

# Blockchain-Based Model for Warehouse Management Systems for Artworks and Collectibles <sup>†</sup>

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**Abstract:** In the area of artworks and collectibles, secure storage and accurate management play crucial roles. Increased attention to the provenance, condition, and authenticity of items challenges traditional warehouse management systems (WMS). This paper introduces a novel blockchain model combined with internet of things (IoT) devices and radio-frequency identification (RFID) tags, all dedicated to the management of warehouses. It proposes a secure and accountable way to track art pieces with an immutable ledger for transaction records and real-time monitoring of IoT environmental conditions. The model addresses key challenges in the art sector, such as the security and provenance verification of the artworks, enhances inventory accuracy, reduces human error and provides a solution in terms of tracking valuable items.

**Keywords:** WMS; IoT; blockchain; RFID; Hyperledger Fabric

## 1. Introduction

Most of the world's artworks remain in hiding, taken away with care to special warehouses (WH) or rooms. A very small part—only between 2% and 8% of the entire collection—is located at big museums [1]. They still face hard challenges versus traditional, very first-level administration systems in the storage of unique paintings or collector items. Critically, the requirements of such warehouses are to safeguard the articles, maintain their condition, and lastly, check their authenticity and origin. Technology provides some promising solutions to these challenges. From this perspective, blockchain technology is secure and transparent, and it might, therefore, give a seemingly immutable record of transactions and movement of goods in and out of the warehouse. The authors' idea is based on the use of blockchain with real-time tracking capabilities, constant monitoring of the environment by IoT sensors, and effective RFID technology; the result would be a very secure system that could be beneficial for the management of these valuable pieces (statues, sculptures, and collectible items) in warehouses and museums belonging to art galleries.

Provenance, security, and inventory management are of the greatest importance in the complex area of art and collectibles. Blockchain technology is essentially decentralized, so it perfectly creates an ideal platform with an immutable register for recording the provenance and changes of ownership for art and collectibles. Such an attribute is of importance to an industry in which authenticity and history require high value from items. Additionally, blockchain facilitates secure and transparent transactions, enabling exchanges without the need of trust in stakeholders.

Moreover, in addition to blockchain technology, IoT devices with RFID tags bring efficiency and accuracy to inventory management. IoT devices offer real-time tracking to the environmental condition and physical security of artworks. On the other hand, RFID tags offer easy methods of identifying and cataloging works of art and collector items with minimal human error, hence making inventory management much more effective.



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This paper explores the integration of IoT devices, with blockchain and RFID tags, within a warehouse management system (WMS) designed for the storage of artworks and collectibles and proposes a blockchain-based model for this type of WMS. The aim is to find out how such synergy not only addresses traditional challenges in the sector but opens new ways for innovation. This study, therefore, through the intensive assessment of existing practices and presentation of an innovative model, seeks to contribute to the emerging field in the management of artworks, highlighting the potential for improved security, tracking provenance and inventory accuracy.

## 2. Related Works

The integration of IoT devices with RFID tags in warehouse management systems is not something new to the sector. However, security and transparency in such decisions are lacking. In [2], the authors concentrated on advancing warehouse inventory management through the integration of IoT and RFID technology. This system targets localizing and management improvement for its inventory in a large-scale warehouse. The proposed product identification and tracking system is cost-effective, deploying RFID technology and open-source hardware like the Raspberry Pi, combined with ESP8266 Wi-Fi modules, in order to come up with a dynamic solution in comparison with the rest. Goods are marked with RFID tags, which are read by RFID readers at different positions in warehouses. This information is then processed and managed through a central server, facilitating real-time access and updates to inventory information. This system not only reduces manual search efforts, but also increases the accuracy and efficiency of warehouse operations. This practical implementation shows the practical application of IoT and RFID in the optimization of warehouse inventory management and hence has derived benefits from merging these into the operations of industries. However, more research may be needed in relation to some security, scalability, and reliability issues. The paper [3] presents an in-depth analysis of an inventory management system using RFID technology and IoT devices. The system is intended to automate the inventory check process in industrial conditions with a basis of RFID tags for equipment and tools, a cloud database for real-time data management, and a mobile application for operations. The study ascertains the possibility of using the system in minimizing labor expenses and human errors in the process of inventory management. The research highlights the effectiveness of integrating RFID technology with IoT to improve the system for inventory management. The latter offers invaluable insights into the operational benefits while at the same time encouraging further research into its scalability, security, and economic feasibility to be ascertained for full applicability in various industrial scenarios.

Table 1 shows a comparison of several papers included in the research in which different technologies are used to achieve the expected result in warehouse and inventory management systems and supply chain management.

In conclusion, it should be noted that in the areas of supply chain management and warehouse and inventory management, the most used technologies to automate the workflow are RFID stickers combined with IoT devices. Just about all the articles conclude that such systems require follow-up research in the aspect of improvement in security and scalability. Those are mostly the reasons why in those areas, blockchain technologies are becoming more and more popular, with preferences towards Ethereum and Hyperledger Fabric.

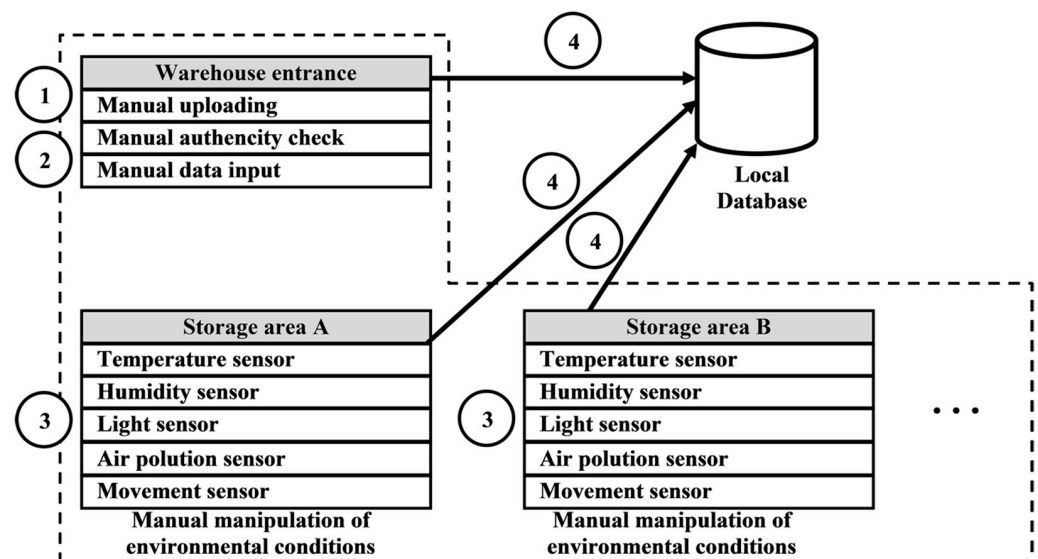
It is noticeable that when payment is involved in the whole process, Ethereum is the preferred blockchain, but when it comes to authorization and enhancing security, Hyperledger is more suitable. In the context of artworks and collectibles, market share is relatively small compared with other sectors, although the high price commanded by individual items may be a source of significant total income to artists and galleries. Due to the presence of fewer payments in the overall process and the need for higher security, the authors propose Hyperledger Fabric as the better platform.

**Table 1.** Comparison of existing solutions.

| Paper | Area                                    | Blockchain                     | RFID | IoT | Database       |
|-------|-----------------------------------------|--------------------------------|------|-----|----------------|
| [4]   | Supply Chain Management                 | Ethereum                       | Yes  | Yes | -              |
| [5]   | Inventory Systems                       | -                              | Yes  | -   | Cloud Storage  |
| [6]   | Supply Chain Management                 | Yes                            | Yes  | Yes | Distributed    |
| [7]   | Supply Chain Management                 | Ethereum Kovan                 | Yes  | Yes | Distributed    |
| [8]   | Apparel Supply Chain Management         | Yes                            | Yes  | Yes | -              |
| [9]   | Inventory and Supply Chain Management   | Ethereum<br>Rinkeby/Ropsten    | Yes  | Yes | IPFS           |
| [10]  | Supply Chain Management                 | -                              | Yes  | Yes | -              |
| [11]  | Inventory Management Systems            | -                              | Yes  | Yes | Cloud Storage  |
| [12]  | Apparel Supply Chain Management         | Yes                            | Yes  | Yes | EIS            |
| [13]  | Warehouse Management System             | -                              | Yes  | Yes | Cloud Storage  |
| [14]  | Warehouse Management System             | -                              | Yes  | Yes | Local Database |
| [15]  | Warehouse Management System             | -                              | Yes  | Yes | Cloud Storage  |
| [2]   | Warehouse Management System             | -                              | Yes  | Yes | Central Server |
| [16]  | Warehouse Management System             | Ethereum                       | Yes  | Yes | Cloud Storage  |
| [17]  | “Warehouse and Supply Chain Management” | Hyperledger<br>Fabric/Composer | -    | -   | -              |

### 3. Traditional Model of Receiving and Storing Artworks and Collectibles in Specialized Warehouses

In Figure 1 is shown the traditional method of receiving art pieces along with their storage conditions.

**Figure 1.** Traditional model.

**Receiving artworks:** High-value art is usually carried in specially designed high-security containers, which can protect the art from any form of vibration, shocks, or variations in the environmental condition.

**Quality and authenticity check:** It is necessary to check the quality and authenticity by visual inspection to find any visible damage or difference from the documented state. Technical analysis may include the use of infrared spectroscopy, X-ray, or other technologies for a detailed examination of the materials, techniques, and any previous restorations. Authentication is achievable through evaluation by an expert or an authentication specialist who is experienced in specific eras, styles, or artists. Such an evaluation can last from several days to even a year.

**Storage process:** Temperature control is important. Normal ranges are between 18 °C and 22 °C, but this can vary. Above all, sudden changes must be avoided. The humidity

rate is approximately 50% with possible fluctuations between 40% and 60%, although it is highly recommended that it should not exceed such limits. Thus, the growth of mold or material damage is avoided. Artworks in storage have low, controlled lighting conditions to avoid damage due to UV rays and high light. The warehouses are designed in such a way as to prevent dust and air pollution. The proper care of air and cleaning of filters are well maintained. The warehouses are well equipped with high-security video surveillance and controlled safety of access to protect against theft and damage, in addition to being fireproof.

**Security and Management:** With the help of characteristic, condition, and storeroom location information, all the components are registered in the database. Access to works of art is administered in a strict mode—only authorized personnel can manage the whole range of handling with these objects.

This is a complex process that demands significant investment in technology, equipment, and skillful personnel. It may be very slow, expensive and involve too many people. This can increase human errors and, as a result, the risk of a security breach. The improvement of such management systems has an important role in preserving the value and quality of artworks and collectibles over time.

#### 4. Proposed Model of Receiving and Storing Artworks and Collectibles in Specialized Warehouses Integrating Blockchain Technology in the WMS

Automated warehouse management systems, RFID technologies, IoT sensors for the environment and blockchain technologies together can form a decentralized data registry that revolutionizes the management and storage of one-of-a-kind and expensive pieces of art in the world. In Figure 2 is shown the proposed method integrating blockchain technology, IoT devices and RFID tags into the WMS.

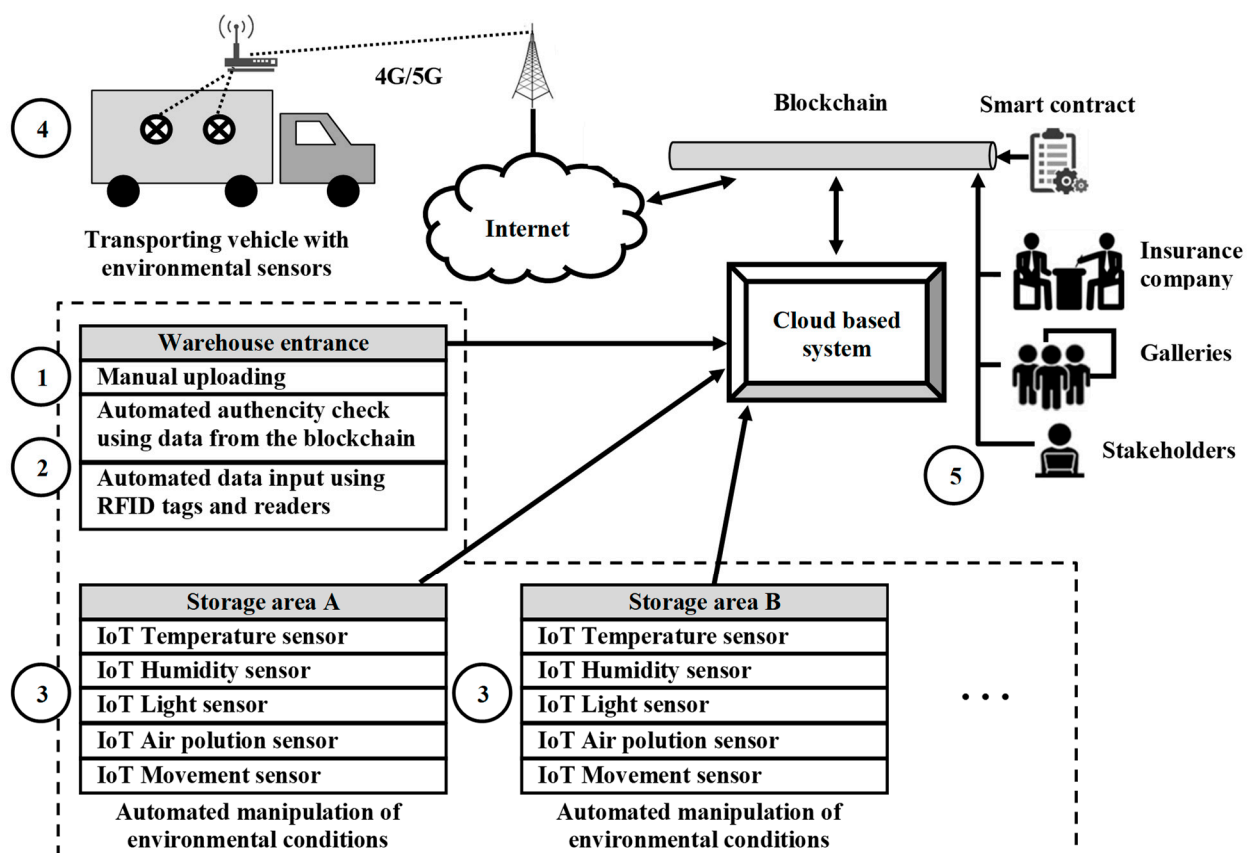


Figure 2. Blockchain-based model.

### 1. Receiving artworks

**RFID tags:** Every item, with information relating to origin, authorship, and previous ownership history, can be uniquely identified by RFID stickers.

**Blockchain records:** Scanning the RFID tags shall automatically update the database on the acceptance of new artworks into the warehouse.

### 2. Quality and authenticity check

**Automated checks:** After careful examination of the integrity of the piece of art, scanning and analyzing data from the RFID tags is applied. The goal is to acknowledge whether there is a match with the stored information concerning authenticity and quality.

**Blockchain records:** Verification results are recorded into a blockchain, meaning all records inside it carry the ability for immutability, transparency, and very high trust in the assessment process.

### 3. Storage process

**IoT environmental control sensors:** IoT sensors are used for monitoring and controlling the required conditions for best storage temperature, humidity, light, and air quality. WMS can determine the location of each item in the warehouse using RFID technology, thus aiding in quicker localization and management.

**Blockchain records:** Crossing the predefined threshold will result in recording data in real time on the blockchain and making it available for analysis.

### 4. Security and Tracking

**Automated Tracking:** Every move of the item within or out of the warehouse is automatically registered using RFID scanning, hence providing the history of location of the item with accuracy and transparency.

**Blockchain records:** Every move is recorded in the blockchain with full and immutable history, including operations, production, restoration activities or loans for exhibitions, including changes of ownership.

### 5. Data access and management

**Decentralized access:** Stakeholders can have the updated information related to the status and location of the work made available to them through secure and decentralized access to the blockchain register.

Such integration with automated and intelligent technologies will make the management of these expensive artworks easier, at the same time enhancing the levels of security, transparency, and efficiency for storage and transport.

For implementation of the model, the Hyperledger Fabric (HF) platform should be used. This is a private distributed ledger intended for enterprise application, which requires proofing. HF has specific features: a flexible and modular design; fast block transfer; Byzantine Fault Tolerant consensus mechanism; and low energy consumption. All peers maintain one ledger for the channel to which they are subscribed (there is possible to be more than one channel). Peers initiate transactions and send them to the nodes that store a copy of the blockchain and a current state of the data. As the necessary recovery, storage and rental activities require different data and work with different actors, the use of multiple channels is required.

The business logic is implemented by smart contracts (in terms of HF named “chain-codes”). They are written in Go language. Using API interfaces, external applications can connect to them and exchange data.

In Figure 3 is given the implementation of the proposed model in the HF network. It consists of four channels:

- Channel 1—for verification of authenticity—authenticity- and quality check-related data and documents;
- Channel 2—for storage data—information related to environment condition monitoring via IoT sensors;

- Channel 3—for transactions and ownership—purchases, ownership transfer and rentings from galleries;
- Channel 4—for transporting in and out of WH—data from IoT sensors in transporting vehicles to and from WH.

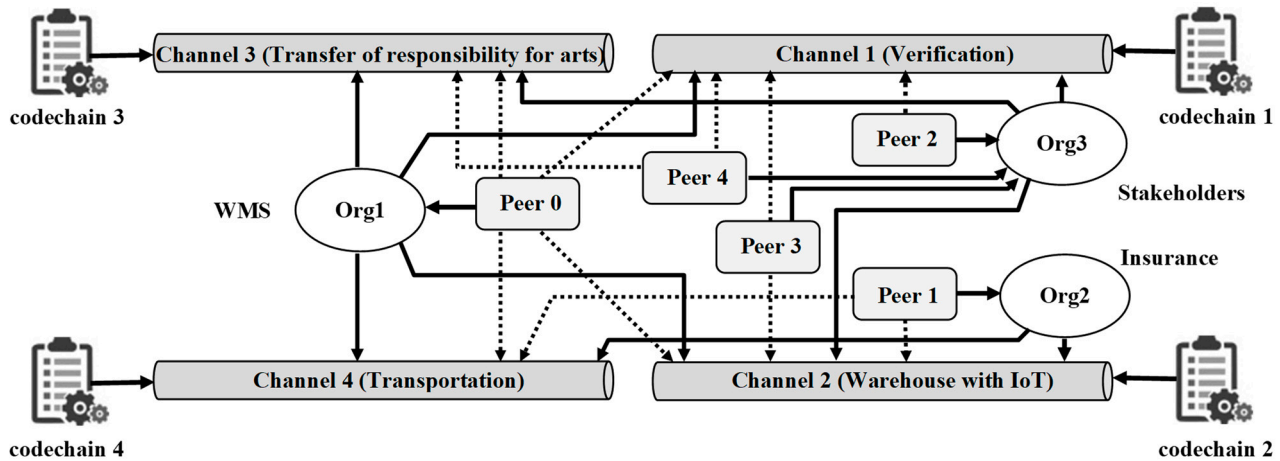


**Figure 3.** Blockchain implementation of the proposed model.

There are three participants (organizations): Org1—warehouse management system; Org2—stakeholders, which include artwork owners and galleries; Org3—insurance companies. The solid arrows represent the organizations' access to data in the respective channels. The dashed arrows represent peers' read/write operations on the channels.

Peer0 has access to all channels for writing and reading data. It uses information from IoT sensors and stores it in the blockchain. The insurance company (Peer1) has read-only access to the information received from the IoT sensors in the WH and during the transportation of arts between the WH and the stakeholders or galleries. This information can be used in the occurrence of an insured event.

Access to verification channel (Channel 1) is supported by Peer2. It writes proofing data for every item identified by RFID stickers. When the item is verified, it must be placed in appropriated storage area. The information for this action is stored by Peer3 in Channel 2. When there is a need to transfer responsibility between stakeholders and/or galleries (in case of exhibition), Peer4 writes relevant information in Channel 3. Both Peer3 and Peer4 use verification data from Channel 1.

The model is built as an HF network. The peers are implemented as docker containers (Figure 4). This ensures that execution is succesful and it gives possibility for future implementation in a distributed environment.

Testing the functionality of chaincodes implementation is performed by an administrative docker container with a command line interface. It is used for sending requests to smart contracts. In Figure 5 is shown a request for creating a record in Channel 2 due to periodic reporting of the environment conditions of an object from the IoT sensors in the warehouse. The information includes the time of the report, the name of the object and the values of sensor indicators.

The finding of information about the state of a certain object stored in the warehouse can be carried out according to different criteria. Figure 6 shows a search query by object name. Successful execution is indicated by the result code (status 200). Two entries for the searched object (Mona Lisa) are shown.

| CONTAINER ID      | IMAGE                                      | COMMAND                  | CREATED    |
|-------------------|--------------------------------------------|--------------------------|------------|
| STATUS            | PORTS                                      | NAMES                    |            |
| 4f1ff47ea88c      | hyperledger/fabric-tools:latest            | "/bin/bash"              | About a mi |
| Up About a minute |                                            | cli                      |            |
| 95dfa44414bd      | hyperledger/fabric-peer:latest             | "peer node start"        | About a mi |
| Up About a minute | 0.0.0.0:11051->11051/tcp                   | peer0.org3.example.co    |            |
| daf742daaf01      | hyperledger/fabric-peer:latest             | "peer node start"        | About a mi |
| Up About a minute | 0.0.0.0:9051->9051/tcp                     | peer0.org2.example.co    |            |
| c141fa9a9442      | hyperledger/fabric-peer:latest             | "peer node start"        | About a mi |
| Up About a minute | 0.0.0.0:7051->7051/tcp                     | peer0.org1.example.co    |            |
| 3c5745403fc0      | hyperledger/fabric-orderer:latest          | "orderer"                | About a mi |
| Up About a minute | 0.0.0.0:11050->7050/tcp                    | orderer5.example.com     |            |
| 7f7dd81953e4      | hyperledger/fabric-couchdb                 | "tini -- /docker-ent..." | About a mi |
| Up About a minute | 4369/tcp, 9100/tcp, 0.0.0.0:9984->5984/tcp | couchdb2                 |            |
| 808b38da6b40      | hyperledger/fabric-orderer:latest          | "orderer"                | About a mi |
| Up About a minute | 0.0.0.0:9050->7050/tcp                     | orderer3.example.com     |            |
| eadd7b37fdb       | hyperledger/fabric-couchdb                 | "tini -- /docker-ent..." | About a mi |
| Up About a minute | 4369/tcp, 9100/tcp, 0.0.0.0:5984->5984/tcp | couchdb0                 |            |
| 0004f8741c5e      | hyperledger/fabric-orderer:latest          | "orderer"                | About a mi |
| Up About a minute | 0.0.0.0:10050->7050/tcp                    | orderer4.example.com     |            |
| 26e7b77a8762      | hyperledger/fabric-orderer:latest          | "orderer"                | About a mi |
| Up About a minute | 0.0.0.0:8050->7050/tcp                     | orderer2.example.com     |            |
| a3279fbe3b7f      | hyperledger/fabric-orderer:latest          | "orderer"                | About a mi |
| Up About a minute | 0.0.0.0:7050->7050/tcp                     | orderer.example.com      |            |
| b4830alee2da      | hyperledger/fabric-couchdb                 | "tini -- /docker-ent..." | About a mi |
| Up About a minute | 4369/tcp, 9100/tcp, 0.0.0.0:7984->5984/tcp | couchdb1                 |            |

**Figure 4.** Fabric network with docker containers.

```

invoke result: version:1 response:<status:200 > payload:"\n o, \2218\301\230\2368\02
2dUQ\177>\035&\355\177\244\220t\027\036K\017: \345\356\205\024\003\320\022\346\001\n
\315\001\022\030\n\0041scc\022\020\n\016\n\010smartcon\022\002\010\003\022\260\001\n
n\010smartcon\022\243\001\032\240\001\n\tId-baiCMR\032\222\001{\\"Name\\":\\"David\\",
\\"TimeStamp\\":\\"2024-04-07 21:19:15\\",\\"Temp\\":\\"23oC/70oF\\",\\"Humidity\\":\\"25.541%
/ 39.2g/m3\\",\\"Light\\":\\"11.85 lux\\",\\"Air\\":\\"0.6%\\",\\"Move\\":\\"No\\",}\032\003\010\
\310\001{\\"017\022\010smartcon\022\0031.0\\",\"endorsement\\":\"n\007Org1MSP\022\
252\006-----BEGIN CERTIFICATE-----\nMIICKTCCAo+gAwIBAgTRAJ/Hn9qGcYJ9R+cjQ7hswWcYy
IKoZiZj0EAWIwczEL\nMAKGA1UEBhMCVVMxZARBgNVBAgTCkNhbmG1mb3JuaWEXFjAUBGNVBAcT
DVNhbGlB
G\ncmFvY21yZ28xGTAxhGNVBAcTEG9yZ2EuZXhhbXBsZS5jb20xHDAaBgNVBAMTE2Nh\nLm9yZ2ZuZXhhbXBs
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CBMKQ2FsaWZvcm5pYTEwMBGGA1UEBxMN\nu2FuIEZyYW5jaXNjb2ENMAsGA1UECzMEcGVlcjEjFjE0
B0GA1UEA
xMwcvGVlcjAub3Jn\nnM55leGftcGxllMnVbTBZMBMGByqGSM49AgEGCCqGSM49AwEHA0IABNrci+3cky5L\nuXtsd3B3UzOpEsEJYn9YgT5U6gxX91WVd0KIOzg8A8kjm/swKKAckZcNkZCTC\noNrtRvjPxdPajTbLm
A4GA1UdDwEw/wQEAwHgdDAMBGNVHRMBGAfBEAjaAMCSGA1Ud\n\ntWqMKMzAIKKoDOBBE1VYbHVBHGdsb/
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psumpeqIgmLlU\nGiti7J51kI9GhcvsfNWXD5+4B/Zwni9gf19ea8s=\n-----END CERTIFICATE-----\n
signature\\":\"0E\001\000\0373\264\242\034\234\212\362\263\366\346\223\236\345\337\30
1L\354\242\347\364\014\007\022`221qmb\207\337\002 >i\301\177~+\210\033Fwn\230\352?
\374K\361\2319P7\374\034\331\237\246\253\371V\270\237\331\" >
2024-04-11 10:19:04.943 UTC [chaincodeCmd] chaincodeInvokeOrQuery -> INFO 04c Chain
code invoke successful. result: status:200

```

**Figure 5.** Writing into blockchain.

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[0031.0" endorsement:<endorser:"\n007OrgIMSP\022\252\006----BEGIN CERTIFICATE----
\nMIICKTCCAc+gAwIBAgIRAJ/HN9qfCeyJ9R+cQ7q7hswwCgYIKoZIzj0EAwIwczEL\nMAkGA1UEBhMCVV
MxEzARBgNbVABGtCkNhbGlm3JuaWExFjAUBGNVBAcTDVNBhbiBGnmcFuY21zY28kGTAXBGNVBAoTEG9yZzE
uZXhhbXBsZS5jb20xHDAaBgNVBAMTE2NhcnLm9yZzEuZXhxbXBsZS5jb20wHicm5jQWNEaXMTAWhcnAw
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nU2FuIEZyYW5jaXNjbzENMAsGA1UECjMEcGVlcjEjFmB0GA1UEAxMwCjVlcjAub3Jn\nnMS5leGFtcGxlLnNv
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WD5+4B/Zw7niqfj9lea8s=\n-----END CERTIFICATE-----\n\n\nsignature:"0E0021\000\275\223
\360\323gwKQ\256\033\201\277\3\nSM3\222s\016\264\307\321\301\027s\220\375\351\002
:\3\026\212ghj\h311\036.\333\025+\261v\030\032!\344\257AI)\326\3461\340\271gC,'">
2024-04-11 10:44:25.204 UTC [chaincodeCmd] chaincodeInvokeOrQuery -> INFO 04c Chain
code invoke successful. result: status:200 payload:[{"key":"Id-AjWwhT","
Record":{"Air":{"0.6%"},"Humidity":{"27.3% / 35.87g/m3"},"Light":{"22.03 lu
x"},"Move":{"No"},"Name":{"Mona Lisa"},"Temp":{"24oC/70oF"},"TimeStamp":{"2
024-01-12 08:29:11"}},{"key":{"Id-XVlBzg"},"Record":{"Air":{"0.5%"},"Humid
ity":{"27.48% / 38.57g/m3"},"Light":{"21.93 lux"},"Move":{"No"},"Name":{"Mon
a Lisa"},"Temp":{"22oC/70oF"},"TimeStamp":{"2024-04-02 13:09:35"}}]}
```

**Figure 6.** Reading from blockchain.

The tests prove the functionality of the proposed model.

## 5. Conclusions

This paper introduces a new model for a warehouse management system to safely store and accurately manage artworks and collectibles by using blockchain, IoT devices and RFID tags. This integration enhances real-time data processing, security and confidentiality issues of information relating to the items stored and transferred across the different sets of stakeholders involved in the process of warehousing. The proposed model integrates smart contracts, blockchain technology and IoT sensors, which can help fix long-existing challenges to security, provenance verification and inventory accuracy in this extremely narrow scope of application—artworks and collectibles management.

When generally considered and viewed from the wider perspective of Industry 4.0, the model relates to an abstract framework addressing the demands required for modern warehousing and inventory management. It includes a multi-layered approach involving different participants in relation to the security and confidentiality of the data that would generally increase the overall efficiency for monitoring and managing valuable artworks and collectibles. This is indeed a big step in proving that blockchain technology in combination with IoT sensors and RFID stickers offers a secure, transparent and reliable system for the art sector, providing an immutable ledger for transaction records and environmental conditions.

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