the NFT to the buyer while splitting the funds according to the logic of the contract: the artist gets the sales amount, and the buyer owns the NFT. Upon resale of the NFT by the buyer, the smart contract again comes into effect. This contract transfers the NFT to the new buyer, deducting a royalty of 10%, before transferring that share to the original artist's address without interference.

Therefore, there are some advantages of Smart Contracts in NFTs. Firstly, automation means that all stages of an NFT life cycle—for example, minting, sales, royalties, and changes in ownership—are automated through smart contracts, thus making them both efficient and accurate. Secondly, smart contracts are transparent by default, being innately on the chain for anyone who legally can view or verify them. This creates trust with no intermediaries. Thirdly, security: strong cryptographic algorithms such as ECC and SHA-256 ensure that transactions are not capable of being tampered with or any form of general fraud. Lastly, efficiency is significantly enhanced by eliminating intermediaries, reducing transaction costs, accelerating processes, and minimizing errors. These features make smart contracts an indispensable tool in the NFT landscape.

In the context of NFTs, smart contracts are the backbone that ensures seamless transactions, secure ownership transfers, and fair distribution of royalties. By leveraging cryptographic security and blockchain immutability, smart contracts automate complex processes while providing transparency and security, making them indispensable in the digital art ecosystem.

2.3 Applications of NFTs In Cultural Heritage

NFTs hold transformative potential for preserving and promoting cultural heritage. By tokenizing traditional art forms, performances, and artifacts, NFTs enable cultural institutions to create

immutable digital representations of these assets. This not only safeguards their authenticity but also ensures long-term accessibility and global visibility [6,15]. Tokenization offers new avenues for monetizing cultural heritage, allowing institutions to generate revenue through the sale or licensing of digital representations. Additionally, NFTs democratize access to cultural heritage by making digital artifacts accessible to a global audience, overcoming traditional barriers such as geographical limitations [16]. The detailed mechanisms of how blockchain technology and smart contracts contribute to metadata preservation, authenticity, and accessibility are further explored in Section 4.3.

2.4 Challenges in the Adoption of NFTs

Some of the key challenges in NFT adoption include energy consumption, scalability, and the need for a legal framework regarding ownership and copyright protection. In addition to the security through blockchain technology, both environmental impact and scalability remain under continuous improvement in pursuit of widespread adoption. Probably one of the most advanced criticisms against the use of NFTs, particularly those minted on platforms such as Ethereum, is the high use of energy coming from PoW consensus mechanisms. Ethereum, before its shift to Ethereum 2.0 and Proof of Stake, relied on energy-intensive mining operations to validate a transaction in the case of the creation and selling of NFTs. This indeed provokes very strong concerns about environmental sustainability related to NFTs. The PoW in Ethereum can use as much energy as whole nations; hence, this gives birth to serious environmental concerns that affect the perception of the public about NFTs [17]. While Ethereum is migrating to PoS and is expected to decrease its energy consumption by as much as 99%, other NFT platforms that are still based on PoW are attracting increasing criticism [18-21]. There is a general reluctance from artists, creators, and collectors towards the creation or trading of NFTs due to the fear of contributing to carbon emissions. Therefore, many have called for more environmentally sustainable blockchain solutions or Layer 2 scaling solutions that consume a minimum amount of energy.

The next big challenge to mainstreaming NFTs is the scalability of blockchain networks. Scalability refers to the ability of a blockchain to scale its load - that is, handle an increasing number of transactions without losing speed or efficiency. As more and more people start minting, buying, and selling NFTs, this causes congestion in platforms such as Ethereum's network, leading to high gas fees - or the price one pays for a transaction on the blockchain network. Sometimes, during periods of high demand, the gas fees jump up and down wildly, thus making NFT transactions unaffordable for most users [22]. Remediation for this scalability issue includes studying Layer 2 scaling solutions such as zk-rollups and sidechains, which attempt to alleviate some of the load off the main chain by processing either in batches or off-chain. These technologies could help take some load off the main blockchain by processing transactions either off-chain or together in batches, hence reducing the costs and increasing the speed of transactions [23]. However, the adoption of these solutions is still in its early stages, and their integration into mainstream NFT platforms remains a challenge.

Still, the legal framework with regard to the ownership and copyright protection of NFTs is in a no-man's-land and underdeveloped. While an NFT can give ownership over a digital asset on-chain, it does not give ownership over the intellectual property attached to it and automatically gives the holder reproduction and sales rights to the work. The result is confusion on the part of buyers and sellers alike. Some purchasers of NFTs even labor under the misapprehension that they have obtained full ownership rights in the underlying digital content. Without a consistent legal framework, the enforcement of copyright laws has proven complex across different jurisdictions, with some selling artists' work as NFTs without their permission [24,25]. For instance, high-profile

cases like the unauthorized tokenization of artworks by famous artists have raised concerns about the enforceability of copyright laws in the NFT space. In response to these challenges, platforms like Pentas.io have implemented measures such as verification badges and stricter onboarding processes for creators. However, these solutions are not foolproof, and legal experts are calling for clearer regulations that explicitly define the rights associated with NFT ownership and the responsibilities of marketplaces.

These are the various challenges that a number of solution initiatives are underway to address. On energy use, the transition to PoS and the development of Layer 2 solutions promise a drastic reduction in environmental impact from blockchain networks. On the other hand, advances in interoperability and legal frameworks could sort out issues to do with scalability and ownership. For instance, the Digital Services Act of the European Union tries to broaden the scope on digital platforms that might involve NFTs and digital assets [26,27].

3. Methodology

This study employs a mixed-method approach, combining a review of relevant literature with the development of mathematical models that describe the operation of smart contracts in NFTs. A case study analysis was also conducted to examine how Malaysian artists and cultural institutions can benefit from implementing smart contracts and NFTs. The qualitative insights from a literature review and case study analysis are combined with quantitative models explaining the technical details of smart contracts in NFTs. The data collection process includes reviewing academic papers and technical whitepapers; and conducting expert interviews, while Mathematical Modeling focuses on scientifically describing how royalties and ownership transfers are automated in NFT transactions using blockchain technology. This approach provides a holistic view of how NFTs and smart contracts benefit Malaysian artists and cultural institutions, combining theoretical understanding, real-world insights, and mathematical rigor.

3.1 Data Collection

Data was collected from various sources, including academic papers, blockchain whitepapers, and reports from NFT platforms. Additionally, interviews were conducted with five experts from the NFT and blockchain industry in Malaysia, focusing on how smart contracts are currently used and their potential for promoting cultural heritage. Literature and whitepapers provide critical resources for understanding the foundational and practical aspects of NFTs and blockchain technology. Academic papers offer scholarly insights into blockchain, NFTs, and smart contracts, building a robust theoretical understanding of these technologies. Complementing this, blockchain whitepapers, such as Ethereum technical documents, provide detailed explanations of how blockchain platforms operate and the integral role smart contracts play in facilitating NFT transactions. Furthermore, reports from NFT platforms like Pentas.io may include data on how NFT transactions are conducted, how royalties are distributed, and the challenges and opportunities presented to artists.

Additionally, interviews were conducted with five experts from the NFT and blockchain industry in Malaysia. These experts included NFT artists, blockchain developers, and cultural institutions involved in NFTs. The purpose of these interviews was to gather qualitative insights on how smart contracts are currently being used in the industry and how they might be applied in promoting and preserving Malaysian cultural heritage. The questions focused on: the real-world use of smart contracts (for example, how artists are using them to receive royalty payments). The potential challenges faced in implementing this technology in Malaysia (for example, understanding blockchain

technology, legal concerns, or financial limitations). How NFTs are impacting the cultural and financial aspects of digital art and heritage preservation. By combining these sources, the study gathered both qualitative and quantitative data that would help in developing a deep understanding of the application of NFTs and smart contracts.

3.2 Mathematical Modeling

This section explains the quantitative approach used in the study. The goal of mathematical modeling is to provide a scientific and technical explanation of how smart contracts automate processes like royalty payments and ownership transfers in NFT transactions. The operation of smart contracts plays a crucial role in NFT transactions, acting as the core technology that enables their functionality. Smart contracts are the core technology that powers NFTs. The study builds mathematical models to explain how they function in practice. For instance, the model would show how a smart contract is triggered when an NFT is sold or resold, automatically transferring ownership from the seller to the buyer and distributing royalties to the original artist.

To further elaborate, the study introduces a royalty distribution model. The royalty distribution model is the operation of smart contracts in NFT transactions which was mathematically modeled to illustrate how ownership transfers and royalty payments are automated. These models were built on concepts from DLT and cryptographic principles, providing a scientific basis for understanding how NFTs can benefit Malaysian artists. Consider a scenario where an NFT is resold multiple times, and the artist is entitled to a royalty on each resale. The total amount received by the artist can be modeled as a sum of royalties from each transaction, denoted as R_n, where n is the number of times the NFT has been resold.

Let P_n be the price of the NFT during the $n-th$ resale, r be the royalty rate as a percentage, and R_n be the royalty earned by the artist during the $n-th$ transaction. Then, the royalty for each resale is given by Eq. (1):

$$R_n = r \times P_n \tag{1}$$

The total royalties T earned by the artists after N resales can express as in Eq. (2):

$$T = \sum_{n=1}^{N} \mathrm{R_n} = \sum_{n=1}^{N} (r \times P_n) \tag{2}$$

This formula guarantees that the artist benefits from the future appreciation of their work, incentivizing creators to tokenize their assets on blockchain platforms.

Additionally, the model incorporates the mechanism of ownership transfer, where the smart contract automatically updates the NFT ownership record on the blockchain when the NFT is sold. The blockchain ensures that this process is secure and transparent, with ownership changes permanently recorded and verified by the decentralized network. The mathematical model adds scientific rigor to the study by quantifying how NFTs and smart contracts automate key processes, supporting the qualitative findings from the literature review and case study analysis.

In a blockchain-based system, the integrity of each transaction is ensured by cryptographic hashing. Every block contains a cryptographic hash of the previous block, a timestamp, and transaction data. The blockchain immutability and resistance to tampering come from the difficulty of altering any part of the chain without recalculating all subsequent hashes. If $H(B)$ represents the hash of a block B, the validity of the blockchain is maintained, as in Eq. (3) if:

$$H(B_n) = SHA - 256\ (B_{n-1,}T_n) \quad (3)$$

Where B_n is the $n-th$ block in the chain. T_n is the set of transactions within the block B_n. If any attempt is made to alter a past transaction, the hash of that block would no longer match, and the chain would be invalidated, ensuring security.

4. Results

4.1 Blockchain and Smart Contract Infrastructure for NFTs

NFTs can be securely minted, sold, and transferred in a decentralized environment provided by Blockchain, with no intermediaries involved. This is an essential feature because conventional modes of sale and art distribution have been crippling the exposure of artists to the global audience in the Malaysian art market. The findings indicated that smart contracts on Ethereum, written in Solidity, are the backbone for automation of royalties and transfer of ownership. Meanwhile, the adoption of NFTs on a blockchain–a platform like Ethereum or Binance Smart Chain–could be a new line of revenue for artists in Malaysia. Through blockchains, Malaysian artists now have channels to directly connect with their respective buyers, bypassing all the usual intermediaries to increase their possible earnings.

4.2 Mathematical Modeling of Royalty Distribution

The system is able to model and deploy smart contracts to handle royalty distribution. For instance, when an NFT has multiple resales, a certain predetermined percentage of each sale price is automatically transferred to the original artist. Such processes are achieved by a smart contract. The mathematical modeling of NFT transactions, focusing on ownership transfer and royalty payments, is based on logical construction within smart contracts that automate these processes. The ownership transfer of an NFT transaction depends on secure transaction processes, embedded in the blockchain, which ensures immutability and transparency. Ownership of the NFT is transferred from the seller to the buyer once the conditions of the smart contract, such as payment, are met.

Let, T_x be the transaction that occurs at the time t_x, B_{new} be the address of the buyer, B_{old} be the address of the seller (previous owner), NFT_{id} be the unique identifier of the NFT, and $H(T_x)$ be the hash of the transaction, used to verify it on the blockchain. The ownership transfer occurs if, Eq. (4),

$$Ownership_{new} = \{B_{new}, NFT_{id}\} \text{ if } H(T_x) \text{ is valid.} \quad (4)$$

This means that once the transaction T_x is verified on the blockchain, ownership of the NFT with ID NFT_{id} is transferred from B_{old} to B_{new}. The transaction hash $H(T_x)$ guarantees the immutability of the transfer. The royalty payment model automatically distributes a percentage of the resale value back to the original creator (artist) each time the NFT is resold. This is a core feature of smart contracts that ensures creators continue to earn revenue from their work even after the initial sale.

Let, P_n be the sale price of the NFT during the $n-th$ resale, r be the royalty rate (expressed as a percentage), and R_n be the royalty earned by the artist from the $n-th$ resale. The formula for the royalty payment is as Eq. (5):

$$R_n = r \times P_n \quad (5)$$

where, R_n is the royalty the artist earns from the $n-th$ sale, P_n is the sale price during the $n-th$ transaction, r is the royalty rate set by the artist (e.g., 10% or 5%). The total royalties T_R the artist earns after N resale can be calculated as in Eq. (6):

$$T_R = \sum_{n=1}^{N}(r\ X\ P_n) \quad (6)$$

This formula sums the royalties from each sale, ensuring that the artist receives a consistent percentage of every resale. Assuming a Pentas.io artist mints an NFT with a 10% royalty rate, and the initial sale price of the NFT is 2 ETH. The artist earns the royalties two times.

First sale: The NFT is sold for 2 ETH. The artist earns a 10% royalty from the first sale as in Eq. (7):

$$R_1 = 0.10\ \mathrm{X}\ 2 = 0.2\ \mathrm{ETH} \quad (7)$$

After the first sale, the artist receives 0.2 ETH in royalties. Second sale: The buyer resells the NFT for 5 ETH. The artist earns a 10% royalty from this resale as in Eq. (8):

$$R_2 = 0.10\ \mathrm{X}\ 5 = 0.2\ \mathrm{ETH} \quad (8)$$

After the second sale, the artist receives 0.5 ETH in royalties. Total royalties**:** After 2 sales, the royalties T_R. [(Eq. (9)]. The artist has earned.

$$T_R = R_1 + R_2 = 0.2\ \mathrm{ETH} + 0.5\ \mathrm{ETH} = 0.7\ \mathrm{ETH} \quad (9)$$

So, after two transactions, the artist has earned a total of 0.7 ETH in royalties through the smart contract on Pentas.io.

Smart contracts offer several benefits to NFT artists on platforms like Pentas.io, streamlining processes and ensuring fair compensation. First, they enable automated royalty payments, ensuring that every time an NFT is resold, the artist automatically receives a percentage of the sale price without requiring manual intervention. This guarantees continuous earnings from subsequent transactions. Second, they provide transparent ownership transfer, where the smart contract securely and automatically updates the NFT ownership on the blockchain once a sale is verified, maintaining integrity and trust in the process. Finally, these mechanisms promote financial sustainability, allowing artists to earn consistent income from their creations even after the initial sale. This supports long-term economic stability for digital creators, particularly benefiting the growing NFT ecosystem in Malaysia.

This mathematical model and example demonstrate how smart contracts can provide automated and ongoing financial benefits for artists on platforms like Pentas.io, ensuring that they are compensated fairly throughout the lifecycle of their digital art.

4.3 Cultural Heritage Preservation

The integration of NFTs and blockchain technology offers profound implications for preserving Malaysia's rich cultural heritage. By leveraging decentralized DLT and smart contracts, cultural artifacts can be tokenized, embedded with critical metadata, and preserved for future generations while maintaining their authenticity and accessibility.

4.3.1 Metadata preservation and authenticity

One of the core features of blockchain in cultural preservation is the ability to encode metadata associated with digital representations of cultural artifacts. Metadata includes essential details such as the origin or geographical location of the artifact (e.g., a traditional batik pattern from Kelantan). (e.g., a traditional *batik* pattern from Kelantan), historical significance and date of creation, and artist or craftsman information. By embedding this metadata on the blockchain through smart contracts, cultural institutions ensure that it remains tamper-proof and immutable. For example, hashing algorithms like SHA-256 generate a unique digital fingerprint for each asset, ensuring that even the slightest modification is detectable. This capability is crucial for preventing falsification and ensuring that the authenticity of cultural assets is preserved throughout their lifecycle. Institutions can also use this metadata to certify the cultural significance and provenance of artifacts, bolstering trust and accessibility for researchers and enthusiasts worldwide.

4.3.2 Immutable ownership and provenance records

The use of blockchain ensures the immutability of ownership and provenance records for tokenized cultural artifacts. Once an NFT is minted, its ownership and transaction history are recorded on a cryptographically secure distributed ledger. This capability prevents the illicit trade of cultural property and provides a verifiable chain of custody for each artifact. For instance, a traditional Malay kris (ceremonial dagger) tokenized as an NFT would have its creation details, ownership history, and cultural context permanently recorded. Future custodians can verify these details on the blockchain, ensuring transparency and authenticity.

4.3.3 Enhanced accessibility and engagement

NFTs democratize access to cultural heritage by digitizing and tokenizing artifacts. Traditional barriers such as geographical limitations are eliminated, enabling global audiences to engage with Malaysian cultural heritage through digital platforms. Smart contracts can facilitate controlled access to digitized assets, specifying terms for viewing, reproduction, or educational use. For instance: a tokenized Wayang Kulit (shadow puppet) performance could be accessed globally via an NFT platform, with revenue from viewership directed toward preserving the physical artifacts, and museums can utilize revenue generated from NFT sales to sustain their operations and support the restoration of traditional art forms.

4.3.4 Challenges of cultural heritage tokenization

While NFTs offer immense potential, challenges such as data storage limitations, interoperability, and ethical considerations persist. Blockchains like Ethereum have limited storage capacity, necessitating off-chain solutions such as InterPlanetary File System (IPFS) to store large files while maintaining hashes on-chain. Additionally, the lack of interoperability between blockchains may hinder long-term accessibility. Ethical considerations, including the commercialization of national treasures, require careful handling. Policies must respect cultural sensitivities and ensure that Indigenous communities benefit from the tokenization of their cultural expressions.

4.3.5 Challenges in adoption NFTs

The energy consumption of blockchain networks, particularly those using the PoW consensus mechanism, has been a significant concern for the adoption of NFTs. PoW-based systems like Ethereum historically required extensive computational power to validate transactions, leading to considerable carbon emissions. This has raised questions about the environmental sustainability of blockchain technologies and their implications for industries such as cultural heritage preservation Ethereum to PoS with Ethereum 2.0 represents a critical step toward addressing these concerns. Unlike PoW, PoS validators stake cryptocurrency as collateral to validate transactions, eliminating the need for energy-intensive computations. This transition is projected to reduce Ethereum's energy consumption by up to 99%, significantly mitigating its environmental footprint.

Moreover, Layerk-rollups and Optimistic Rollups further enhance scalability and efficiency [23]. These technologies enable off-chain transaction processing, reducing the computational burden on the main blockchain. This not only decreases energy consumption but also lowers transaction costs, making NFTs more accessible to a wider audience. Despite these advancements, challenges have yet to transition to PoS or implement sustainable alternatives. The adoption of PoS and similar technologies across all NFT platforms is crucial for achieving a greener blockchain ecosystem. For Malaysian artists and cultural institutions, prioritizing sustainable platforms will be essential for balancing innovation with environmental responsibility.

4.4 Summary of Finding

The findings from this study highlight the transformative potential of blockchain technology and smart contracts for the preservation of cultural heritage. By encoding critical metadata about the origin, history, and cultural significance of artifacts, blockchain ensures that Malaysian cultural heritage can be protected, authenticated, and shared with future generations in a transparent and immutable manner. Despite the technical challenges, such as data storage limitations, interoperability, and ethical concerns, the use of blockchain presents an innovative way to digitize, preserve, and commercialize cultural heritage in a way that benefits both artists and cultural institutions.

5. Discussion

5.1 Benefits of Smart Contracts in Promoting Malaysian Arts

Smart contracts significantly impact the Malaysian arts sector by automating royalties and ensuring secure transactions. As highlighted in Section 2.2, their transparency, security, and efficiency enable sustainable financial models for artists and institutions.

5.1.1 Automation of royalty payments

By embedding royalty logic into NFTs, smart contracts ensure that artists automatically receive a percentage of resales without intermediaries, as discussed in Section 2.2.1. This feature guarantees that artists continuously benefit financially from the appreciation of their digital works, even when ownership changes over time. The mathematical model used for calculating these royalties is based on DLT and cryptographic principles that provide transparency and immutability. For instance, using the formula in Eq. (10):

$$R_n = r \times P_n \quad (10)$$

Where R_n represents the royalty earned by the artist in the $n-th$ transaction, r is the royalty rate, and P_n is the price during the resale. By ensuring the automatic execution of this formula within the smart contract, artists are guaranteed fair compensation from the secondary markets, which is often missed in traditional art sales.

5.1.2 Transparency and decentralization

Another major benefit of smart contracts is their ability to operate within a decentralized environment. Since transactions are executed on the blockchain and recorded on a public ledger, all operations - whether sales or royalty payments – are verifiable and traceable by any participant in the network. This transparency ensures trust between buyers, sellers, and artists, thus promoting a fairer digital marketplace.

5.1.3 Preservation of cultural heritage

For Malaysian cultural institutions, smart contracts enable the tokenization of traditional art forms, such as *batik*, *wayang kulit*, or wood carving, while ensuring that the digital representations remain under the control of the institution. Metadata related to the origin, authorship, and historical significance of these artworks can be immutably recorded on the blockchain, ensuring that future generations will have access to authentic records of Malaysia's cultural heritage. Additionally, the automation of revenue streams through smart contracts enables institutions to allocate resources toward the conservation of these traditional art forms.

5.2 Overcoming Challenges in NFT Adoption

Despite the clear benefits of NFTs and smart contracts, technological and infrastructural challenges must be addressed to ensure broader adoption in Malaysia. As highlighted in Section 4.3.5, transitioning to energy-efficient blockchain systems like PoS significantly reduces environmental concerns, while Layer 2 scaling solutions, such as zk-rollups, enhance scalability and reduce transaction costs [23]. However, the adoption of these technologies must be complemented by user-friendly platforms to lower technical barriers for artists and institutions. The study found that many Malaysian artists are already preparing for the shift to PoS due to its eco-friendly nature and potential for scalability. Moreover, artists and institutions looking to minimize their environmental impact are increasingly considering the Binance Smart Chain, which operates on a Delegated Proof of Stake (DPoS) system, thus consuming less energy per transaction.

The scalability of blockchain platforms is another significant challenge. As NFT adoption grows, networks like Ethereum have experienced congestion, resulting in high gas fees and slow transaction times. These issues pose barriers, especially for artists selling NFTs at lower price points, as the transaction costs can often exceed the value of the artwork itself. One potential solution discussed in the study is the adoption of Layer 2 scaling solutions, such as zk-rollups and Optimistic Rollups, which allow for more transactions to be processed off-chain before being settled on the main blockchain [23]. These Layer 2 solutions can significantly reduce both transaction costs and processing times, making NFTs more accessible for Malaysian artists. However, the integration of Layer 2 solutions remains in its early stages and will require further development for widespread adoption.

Another challenge identified in the study is the technical complexity involved in minting and selling NFTs. Artists often lack the technical knowledge to deploy smart contracts or interact directly with the blockchain. Instead, they rely on third-party platforms that abstract away the complexities of smart contract deployment, which can introduce additional fees and reduce the artists' control over their work. Efforts to create more user-friendly platforms that integrate drag-and-drop functionality and simplified smart contract interfaces are underway. Still, until these solutions become widely available, technical barriers will continue to hinder NFT adoption among less tech-savvy artists.

5.3 Legal and Ethical Considerations

The legal framework surrounding NFTs and smart contracts is still in its nascent stages, particularly in Malaysia. Several legal and ethical concerns must be addressed before NFTs can be fully embraced by the Malaysian art community. One of the primary legal challenges associated with NFTs is the issue of intellectual property (IP) rights. While NFTs provide proof of ownership over a digital asset, they do not necessarily grant the holder any copyright over the underlying work. For instance, purchasing an NFT of a digital artwork does not automatically allow the buyer to reproduce or distribute the work without the permission of the artist. The study found that many Malaysian artists are unaware of the distinction between ownership and copyright when selling NFTs, leading to potential legal disputes. To mitigate these risks, smart contracts need to clearly define usage rights and explicitly state what the NFT holder is allowed to do with the asset (e.g., display it in private collections or resell it). Without clear legal frameworks, artists and collectors alike are exposed to the risk of copyright infringement.

Furthermore, the issue of unauthorized duplication of digital assets was another major concern identified in the study. While NFTs can guarantee ownership, they do not prevent the copying or duplication of the underlying digital work. For instance, an artist's work may be tokenized without their consent, or an NFT buyer may attempt to create unauthorized copies of the artwork. Smart contracts can help address this issue by embedding legal protections and copyright enforcement mechanisms into the token itself. For example, smart contracts can ensure that any unauthorized reproduction or distribution of the asset results in penalties or revocation of ownership rights. However, the enforcement of these mechanisms will depend on the development of international regulations that govern the use of NFTs across different jurisdictions.

In conclusion, while smart contracts and NFTs present numerous benefits for Malaysian artists and cultural institutions, there are still significant technical challenges**,** energy consumption issues, and legal ambiguities that must be resolved for broader adoption. By addressing these concerns through scalable blockchain technologies, eco-friendly consensus mechanisms, and the development of clear legal frameworks**,** the Malaysian art sector can fully leverage the transformative potential of NFTs and smart contracts to promote both financial sustainability and cultural preservation.

6. Conclusions

This paper analyzed the technology that provides NFT which is SmartContract that can be used to reinvent Malaysian art and cultural heritage. NFTs provide a decentralized, transparent, and secure approach to manage ownership transfers, royalty payments, and transaction verifications through the use of blockchain technology and cryptographic security protocols. This study has pointed out some important technical advantages and disadvantages. Automatic ownership transfers and royalties are among some of the keys. Smart contracts also automate some of the most important

processes behind NFT sales — transferring ownership, paying royalties, etc. These contracts which are deployed on decentralized blockchain platforms for example Ethereum and Binance Smart Chain, are self-executing and make sure artists always get a share of the sale each time their work is resold. Together, the mathematical models shown in this paper prove that royalty distribution models can secure artists a percentage of any resale and thus, model an ongoing stream of revenue. For instance, the model $R_n = r \, \mathrm{X} \, P_n$ ensures that artists receive royalties in an automated, immutable manner without the need for intermediaries. Furthermore, smart contracts offer secure and transparent ownership verification, ensuring that all transactions and transfers are recorded on the blockchain-distributed ledger. This immutability helps to prevent fraud and guarantees the authenticity of digital assets, which is essential in preserving the cultural and historical significance of Malaysian heritage.

Although apparent potential impacts of smart contracts exist, the authors developed their research with particular points to note; there are considerable and technical challenges to current blockchain infrastructure, particularly regarding environmental sustainability and scalability. Proof of Work (PoW) networks like Ethereum, face serious scalability issues and are very energy-draining. High gas prices and considerably slow transaction speeds become an impediment to artists or institutions that want to touch base with NFTs, especially from conference nations like Malaysia when there is network congestion. The only way to cut through these roadblocks, of course, is shifting toward low-impact consensus mechanisms such as PoS. ETH 2.0 will reduce energy consumption by as much as 99%, thereby improving the sustainability of NFT within a Web 3 ecosystem. Additionally, there are Layer 2 solutions such as zk-rollups and Optimistic Rollups that can scale the work performed on the chain by only submitting the output of transactions which greatly reduces cost [23]. The priority of future research should be to make these technologies work well so that NFTs are a useful tool for various Malaysian artists and institutions.

Other technical benefits and challenges include cryptographic security and integrity of data. Cryptographic security built into smart contracts makes digital transactions secure with integrity and confidentiality. Techniques like ECC and SHA-256 hashing mean everything when it comes to the verification of the ownership and origin of NFTs. By implication, a tamper-proof record of true ownership is prospective in maintaining such assets over a very long time, as heritage assets get tokenized by Malaysian cultural institutions. Blockchain's decentralized nature guarantees a situation where no one party can alter data once it gets recorded, setting up a strong framework to protect digital cultural heritage in its authentic form. Furthermore, smart contracts allow the function to encode rich metadata directly into the token to ensure that crucial information about the origin, authorship, and cultural context in which any particular digital asset took birth gets invaluably time-stamped and remains accessible for times to come. This is of particular importance with traditional knowledge and Indigenous cultural expressions, which are particularly vulnerable to misappropriation or distortion in digital forms.

Traditional knowledge and indigenous cultural expressions need to be adequately protected, as these are the ones facing the highest chances of being commercially exploited or misrepresented in their digital forms. Some studies have applied digital cultural heritage aspects in their applications such as [28,29]. One relevant finding of this study is that there is sufficient demand for a comprehensive legal framework concerning the use of NFTs and smart contracts in Malaysia. While the NFT applications are highly encouraging in the field of artwork, the legal status of IP and copyright protection is not clear. There are gaps in the extortion of copyright law through smart contracts presently, especially in unauthorized duplication of digital assets. The paper has called for clear legal guidelines that will protect Malaysian artists and cultural institutions to ensure that the intellectual property rights associated with NFTs are preserved. Besides, the commercialization of cultural heritage has also got ethical issues that must be addressed. This means that cultural institutions in

Malaysia should ensure tokenization respects the cultural sensitivities of the local communities and does not alienate them through commodification or exploitation of their traditional heritage. Integration of smart contract-based copyright protections will be one of the key features in preventing the unauthorized use or reproduction of tokenized cultural assets.

NFTs and smart contracts in the Malaysian cultural economy have a great future, but there are some developments that we need before they can continue to grow. First, blockchain platforms need to be developed with energy efficiency. As the blockchain network battle continues, alternative greener protocols such as PoS and DPoS should be used to lessen the environmental effect of NFTs being used by thousands of end consumers. Second, Layer 2 scaling solutions will remain the most critical factor that will enable NFTs to be scalable and none of the artists and buyers need to pay a large amount as a transaction fee. This takes the pressure off the main blockchain networks which may facilitate more rapid and less expensive transactions. This will be even more crucial as Malaysian Artists tokenise their work and find an international audience. Last but not least, we need a workable legal framework to enforce access rights of creators when the intellectual property is embedded in these NFTs. Regulations must be developed to balance maintaining copyright enforcement against cultural considerations of the digital creation and exchange of these cultural digital assets – a sweet spot that only policymakers, technologists, and cultural institutions can arrive at collectively.

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