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Salsal: blockchain for vetting cultural object collections

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Abstract

Many modern cultural object collections suffer from the problem of being obtained in unethical and illegal circumstances. Additionally, information about collections, including their status, object descriptions, and other data need up-to-date information presented to users. We propose a novel blockchain tool called Salsal that enables the vetting of objects, individually or as part of more extensive collections, to meet required ethical and legal guidelines while informing users about relevant information regarding collections. Blockchain provides a better and more rapid way for users to know about collections using a decentralized and immutable ledger technology. Blockchain can be used to incentivize or even pressure collections to vet their objects for ethical and legal guidelines that can benefit the public who use object collections. The prototype software we have made is presented and compared to other blockchains, with code and demonstration provided. We present how our blockchain can enable benefit, providing a useful vetting process for cultural objects, and allowing a user community to contribute to collections in a transparent and secure manner.

Keywords Blockchain, Archaeology, NFTs, Heritage, Databases

Introduction

Cultural objects, including those in museums or other institutions, have increasingly been scrutinized by academics and the public [1, 2]. Concerns regarding how collections have been obtained and if they meet current ethical and legal standards are among some considerations [3]. Globally, heritage is facing more significant threats; cultural objects have been stolen and often used to fund various other illegal or violent activities [4, 5]. Conflict and looting have greatly affected and damaged heritage in countries impacted by events. Tracking objects looted in war or other civil conflict has proven to be a persistent problem. Other concerns include cultural object collections, particularly for heritage specialists and the public, having inequalities in access and ownership. Given these concerns, increasingly the wider public expects heritage collections in museums or other institutions to be ethical and obtained legally. The public may then require a way in which the current known status of objects' legality, how they were obtained, and other qualities, such as conservation and current location, be made evident.

A potentially significant solution that addresses such concerns for cultural object collections is to urge, encourage, or even pressure collectors to share their collections with experts to enable legal and ethical checks while providing real-time recording and information updates about given collections. One method that can aid in this endeavor is to use blockchain technologies that provides accurate recording of object information and to share collections' data with relevant parties, enabling

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necessary vetting and even public pressure to share how collections were obtained.

Blockchain technologies, or Distributed Ledger Technology (DLT), act as shared databases, providing a method for tracking, checking, and updating information [6, 7]. This is accomplished by recording a series of previous versions of object files and history for specific objects, while sharing them among experts and interested communities. For cultural object collections, we propose that the technology be used to pressure or incentivize collections to share information about how they were obtained and combat the illegal trade in cultural objects, as objects are vetted and markers of ethically and legally obtained items can be indicated by a community for given collections. The blockchain itself can act as a way to convince those not vetted to undergo vetting to gain more comprehensive community approval; community involvement around a blockchain creates social or even economic incentives to vet given collections. Overall, addressing challenges related to ethical and legal acquisition of cultural objects, blockchain technology is positioned as a solution to ensure transparency and trust in the cultural heritage sector.

Simply recording cultural object collections would not be different than most standard databases. However, some requirements are needed if collections are to be shared across a broader community that encourages greater adoption of ethical and legal principles. Namely, these can be summarized in the following:

1) Getting collectors to vet and share their collections so that they can be ethically or even legally approved;
2) The collections need to be evaluated by relevant experts to verify the life history of objects;
3) Real-time and updated information about objects (e.g., missing, damaged, conserved object or not, or other data) should be enabled as information needs to be accessible to relevant parties.

Using blockchain technologies appears to be a way in which a chain of previous versions of given object files and objects' histories can be recorded and shared among relevant experts and collectors. This allows one to track, vet, and update relevant information about cultural objects without having a centrally managed system, as many cultural institutions currently use, where users can access such a system. The benefit of this is it enables a larger pool of contributors to update information and knowledge about cultural objects. Furthermore, blockchain could incentivize collections by providing access to non-fungible tokens (NFTs) for specific objects and/or collections, which could be sold to raise revenue. Current solutions, such as centralized databases, do not enable an easy participatory community to assist with cultural object vetting. There is a need for a decentralized, secure, and participatory system that is offered by blockchain to aid with tracking and vetting of cultural objects.

Based on this, we propose developing a novel blockchain tool we call Salsal. This tool enables sharing, storage, and investigation of cultural object collections. This includes individual or multiple objects provided by different collectors, such as museums and university collections. The purpose is to use such a tool to verify and vet given collections to determine if part or all of the collections have been obtained in a legal and/or ethical manner. Salsal helps collectors validate that their collections comply with given standards, particularly as they change. Those interested in the collections, such as a collections' user community, could obtain real-time information about the collections, including the status of objects, such as their conservation state. Another novel benefit for cultural heritage is the tool enables NFTs to be included for collections, where users sell and use proceeds from NFTs to fund their collections, including their maintenance. This provides incentives and helps to fund cultural heritage specialists to manage their collections and develop blockchain as a long-term solution for cultural object management.

The below sections present background discussing the need for a blockchain solution based on current needs in cultural heritage and object management. The current state of the art in cultural heritage and blockchain along with what solutions are offered are discussed. We then present our system developed that addresses the needs as outlined in the background. The system application of this blockchain tool are given, along with how it compares to other tools used in heritage and other areas. A discussion that highlights how we address key challenges and needs within cultural heritage and object management is presented.

Background and literature review

Need for object tracking

Demonstrating cultural object collections have been obtained ethically and have not been stolen has been difficult for many museums and object collections in various countries and regions. Cultural objects have often been illegally appropriated as byproducts of war, occupation, and conflict; events have witnessed this over the last two decades in places such as the Middle East (e.g., Iraq and Syria) [5, 8]. However, looting and war are just one way objects are obtained illegally. Many ethical considerations are of interest to many collection users. Existing older collections, including those in minor and major museums, are being reassessed for how they were ethically obtained [9]. Well-known items such as the Benin bronzes or Parthenon (Elgin) marbles have created debate on the circumstances in which they were obtained [10, 11]. More commonly, but perhaps with less media attention, smaller or less known museums and collections, including private collections, are being questioned regarding the legal or ethical circumstances in which objects were obtained, even if the collections are decades old [2, 12–14]. Whether objects were obtained legally or not, ethical guidelines are shifting such that museums and object collections are increasingly expected to have obtained their objects in ways that do not reflect inequality and subjugation of native populations [15, 16]. Even if objects were obtained in a manner that was deemed ethical, object care is an essential part of continued ethical management of collections, requiring monitoring and updates on cultural objects' status [17]. Systematic looting and growth of the cultural object market means that legal, although potentially unethical, and illegal sales of objects, often in the context of conflict, puts additional reasons to monitor and vet museums and other collections [5, 18–20]. Cultural property obtained, particularly in the context of conflict, could also fund violence and other socially damaging activities beyond the destruction of heritage [21]. These reasons create a need to understand the life histories of objects and understand how objects were obtained.

Blockchain use in heritage and related areas

A recent literature review has indicated that in cultural heritage, blockchain has been used for purposes such as enabling provenance and authenticity verification, demonstrating rights and ownership rights management for objects, and digital ownership and protection of cultural objects [22]. Papers collectively suggest that blockchain technology can offer various benefits in cultural heritage management, including increased transparency, authenticity, and efficiency. Digitization has included digital preservation and creation of digital objects that are unique, including NFTs [23, 24]. For museums, blockchain technology offers a way to also monitor the location and lending of objects to other institutions [25]. Others have also seen blockchain as a way to empower cultural or art providers by creating digital currencies and means to manage their welfare outside of the conventional art market [26]. Trček [27] suggests that blockchain can help preserve cultural heritage by providing a decentralized and immutable system that can authenticate cultural objects and prevent fraud. Overall, there has been more use of blockchain in fine art and some cultural industries rather than other aspects of cultural heritage, such as museums and object collections used by the wider public [28, 29].

While the use of blockchain is still relatively rare in cultural institutions, museums and object collections have been contemplating or even beginning to implement blockchain in operations. Gallagher and Fuentes [30] found the British Museum's collaboration with its partners inefficient, such as individual collectors and universities. They state that there is no centralized market where an art piece's transaction history is tracked. To solve this issue, they suggest a solution where a blockchain-based public ledger is shared between collectors and museums for tracking object locations. In 2019, the British Museums loaned about 2,800 items to over 100 worldwide locations. A solution to tracking these objects is to use a public ledger technology containing the artifacts' histories. The first publicly declared Blockchain system for archaeology is KAPU, which attempts to create a decentralized ledger technology that preserves human history [31]. It uses Delegated Proof of Stake; in this case, only 51 people are responsible for approving transactions rather than the whole network. The system appears to be at an early stage, but it is designed around using blockchain to better protect heritage through a shared network of decentralized users. Whitekar et al. [32] proposed a blockchain system that attempts to disincentivize the sale of looted objects through a managed system that encourages shared stewardship, ownership, and display of objects. This could act as a way to solve disputed objects, where tokens and revenue sharing could be possible through the blockchain.

Some prominent database tools used in cultural heritage include decentralized and centralized systems; this include blockchain as well as other types of databases and NFT tools. The KAPU system was created to make collections immutable and everlasting, employing a Delegated Proof-of-Stake (DPoS) system, which eliminates the need for the whole network to validate a transaction, as opposed to the standard proof-of-stake (POS) paradigm [33]. The DPoS architecture, on the other hand, only requires a limited number of delegates to validate a transaction. In addition to KAPU, Codex is one tool which provides a way to create NFTs. As an NFT-based system, Codex uses blockchain technology to secure its platform. Subsequently, it also deploys cryptography. Users sign up or create a profile for Codex accounts with their existing Wallet and email address [34]. Another option is S-Museum; this provides an easy solution for managing museums with modules for collection management and territorial heritage management. S-Museum utilizes SQL solution to store data in a value store with indexation in full-text [35]. The Canadian Heritage Information Network (CHIN) System is a centralized system owned by the Canadian Special Operating Agency for offering valuable collections management resources. This system enables Canadian museums to record, manage, and share data concerning collections [36].

Given the relatively limited use of blockchain in cultural heritage, we investigated similar areas to gain insight on how blockchain has been used and to indicate how to best develop our system. The gem industry has had similar circumstances in having a fragmented community, but with clients interested in knowing the ethical and legal status of objects sold [37]. In this industry, knowing current provenance, where and how gem materials are mined and manufactured, and general life-history of objects is seen as necessary but historically has been difficult [38]. Tracking object history and providing verifiable detail about objects has been critical in the development of blockchain for this industry [37, 39, 40]. The industry is often investigated by different organizations concerned with gemstones' origins and sustainability footprint that customers want to know more about. An example blockchain solution is known as the "Diamond Time-Lapse Protocol" [41]; this is created to confirm the legitimacy and keeping of diamonds. A ledger is created that displays data on where the diamond was mined, the current attributes of the gem, processes that have been used on the gem, such as polishing, the craftsperson who fashioned the gem, and certification, such as authenticity or grade.

In blockchain solutions for the gem industry as given in the literature and in other supply chain literature reviews [39–42], we determine there are different ways to trace objects, and they can be used on gems to note their provenance to increase the industry's transparency with users and customers. This also includes using blockchain at different life cycle stages for objects:

(a) Mining stage: After mining is done and a rough stone is obtained, it is added to the blockchain with data and receives a unique ID.
(b) Cutting stage: The stone is cut by a gem cutter and polished. NThe blockchain is updated with new data concerning the stone.
(c) Retail item stage; the stone is bought by a jeweler and used for a necklace. Now, the data on this manufactured necklace will be stored on the blockchain.
(d) Consumer stage: The necklace reaches the customer. Documentation of the ring's history hosted on a platform can be given to the customer, and the customer's data can be stored on the blockchain.

This literature demonstrates that the technology provides a method to trace objects permanently and in different states. Similarly, cultural property could be traced back for ownership and life history, which can be permanently recorded. In other words, there is potentially an unchangeable record for objects' histories. Tracking provenance has been one way in creating greater trust in the gem industry, particularly as the industry has had to deal with ethical and legal issues comparable to cultural heritage. Blockchain offers a way in which cultural heritage can also engage its user community while building trust on critical issues such as provenance history.

Blockchain solutions for object management

Given the cultural and economic value of cultural objects, there is a need to find an adequate storage and management systems that track objects and their current state, demonstrate their origin, and provide information on their ethical/legal status to a user community and interest groups. Current efforts in cultural heritage are largely not facilitating user participation that enables a way to track the status of given cultural objects. Additionally, community-based vetting of objects is needed to build confidence in cultural object collections to show that they have been obtained in a legal and/or ethical manner. Blockchain is a potential solution, as the technology uses shared, immutable ledgers that facilitate recording transactions and tracking assets in a business network [6, 32, 43]. Real-time information is critical to interested parties in many fields, including those interested in cultural object collections. Fast and accurate information received benefits interested parties, including those who verify objects' ethical/legal status and collectors themselves who receive this information. For those verifying objects, the current status and sequence of how objects were obtained and moved allows an accurate reconstruction of the object's history and provenance, which is critical in the vetting process [32, 37]. For collectors, object history is essential for establishing credibility with the public, including the user community that seeks to access collections for research or interest. In contrast, updates on the state of the object allow the public or users to know about the current status of the object, such as the need for conservation.

Blockchain is ideal for delivering that information because it provides immediate, shared, and completely transparent information stored on an immutable ledger that can be accessed by network members [44]. A blockchain network could track object histories, current conservation status, legal/ethical designation and more. The legal/ethical designation could follow or be based on established guidelines such as the International Council of Museums (ICOM) ethical guidelines [45]. Because members share a single view of the state of given data, users can see all transaction details, from end-to-end, giving greater confidence and new efficiencies and opportunities as data about objects evolve. An advantage of blockchain [32] is that a person can trust what is on the blockchain without needing to place their trust on a central authority. Blockchain also supports immutability, which means that data, once it is written, cannot be erased or replaced. Immutability prevents data tampering within the network, whereas blockchain for business uses a shared and immutable ledger that members can only access with permission. Network members control what information each organization or member may see, including actions each can take. This is useful for shared cultural objects, as data tampering could harm the understanding of the state of given objects [46].

Blockchain features include enhanced security, greater transparency, and instant traceability, which are, along with the other attributes mentioned, potentially useful for cultural object collections [25, 47]. Blockchain could build trust in a shared network where users value these qualities. Beyond matters of trust, blockchain delivers other business benefits, including cost savings from increased speed, efficiency, and automation. By greatly reducing paperwork and errors, blockchain significantly reduces overhead and transaction costs, reducing or eliminating the need for third parties or intermediaries to verify transactions.

Methodology

Below, we detail our approach that addresses the needs outlined above for cultural object management. We discuss our technology choices, system and goals, and our design. We provide benchmarking to compare what we develop to other common tools. We demonstrate how Salsal contributes to the preservation of cultural heritage by serving as a tool that adds value by aligning with guidelines, ethical considerations, and the need for monitoring and updating object collections. Pseudocode is provided in the appendix to help demonstrate the overall software structure; a video link is also given that demonstrates the tool's use.

Choice of Ethereum

The first choice we needed to make is the underlying technology; we chose Ethereum for the Salsal Blockchain based on several factors. There are clear benefits in choosing Ethereum which provide advantages and utility to our tool. Firstly, Ethereum is one of the most established blockchain platforms, with a large community and development ecosystem [48, 49]. As a result, Ethereum has proven to be a reliable and secure platform for deploying decentralized applications (dApps) and smart contracts [50]. Secondly, Ethereum's native token, Ether (ETH), is one of the most widely used cryptocurrencies and can be easily traded on major exchanges, providing liquidity to our blockchain network [51]. While it is true that Ethereum's fees can be higher during periods of high network activity, we believe that the benefits of using a public blockchain outweigh the costs of using cryptocurrency that is in limited circulation. Furthermore, public blockchains provide transparency and decentralization, ensuring that no single entity has control over the network [50]. This is particularly important for our proposed Salsal tool, which aims to enable the vetting of cultural object collections in an ethical and transparent manner. By using a public blockchain like Ethereum, we can ensure that the vetting process is open and transparent for users, enabling a wider audience to verify that the collections have been vetted according to ethical and legal guidelines. In addition, the consortium-type blockchains, such as Hyperledger-Fabric, can provide greater control over the network, as they are designed for private, permissioned networks [49]. A public blockchain like Ethereum is more suitable for our proposed Salsal tool because it provides overall greater transparency and decentralization, which are key reasons in why cultural institutions may want to adopt blockchain [52].

In our tool, all users can view the collections, but we give access to the collectors and experts to upload and verify the collections. Therefore, we consider Salsal as a hybrid implementation of Ethereum. There are some potential benefits to using Ethereum as a hybrid blockchain. For one, it can provide greater control and privacy for the participants in the network. Private blockchains are designed to be permissioned networks, where only authorized participants can access the network. This can provide greater security and control for the participants, as they can be assured that no unauthorized parties can access the network. Another potential benefit of using Ethereum as a private blockchain is that it can enable greater scalability and performance. By using a private blockchain, the network can be optimized for the specific use case, enabling faster transaction processing and greater throughput [53]. This can be particularly important for enterprise applications, where high transaction volumes and low latency are critical. Furthermore, there are also some potential benefits to using Ethereum as a public blockchain. One of the main benefits of public blockchains is their transparency and decentralization, which can provide greater trust and accountability [50]. Ethereum has upgraded to the Proof-of-Stake (PoS) consensus protocol, which relies on validators rather than miners. Validators are users who stake their Ethereum (ETH) cryptocurrency and are responsible for verifying transactions. In order to become a validator, a user must stake at least 32 ETH. Once a block is created, two-thirds of the validators must agree on the transaction before it is confirmed. The move to the PoS protocol offers several advantages, including reduced energy consumption and greater scalability. By using validators instead of miners, the system can operate more efficiently, allowing for faster and more cost-effective transaction processing [54].

There are existing examples of hybrid implementations of Ethereum that combine public and private components. For instance, Quorum is declared to be "a permissioned implementation of Ethereum that supports transaction and contract privacy [55]." It is designed to be used in enterprise settings and includes features such as privacy and permissioning. Hyperledger Besu is an open-source Ethereum client that can be used to build both public and private networks. According to the official Hyperledger Besu documentation, the client includes features such as privacy and permissioning, allowing organizations to create private, and permissioned networks that are interoperable with the public Ethereum network [56]. Another example is Geth, which is an Ethereum client that can be used to connect to both public and private networks. According to the official Geth documentation, the client includes features such as mining, peer-to-peer networking, and contract deployment, making it suitable for both public and private use cases [57].

Overall system and goals

Below, we discuss our approach to creating a blockchain for cultural object collections that enables a novel process to vet and share cultural object data. The system is made for museums and other collections, such as university collections, with experts and others invited to view or participate in verifying objects' legal and ethical status. The code is provided as part of this contribution. The system's features contribute to solving real-world challenges in cultural heritage collections, providing a secure and transparent vetting process, ownership tracking, and additional financial incentives through NFTs.

Our system serves two primary functions: recording the provenance of collections and verifying their authenticity through expert evaluation. When first submitting a collection, a collector provides details about their collection using the web application. Multiple experts will then review the information and decide if the collection is authentic or not. If the collection is verified, the collector can convert it into a unique non-fungible token (NFT). These NFTs serve as proof of ownership for each collection as well as provide potential financial benefits, allowing collectors to transfer ownership securely and track changes in ownership over time. The system offers several benefits, including the elimination of data tampering risks, the ability for multiple experts from around the world to verify a collection, and the use of NFTs. By utilizing blockchain technology, we can provide collectors and the public with a secure, transparent, and reliable way to track the authenticity and ownership of collections [58].

There are several key qualities that we believe make it a valuable and novel contribution to cultural heritage collections and based on the needs outlined in the background:

1. It allows collectors to upload and store data about their collections, which include one or multiple objects, including documentation on objects' histories and original provenance, and provide updates on the current status.
2. Collections are vetted to have been legally and ethically obtained. This verification will be done by experts who can also upload documentation as needed about investigated items.
3. It uses blockchain technology to track the current owner of a collection, so when ownership changes, it will be permanently recorded.
4. It allows collections and objects to obtain badges that denote collections have been vetted for ethical and legal status. The ethical or legal guideline could be adapted based on a consensus or well-known guidelines such as ICOM's Code of Ethics.
5. It allows collections to make available or trade non-fungible tokens (NFTs) to incentivize collections to upload and verify their legal and ethical status.

In our tool, a collector adds their collection and object details, such as provenance and object condition, to the system. This will be received as a verification task by the expert, who will provide their judgment on given objects and provenance while also being able to upload supporting documentation or other information. The life history of objects, including different stages where the object may have been, can also be verified. The collection's status after verification will then be outputted to the collector. Ethical standards, such as ICOM's Code of Ethics, could be used to designate or justify a given status. The public can search for collections and receive data on them. To incentivize use, Salsal provides NFTs as a means for collections to benefit from being on the blockchain. In this case, collectors could trade or sell NFTs to raise funds for collections, but before this is possible, collections have to undergo vetting to enable ethical and legal checks. We propose that ethical and legal checks be performed on all collections, with NFTs being used to help convince people to submit their collections while also using the system's long-term growth to encourage collections not yet vetted to submit and incorporate objects. NFTs also certify digital ownership and authenticity, which are stored publicly on the blockchain for quick verification. There are blockchain platforms such as Polygon or Flow that are more suitable for NFT-type solutions due to their low transaction costs and faster transaction processing speeds [59]. Although our proposed Salsal tool is not primarily focused on NFTs, Ethereum does give greater public exposure and enable wider access for NFT markets. The benefits of using a public blockchain like Ethereum outweigh the benefits of using a potentially aster, lower-cost option.

When transactions are submitted, they are stored in blocks. Clients are responsible for submitting transactions. One key transaction in our system is the 'Upload Collection' transaction - when a Collector uploads his/her collection. Below, we designate key terms used for the system:

1. Collector: Museum specialist or Keeper responsible for cultural objects.
2. Collection: Collector's objects, including individual to groups of objects, being uploaded.
3. Expert: Person who verifies objects' provenance and life history. This could be experts (e.g., archaeologists) in given types of objects, police, law specialists, or others who can inform on the ethical/legal aspects of how given objects were obtained and their origin.
4. User Community: People who use or seek to use collections. They would be interested in making sure a collection is ethical/legal.
5. Peers: These are the keepers of the blockchain and are responsible for its overall viability. This would be a group invited to help assign certification badges that demonstrate ethical/legal designation and maintain the system. They are in charge of reviewing the evidence and information collected by experts.

The Collector will have their private key and it will be used for signing the transaction before it is processed. Inside the blockchain, the transaction's time will be stored and it will also be immutable. The transaction cannot be altered afterward.

After submission of documentation, the main task is to demonstrate the objects' legal and ethical status and update the blockchain with a badge or certification regarding legal/ethical status. Transparency of legal/ethical status is a key value provided by Salsal. We propose using the ICOM Code of Ethics as a general inspiration for certifying an object's ethical/legal status. The badges would be numerical designations ranging from 1–5. In this case, '1' would mean the item(s) obtained followed clear and well-established guidelines in the acquisition or how it was obtained in its life history (e.g., such as the Museum Association guidelines [60]). The designation '2' indicates the object(s) appear to be legal and/or ethical, but documentation is not completely clear, and some doubt is evident in its life history. The designation '3' means there is unclear documentation, and the objects are reasonably likely to have been obtained unethically or illegally. For a designation of '4', the objects are not ethically obtained, at least using given standards, and could be illegally obtained. For items with '5', the objects have clear evidence that they were obtained illegally. Additionally, notes or further elaboration on these designations can be provided as part of the certification to clarify why the designation is given. This then provides a way to easily summarise where the verification of the objects has concluded or is currently at. For instance, a designation of '2' may be given for objects, but the collector may seek to provide more clear information to change the designation to '1'. We recognize there could be other designation formats, and this is simply a proposed option. The system allows other standards to be used. For example, an option could be to split the ethical and legal status of objects and have a certification for each separately. Ethical standards, in particular, are still being debated among professionals and may need more updating as standards change. This certification for ethical/legal status is something the user community should decide when using the system. Ownership change is another important quality where the tool has demonstrable capability (e.g., when one museum gives an object to another).

Software design

In our Ethereum-based tool, smart contracts are used and execute instructions after certain conditions are met [61, 62]. Smart contracts are essential components implemented in Salsal that handle data verification, ownership tracking, and NFT creation. Data verification, ownership tracking, and NFT creation are all discussed and detailed below. In our example, the smart contract can assign ownership of an object to another party after the first owner transfers ether to the new owner. This enables transactions without relying on an authority. Ether is the official currency for transaction fees in our tool [6]. A participant must pay this fee - "gas" - to have his transaction executed and stored on the Blockchain. A transaction occurs like this:

1. A participant starts a transaction request from the Ethereum Virtual Machine (EVM).
2. Other participants on the network will then verify this request and carry out the transaction.
3. A state change occurs on the EVM.
4. This change is spread throughout the network.

Figure 1 shows the workflow of Salsal. First, a Collector submits details for verification. Then, data are stored on Firebase, InterPlanetary File System (IPFS) and are on

Fig. 1 The workflow of the Salsal Blockchain

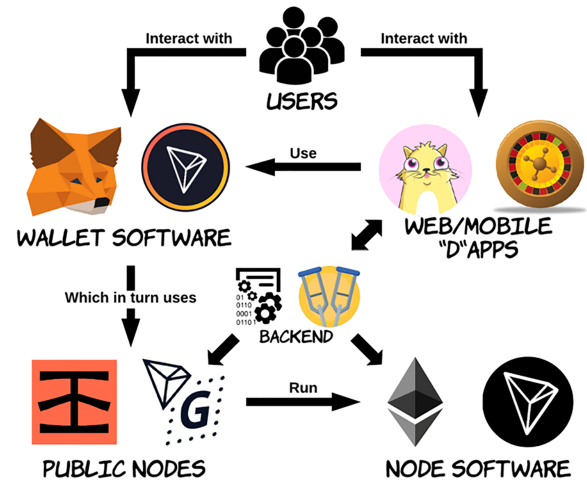

Fig. 2 The dApp architecture developed for the Salsal application that indicates the process of transactions

the blockchain. In the next step, an Expert reviews data and submits verification details about the ethical/legal status of the object. This step could take some time to complete. Data are maintained on Firebase, IPFS and the blockchain during and after this process. Assuming the collection qualifies, the Collector can then turn his/her collection into NFTs. At all stages, data are stored using IPFS; a reference is obtained to documents/images and are stored in the blockchain.

In our case, we build a dApp - a decentralized application (Fig. 2). The decentralized applications use both a front and back end in conjunction with a blockchain network [6].

There are further considerations in the design:

1. Both Collectors and Experts use a web application that utilizes wallet software MetaMask. This integration enables users to interact with the Salsal blockchain using their MetaMask wallet; this provides a user-friendly approach to blockchain interactions between users. Therefore, given the need for a user-friendly approach, our web app (see Availability of Data and Materials) consists of both a front- and back-end.
2. They will interact with MetaMask to obtain an identity and be able to interact with the Ethereum Blockchain. It stores Ethereum addresses and allows the purchase of NFTs.
3. Nodes are used for executing transactions, and you can use public nodes.

As stated, NFTs are deployed to incentivize collectors to use the blockchain; this also helps raise funds to maintain physical collections. In Salsal, verified collections can be converted into NFTs. While NFTs can serve as unique digital tokens that represent ownership of a specific cultural object or collection, they can also potentially have financial value. Collectors can tokenize their collections as NFTs and sell them; Salsal can be used as a platform for a marketplace where collectors can list their NFTs for sale or trade. Rehman et al. [63] state that NFTs represent ownership of unique items. Collectors transfer ownership to another Collector and can do so by "selling" their collection object as an NFT. Physical collection transfers or sales would be between collectors and would be handled privately. A collector who has successfully verified and obtained a high ethical and legal status badge for their collection can tokenize it as an NFT. Transactions are stored in blocks and collectors use private keys to sign transactions, ensuring the immutability and security of these transactions. Additionally, NFTs are useful for owners since they allow only single owners, and due to them being stored on the blockchain, they cannot be tampered with so that ownership data is properly maintained. A token is an instance of a smart contract. Our token contract will contain methods for assigning addresses to collections (which will be represented as tokens).

As Ethereum implements Merkle Trees for efficiently storing the hash inside blocks, we use "Modified Merkel Patricia Trie" as the primary data structure [64]. Our modification and extension of Ethereum's existing data structures helps to suit the specific needs of our tool to cultural heritage collections. Based on this, there are four state tries in Salsal:

1. **World state:** stores account-based information;
2. **Receipt:** records the output of transactions such as its hash and the number of the block;
3. **Account storage:** stores account and contract-based information. It will record how much Ether a Collector or Expert has and how many transactions they participated in;
4. **Transaction:** responsible for recording transactions inside the blockchain.

Account data are not stored in the chain directly. Hashes of the root node - the topmost node of each - are stored inside each block instead [46]. Each block is made of two key parts:

1. **Block header:** contains information such as the hash of the previous block, and timestamp;
2. **Block body:** stores list of transactions and list of uncle blocks. Uncle blocks are leftover blocks after two blocks are created at the same time and one has to be left ou [43].

Data stored would also consist of key characteristics, which are:

1. **Collection ID:** unique identifier/locator for collection;
2. **Collection name:** short-form collection name;
3. **Description:** long-form description;
4. **Current owner:** unique identifier/locator for previous owner;
5. **Previous owner**: unique identifier/locator for previous owner;
6. **Verification status:** rating system based on 1–5 with 5 being clearly ethical/legal as defined by ICOM's Code of Ethics;
7. **Current status:** (e.g., missing/looted, conservation status);
8. **NFT and NFT price:** e.g.,5 ETH.

Benchmarking

Benchmarking is the process of evaluating functions and features of proposed solutions against well-known systems in one or more aspects of their operations. Benchmarking offers essential understanding to help comprehend how the proposed solution compares with similar systems, even if they are in a different business or have a different group of customers. We discuss benchmarking criteria below and this section provides the benchmarking between our tool with the most comparable systems to it:

1. **Solution:** This refers to the name of the blockchain-like system aims to solve.
2. **Technology used:** This includes which technology utilized in the development of the blockchain-like system, is it blockchain or a secure database.
3. **Types of structures:** The architecture of the system, is it centralized or decentralized.
4. **Level of decentralization:** The level of decentralization in the blockchain-like system also matters. This is the extent to which the system is distributed and its nodes operate independently. Decentralization ensures that there is no single point of failure; the system is more resilient. The degree of decentralization can be assessed by examining the number of nodes in the network, the distribution of control among participants, and the potential for a single point of failure. High decentralization could imply a widely distributed network with no single

controlling entity. Low decentralization might suggest a concentration of control in a few entities.

5. **Incentive mechanism:** This refers to the rewards given to participants who contribute to the system's security and maintenance. Incentives could be in the form of tokens, coins, or other valuable assets. The effectiveness of incentive mechanisms can be assessed based on how well they encourage user participation and contribute to the overall goals of the system. High effectiveness implies strong user engagement and motivation; low effectiveness might indicate a lack of incentives or insufficient motivation.
6. **Security level:** Security includes measures such as encryption, consensus protocols, and smart contract audits. We assessed security based on factors such as the robustness of the employed cryptographic algorithms, resistance to attacks (e.g., 51% attacks), and the track record of the underlying blockchain deployed (e.g., Ethereum in Salsal). High security implies resistance to known attacks, adherence to best practices, and a lack of historical security breaches. Low security might indicate vulnerabilities or a history of security incidents.
7. **Throughput:** Throughput refers to the number of transactions that the blockchain-like system can process per second. High throughput is critical for applications that require fast transaction processing, such as payments and trading. Throughput can be measured in transactions per second (TPS) or other relevant metrics, which assess the network's capacity to process transactions. High throughput indicates a scalable system capable of handling a large number of transactions; low throughput might suggest potential bottlenecks.
8. **Energy efficiency:** Energy consumption is a significant concern for blockchain-like systems. Energy efficiency is crucial in reducing the environmental impact of blockchain systems. Energy efficiency could be evaluated based on the consensus algorithm used (e.g., proof-of-stake vs. proof-of-work) and the associated environmental impact. High energy efficiency implies a lower environmental impact; low efficiency might mean a higher energy consumption for network operations.
9. **Price aspect:** The cost of using the blockchain-like system is another criterion for benchmarking. It includes factors such as transaction fees, network fees, and gas prices. The lower the cost the better for users.
10. **Blockchain platform used:** The blockchain platform used in the system include Ethereum, Bitcoin, Binance Smart Chain, and Polkadot.
11. **Consensus protocol:** The consensus protocol is the mechanism used to validate transactions and ensure that the network reaches consensus. Different consensus protocols have varying levels of security, scalability, and energy efficiency.
12. **Ranking:** Benchmarking involves ranking blockchain-like systems based on the criteria above. Overall rankings are based on factors that incorporate the most critical aspects in blockchain tools, which include security, throughput, energy efficiency, and price.

Limitations and benefits of systems

This section presents the description, benefits, and limitations of systems comparable to the proposed solution. Table 1 demonstrates the ranking between the aforementioned system with Salsal, the proposed solution, according to their features. We can see that Salsal blockchain ranks second in level of decentralization, security level, and energy efficiency. It also uses the

Table 1 Benchmarking results based on process described

Criteria	Salsal	Codex	KAPU	S-Museum	CHIN	MineHub	DLT Labs
Technology used	Blockchain	Blockchain	Blockchain	Database	Database	Blockchain	Blockchain
Type of structure	Decentralized	Centralized	Decentralized	Centralized	Centralized	Decentralized	Decentralized
Decentralization Level	High	Low	Medium	N/A	N/A	Medium	High
Incentive Mechanism	Proof of Stake	N/A	Proof of Stake	N/A	N/A	Proof of Work	Proof of Authority
Security Level	Medium	Medium	Medium	High	High	Low	Medium
Throughput	High	High	High	High	High	Low	High
Energy Efficiency	Medium	N/A	High	High	High	Low	Medium
Price Aspect	Medium	Medium	High	N/A	N/A	Low	Medium
Platform Used	Ethereum	N/A	EOS	N/A	N/A	Bitcoin	Ethereum
Consensus Protocol	Proof of Stake	N/A	Proof of Stake	N/A	N/A	Proof of Work	Proof of Authority
Ranking	2	7	3	5	6	1	4

Ethereum Proof of Stake consensus protocol, which is more energy-efficient than the Proof of Work consensus protocol used by Bitcoin. However, it ranks lower in throughput, which is a concern for applications that require high transaction processing speeds. In addition, its incentive mechanism is not mentioned, which could affect adoption by users and miners.

1. **Codex:** For Codex, users can create Codex Record/NFT by uploading images and other supporting documentation. After creating records, users can secure their collections using blockchain technology. Users can sell items by transferring Codex Records to the buyer. Codex allows users to create records explaining the collection's current condition as well as recent events. However, it does not offer means of verifying the accuracy of the details provided by the user. Besides the absence of verifiability mechanisms, Codex also experiences similar limitations as our system since it is based on blockchain technology. The limitations of blockchain technology common between Codex and our system include difficulties in changing smart contracts and lack of adequate legal regulations.
2. **KAPU:** KAPU appears to be the most similar tool to this work. The KAPU network has 51 founding delegates who are elected via a decentralized voting system. These individuals are in charge of validating transactions and maintaining the blockchain; they are compensated for their services. If one of the delegates fails to execute his/her duties, the network may withdraw its votes and elect a new delegate. Each archaeological object will be documented and timestamped. KAPU success is attributable to the ARK team, which is one of the best-performing cryptographic capabilities in the market. The data concerning collections is managed using a shared system. This system enables users to share data about the collection securely, making them easily accessible to system users. The immutability of the KAPU can prevent modification to any records. For instance, due to immutability, users might be incapable make amendments to change payment once the transaction has occurred. Although KAPU uses cryptography to secure data concerning collections, it is notable that this approach does not protect against threats emanating from its design, procedures, or operations. For instance, with a shared system, KAPU might experience vulnerabilities in one node that might compromise the entire system despite its use of cryptography.
3. **S-Museum:** S-Museum covers all the needs of museums by primarily allowing cataloging and physical/digital management of finds. Different modules featured in the S-Museum include an event management tool that facilitates users to perform all forms of collection-related projects. S-Museum uses a centralized database that stores data concerning collectibles. In the absence of backups, database failures might render the system useless and unavailable. This limitation does not exist in decentralized and immutable blockchain systems, such as our system, Codex, and KAPU. The S-Museum system is designed for museum institutions, suggesting that independent collectors should collaborate with museums to use the system or protect their collections.
4. **CHIN:** The CHIN database provides a secure content management system (CMS); CHIN is a web-based application with a secure centralized back-end database for storing data concerning collections. CHIN is a resource linked to archaeology, art history, history, art conservation, intellectual property, museum studies, and natural sciences. Users can access these resources by searching the CHIN website. In this case, users are required to know the name of the resources that they want to access. Similar to S-Museum, CHIN also uses a centralized database for storing data concerning collectibles. In the absence of backups, database failures might render the system useless and unavailable. This limitation does not exist in decentralized and immutable blockchain systems, such as our system, Codex, and KAPU.
5. **DLT and MineHub:** One company, DLT Labs, is using blockchain technology to enable trust between companies that share information [65]. Another company, MineHub, leverages blockchain to provide real-time tracking of minerals while maintaining control of data [66]. One of the primary advantages of using DLT and MineHub is they provide transparency and visibility throughout supply chain transactions, which building trust and reduces the risk of fraud or unethical sourcing. They also provide tamper-proof platforms for recording transactions and data, which increases security and reduces the risk of data breaches in transactions. Through automation and streamlining, greater efficiency and reduction in moving items is evident. Accountability: With greater transparency and visibility, DLT and MineHub can hold parties accountable for their actions, reducing the likelihood of fraudulent or unethical behavior. Key challenges include getting all parties involved to adopt these technologies. This requires significant effort and investment to educate and train stakeholders, which can be a significant hurdle. The use of DLT and MineHub can be complex and requires special-

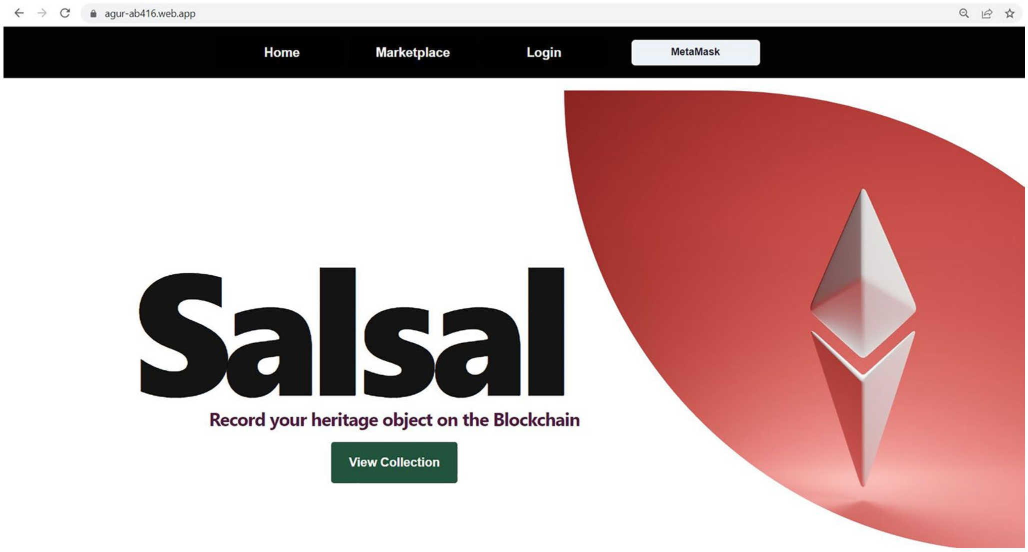

Fig. 3 Home page prototype showing what users first encounter

ized technical knowledge. Another challenge is scalability. As the number of transactions increase, these blockchains can become slower and more expensive to operate, which can limit their usefulness for large-scale applications. With the regulatory environment around blockchain technology still developing, there is uncertainty in using DLT and MineHub. There may be legal and compliance issues that need to be addressed before there is increased adoption.

Demonstration: Salsal and its usage scenarios

This section presents the result of this research that is the Salsal design, prototype, and its usage scenarios. We present an example of coins used in a blockchain, which highlights how cultural objects and collections can be managed and demonstrates the wider value of the approach. The example demonstrates the relevance and applicability of the proposed tool in addressing similar challenges faced by cultural object collections. A video is provided (see Availability of Data and Materials) that helps to demonstrate how Salsal works and the steps involved.

Prototype demonstration

The prototype we have developed provides a front end for users to interact with. After a Collector log in, he/she will be able to upload a collection to the blockchain. An Expert will be allowed to pass his/her judgment on this collection, which will also be updated on the blockchain.

Figure 3 shows the main page we designed using the Balsamiq wireframing tool; this homepage provides an entry point for users who can view collections or chose what options to join depending on the type of user they are (e.g., collector or expert). This entry point provides access to functions and buttons for users that allow visitors to view objects, view their owners and also see object/collection verification, where there is a login function for collectors and experts for them to see objects that need verification. This also allows them to see that objects have been verified before; once objects have been vetted and seen as obtaining a badge equivalent to our '1' designation, collectors can also be allowed to create NFTs and access the NFT marketplace.

Figure 4 shows the key task of uploading collections and information about a given collection being an example of a key task for collectors. Users can upload multiple or single items as part of collections.

Figure 5 shows some of the possible objects that will be available and the information you would be able to get, depending on what had been entered by collectors previously.

The page in Fig. 6 gives access to experts to be able to verify objects, including their legal/ethical status.

Figure 7 gives the approved objects the ability to create NFTs, assuming objects have been deemed ethically/legally acceptable.

Figure 8 provides users with verified objects and the ability to sell given NFTs in a marketplace.

Discussion and conclusions

Recent high profile thefts in cultural institutions such as the British Museum highlight the need to effectively track cultural objects. However, many cultural institutions globally face challenges in tracking

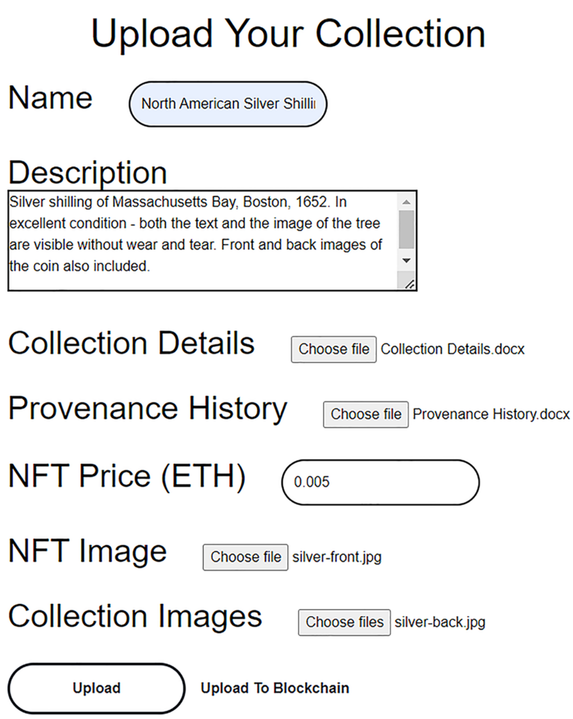

Fig. 4 Page to upload data to the Blockchain

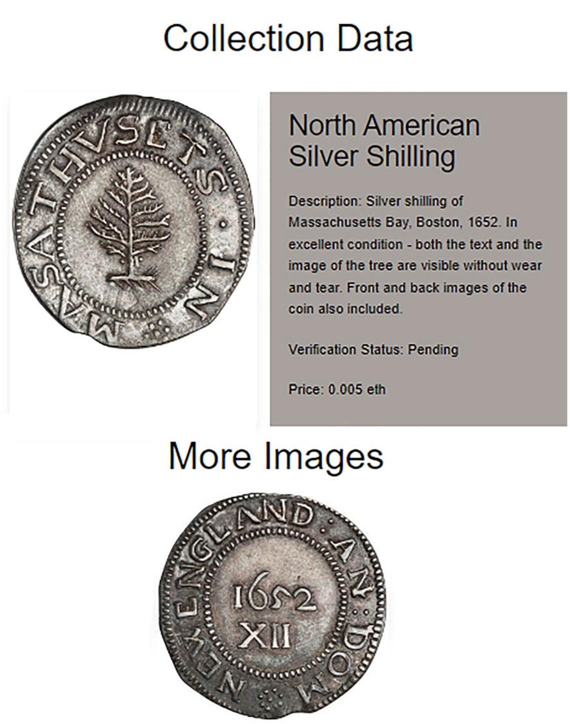

Fig. 5 Displaying objects and their data using the Salsal Blockchain

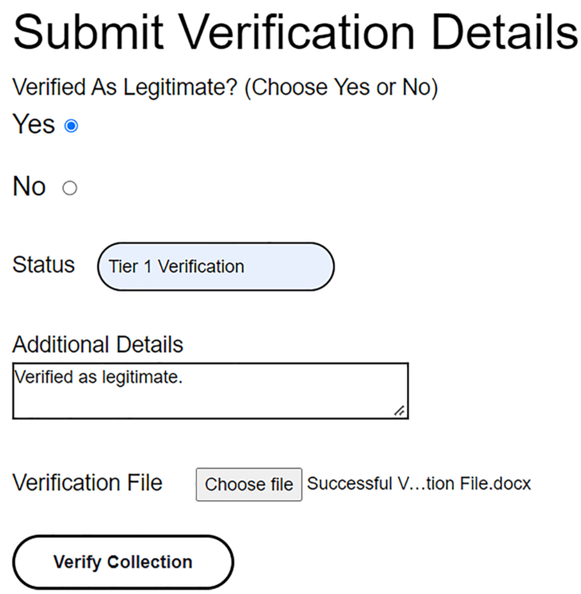

Fig. 6 Expert's page and verification site to approve of object data

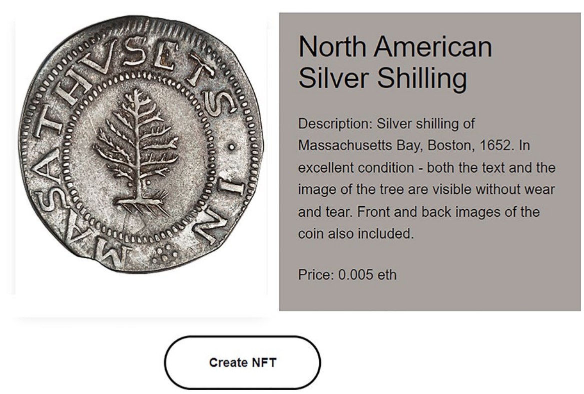

Fig. 7 Page to create NFTs for approved objects

objects within their care. We also demonstrate the ethical and legal challenges cultural object collections are facing. Our solution is to offer a novel blockchain that addresses such challenges while enabling effective object management. Timely sharing of accurate information about objects that allows a clear process to vet and certify cultural objects' legality and ethical status is a need for the cultural heritage community. As a solution, we propose and present a novel blockchain tool to enable a community of experts to provide certification of the ethical and legal status of objects after objects have been uploaded to the blockchain by collectors. Experts are those invited to join and who can provide legal and subject matter expertise regarding given cultural objects and their

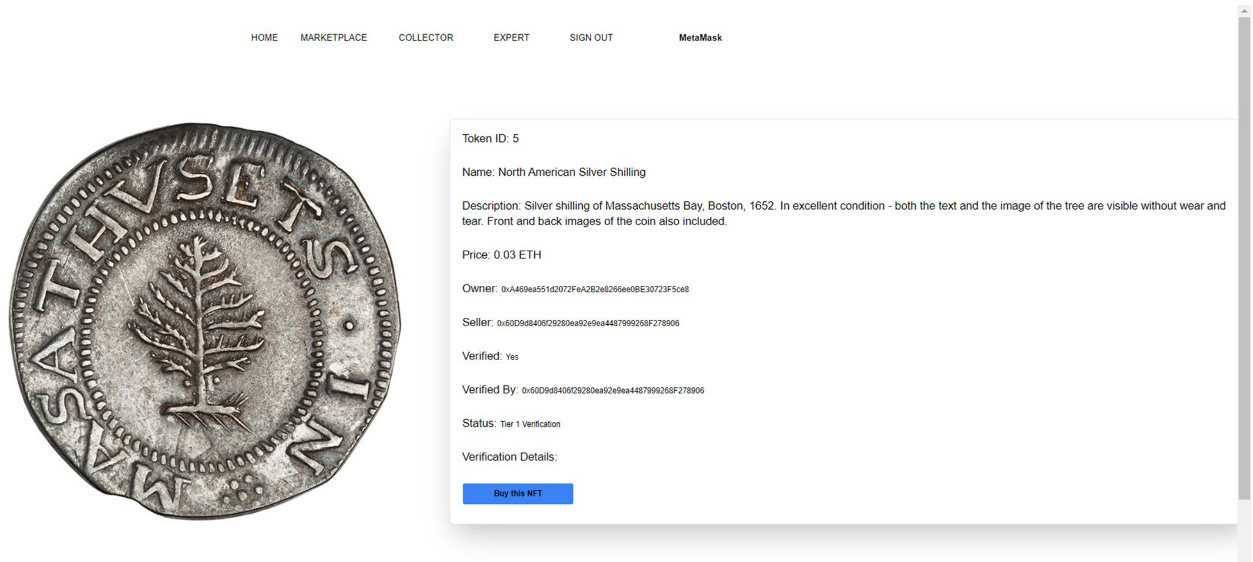

Fig. 8 This page provides the ability to sell NFTs in a marketplace

documentation. The peers are critical to this system, as they provide oversight and maintain the certification process for objects. One potential is to have a rotating board or short-term appointment of members to the board who provide oversight. For now, we do not make decisions on how the peers could be decided, but we state they would be critical in being the arbiters of the ethical and legal designation for collections. As the tool has a certification process, it could help pressure collectors to join such a blockchain since it provides a way to demonstrate how cultural objects were obtained. Joining the blockchain could also create potential pressure for collections to be more open and attempt to certify the ethical and legal status of their collections using experts available. An incentive is also provided for collectors to join and obtain ethical/legal clearance with their collections by utilizing an NFT service we provide, which could allow collections to raise revenues. To benefit from such a system, collections must upload their objects and achieve a top-level certification status that their collections are ethical and legal under some common guidelines used by museums or similar recognized bodies. Once a top-level status is achieved, NFTs potentially could provide a way to make revenues for collections in a manner comparable to other systems [67].

Our main motivation for applying a blockchain approach is that we see great benefits for cultural heritage managers in creating, managing, tracking, and storing cultural objects using such technology. Benefits include documentation that is updated in a decentralized and immutable network. Currently, most cultural objects use centralized systems to manage information, which may not be suitable if users seek a system that provides more rapid information and enables wider participation. This decentralized process is, therefore, another contribution of this work. The system allows collectors and users to verify if collections are obtained in an acceptable legal and ethical manner while using blockchain technology to track the current owner and status of the collection as ownership and status changes. When ownership or status of given objects changes, that information could be permanently recorded and maintained along with the object. Our approach is relatively new to cultural heritage; similarities and differences from current systems were discussed above. We build from previous work [32] and propose a system that can aid in the fight against illegally trafficked art by helping collections to be better certified for public use, while providing incentives to collectors to join a verification process for their cultural object collections. The tool we propose would enable collections to be transparent for users regarding the legal and ethical status of given objects, including the origin and life history of objects, which can be important for research or other access needs as demonstrated in the literature. Compared to other similar tools, Salsal provides advantages in enabling a certification process users increasingly want while enabling a way to monetize collections via NFTs, and without having to sell the original objects, which may motivate collectors to be more transparent with their objects. These novel contributions enable cultural object collections to benefit from blockchain technology that we propose.

Salsal Pseudocode

General workflow pseudocode is given to demonstrate overall structure for Salsal.

```
General workflow pseudocode is given to demonstrate overall structure for Salsal.
# Pseudocode for Uploading Collection Data
function uploadCollectionDetails(collectionDetails, collectorPrivateKey):
        transaction = createTransaction('Upload Collection', collectionDetails)
        signedTransaction = signTransaction(transaction, collectorPrivateKey)
        broadcastTransaction(signedTransaction)
# Pseudocode for Expert Verification
function verifyCollection(collectionDetails, expertPrivateKey):
        verificationTask = createVerificationTask(collectionDetails)
        expertJudgment = provideExpertJudgment(verificationTask,
        expertPrivateKey)
        uploadSupportingDocumentation(expertJudgment)
# Pseudocode for Ownership Tracking using Blockchain
function trackOwnershipChange(collectionID, newOwner, previousOwnerPri-
vateKey):
        transaction = createTransaction('Ownership Change', collectionID,
        newOwner)
        signedTransaction = signTransaction(transaction,
        previousOwnerPrivateKey)
        broadcastTransaction(signedTransaction)
# Pseudocode for NFT Incentives
function createNFT(collectionID, collectorPrivateKey):
        transaction = createTransaction('Create NFT', collectionID)
        signedTransaction = signTransaction(transaction, collectorPrivateKey)
        broadcastTransaction(signedTransaction)
# Pseudocode for Certification Badge System
function provideCertificationBadge(collectionID, certificationLevel, expertPri-
vateKey):
        transaction = createTransaction('Provide Certification Badge', collectionID,
        certificationLevel)
        signedTransaction = signTransaction(transaction, expertPrivateKey)
        broadcastTransaction(signedTransaction)
```

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Author contributions
AK, MA, MH, MG planned relevant sections and approach. Hashir wrote the code. AK and MH created the images. TH created primary goals for the tool. MA conducted user testing. All authors wrote and corrected the article.

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Availability of data and materials
Code for Salsal can be found here: https://github.com/hashir001/agur. The Salsal site, based on this paper and blockchain effort, is found here: https://agur-ab416.web.app/. A Salsal demonstration video can be found here: https://youtu.be/SXqkjJ43daA.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for Publication
The authors hold and provide consent to publish.

Competing Interests
The authors hold no competing interests.

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