The University of Hong Kong
FYP21036 Individual Report - 18/04/2021

Blockchain NFT project (Group 1)

Supply Chain Management using Blockchain and NFT

Increasing Transparency & Traceability

Group Member	UID
Agarwal, Siddharth	3035555482
Bera, Navoneel	3035551735
Lohia, Suyash	**3035550406**

Supervisor: Dr. Yuen, John

ABSTRACT

Supply chain management (SCM) tools and softwares are required to facilitate coordination between entities participating in the global supply chain and logistics management industry. These softwares carry out multiple functions including tracking and authenticating goods in transit. However in the process of exchanging goods between multiple intermediaries a lot of stock value is lost due to thieving and tampering. The existing softwares uses different technologies such as centralised systems, Internet of Things (IOT) devices and blockchain to solve the issue of stock loss, however have been unsuccessful in completely eradicating it.

Our team aims to eradicate this problem by developing a completely foolproof system of tracking and authentifying goods using Non Fungible Tokens. Through this, businesses will be able to completely reduce stock value losses accrued and consumers will have access to all information about the products they are purchasing. The team has successfully developed and tested the product after performing extensive research and ideation on the various technologies.

The team aims to further launch a beta version of the product on app marketplaces such as Appstore, Playstore and further approach businesses to try out the product and receive client feedback. The team shall be adopting a continuous research and development approach to better the product through innovations and finally convert it into a fully functional startup raising funds and simultaneously onboarding clients.

ACKNOWLEDGEMENTS

This project has been supported by the Department of Computer Science, The University of Hong Kong. We would like to express our deepest gratitude to all who have helped us complete the project by guiding us throughout the process. We are especially grateful to our final year project professor Dr. John Yuen who supported us immensely in terms of overall project planning, technological implementation and encouragement to explore novel avenues.

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LIST OF ABBREVIATIONS

ERP Enterprise Resource Planning.

SCM Supply Chain Management

SCMTT Supply Chain Management Token Technology.

RFID Radio Frequency Identification.

GIS Geographic Information System.

NFT Non Fungible Token

UI/UX User Interface/User Experience.

IOT Internet of Things

IPFS InterPlanetary File System

TPS Transaction Per Second

dApps Decentralized Applications

API Application programming interface

JSON JavaScript Object Notation

1 INTRODUCTION

Extensive globalisation and rapid growth of the world economy has led to the formation of a global supply chain management (SCM) and logistics industry. To ensure smooth functioning of this industry by facilitating coordination between different entities, automated supply chain management solutions are developed. Industry giants such as Microsoft, Oracle, SAP, Blue Yonder etc.[1] have launched softwares to solve issues including inventory management, procurement, tracking, authentication, supplier management and many more [2].

However, all existing solutions have a particular drawback; they are unable to perform secure, thorough tracking and authentication of goods in transit. Approximately 20% of stock value is lost as a result of thieving, goods tampering and other inefficiencies across the global supply chain [3]. Therefore, our team focuses on solving the above mentioned problems using a combination of Supply Chain Management (SCM) and Non-Fungible Token (NFT) technology which we call the Supply Chain Management Tokenization Technology (SCMTT).

The following subsections explore the background, objectives and outline for this project report and elaborates on the core use case of the product along with its key features.

1.1 BACKGROUND

Tracking and authentication of goods in transit includes assembly of raw materials, manufacturing, packaging, transporting across multiple stakeholders, warehousing and retailing to reach the end consumer. It directly affects the efficiency of the supply chain pipeline, product safety, delivery performance, controlling costs and regulatory compliance [4].

There has been constant innovation in this field in order to tackle the issues faced while handling the traceability and authentication of goods. Technologies implemented include the usage of barcodes, Radio Frequency Identification (RFID) tags, Geographic Information Systems (GIS) [4] and lately blockchain networks. The product proposed by the team will be utilising novel technologies such as Non Fungible Tokens (NFTs) and blockchain networks to eradicate stock

value loss for businesses and provide transparency for all users. Therefore, the value of this project stems from an effort to help businesses reduce their losses and aim for a more efficient operations model.

1.2 OBJECTIVES

The primary value proposition of this project is to build a SCM software which provides transparency and traceability to all stakeholders involved. The software in the form of a blockchain based web and mobile applications which will be accessible to all stakeholders across the supply chain and be utilising NFT's to facilitate the authentication and transfer of goods.

The product includes a separate mobile application for consumers which facilitates origin traceability and authentication of goods so as to confirm ethical sourcing practices and combat counterfeiting respectively. The team aims to democratize the entire tracking and authentication processes in the supply chain industry by making information decentralized which is easily accessible to the general public.

The team has achieved all its objectives and finished the development of all platforms. The team shall be adopting a continuous research and development approach to better the product through innovations and finally convert it into a fully functional startup raising funds and simultaneously onboarding clients.

1.3 OUTLINE OF THE REPORT

The report starts by giving a brief introduction of the background and objectives, further illustrating the value proposition and the team's motivation for the project in section 1. Section 2 of the report contains the literature review giving background on the technologies used as well as highlighting the related works currently implemented globally and its comparison with the solution proposed by the team. Section 3 elaborates on the methodologies implemented to realize the product. workflow of the product. Section 4 provides the schedule followed to build the product and an extensive update on the software built. Section 5 contains the limitation of the

product, the challenges faced during its development and finally the future plans for its development. Finally, section 6 gives a brief conclusion on the progress report.

2 LITERATURE REVIEW

To further understand the importance as well as the need of the solution, this section elaborates upon core technical components of the application followed by an explanation of related works in the field of SCM.

2.1 TECHNICAL REVIEW

The following subsections will give a brief explanation of blockchain and NFT technologies, their benefits and applicability in the proposed solution statement.

2.1.1 BLOCKCHAIN TECHNOLOGY

Blockchain is a technology that allows authenticated and secure communication between users on its network without the presence of a centralized authority. It is essentially a database of records, capable of storing data of different formats which is publicly shared between all users. For additions to this database, there is a verification mechanism which requires a majority consensus or 50% of its users to confirm the records [5]. Due to the structure of this technology, all data stored are secured, immutable and decentralized in nature.

Using blockchain technology in the supply chain industry, each stakeholder in the network can interact with other stakeholders for information exchange. The traceable and real time nature of blockchain transactions can prevent counterfeiting, increase transparency of the entire supply network, and improve visibility, compliance over outsourced contract manufacturing. It can further reduce paperwork and administrative cost [6].

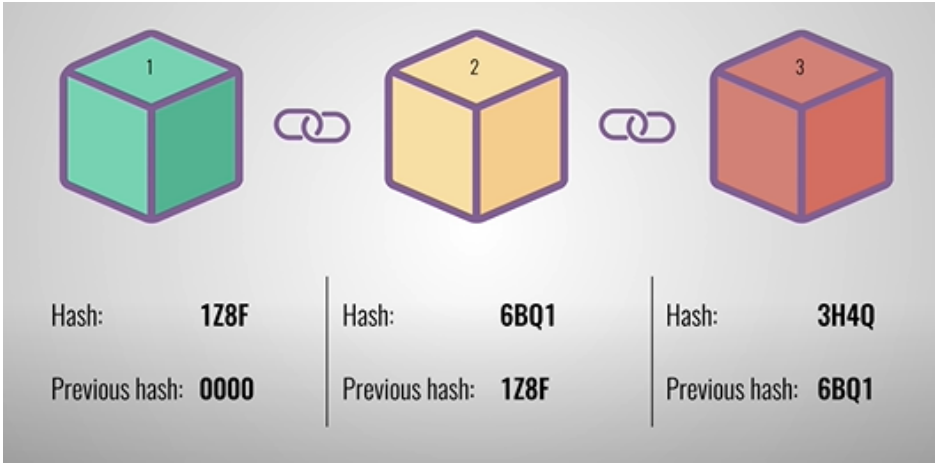

Fig. 1. Anatomy of blockchain

In our project, the exchange of goods needs to be recorded and maintained for all members of the supply chain at multiple locations but having the same information. A member should have a record of the previous transactions but not be able to tamper with them. The importance of SCM for a business also demands the system to be secure. All of these requirements are fulfilled by the aforementioned features of the blockchain.

2.1.2 COMMERCIAL REQUIREMENTS OF BLOCKCHAIN TECH.

To compete with traditional centralized solutions commercially, the blockchain network needs to have an ideal balance between decentralization, security, and scalability within a blockchain infrastructure. Blockchain decentralization refers to the meaningful distribution of computing power and consensus throughout a network, while security reflects a blockchain protocol's defenses against malicious actors and network attacks. Both are considered non-negotiable to the function of a blockchain network. (Fig 2.)

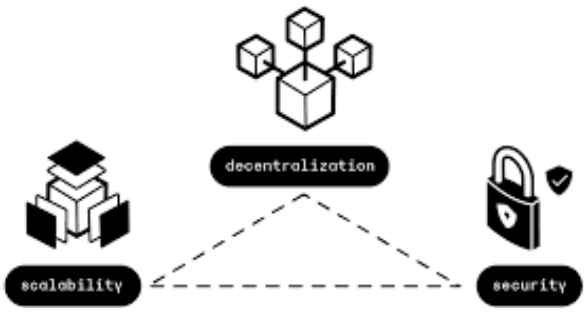

Fig. 2. Blockchain Trilemma

One of the most important pillars and challenging issues in any blockchain infrastructure is its scalability. Scalability refers to the blockchain network's ability to support high transactional throughput and future growth. The transactions per second (TPS) of any network is crucial for commercial viability as it needs to at the least match centralized solutions. For example, the bitcoin blockchain network has a TPS of 4-7 which makes it unsuitable for any high frequency transaction based application. To address the scalability issues, any Layer 1 and Layer 2 scaling solutions have been developed which shall be discussed in the next section.

2.1.3. LAYER 1 AND LAYER 2 BLOCKCHAIN ARCHITECTURE

Layer 1 refers to a blockchain architecture wherein it processes and finalizes transactions on its own blockchain network [16]. The gas fees paid per transaction is also in the native token of the blockchain. All related activities are conducted on its one and only base layer, popular examples include Bitcoin, Ethereum, Solana, Terra etc.

Layer 2 on the other hand refers to a secondary framework or protocol that is built on top of an existing blockchain system [17]. These protocols aim to solve scalability and accessibility issues by developing add-on products catering to commercial needs. The main goal of these protocols is to solve the transaction speed and scaling difficulties that are being faced by the major cryptocurrency networks. Popular examples include Polygon, Polkadot etc.

2.1.4 BLOCKCHAIN SCALABILITY

Layer-1 scaling solutions augment the base layer of the blockchain protocol itself in order to improve scalability. A number of methodologies are currently being developed and practiced. Some solutions include:

- increasing block size, allowing more transactions to be processed in each block,
- changing the consensus mechanism used for example transitioning from Proof of Work to Proof of Stake
- implementing sharding, where the nodes and workload of the blockchain network is divided into shards fastening the consensus process.

Due to technological constraint, Layer 1 solution is both more time consuming and expensive. Layer -2 scaling solutions however entails shifting a portion of a blockchain protocol's transactional burden to an adjacent system architecture, which then handles the brunt of the network's processing and only subsequently reports back to the main blockchain to finalize its results. By abstracting the majority of data processing to auxiliary architecture, the base layer blockchain becomes less congested — and ultimately more scalable [18].

Layer-2 solutions include:

- Nested blockchains: It involves a main blockchain that sets parameters for a broader network, while executions are undertaken on an interconnected web of secondary chains.
- State channels: which facilitates two-way communication between the main chain and off-chain transactional channels where batches of transactions are verified and sealed in the states of the off-chains and are then recorded on the main chain.
- Sidechains: where the main chain is only responsible for security and recording of large batch transactions and the sidechain further provides a public ledger for the intricate details.

In order for our project to be commercially viable and successful, it is imperative to build upon a blockchain architecture with stable scaling solutions. The above mentioned scaling solutions shall be fulfilling all requirements to satisfy the high frequency transactional nature of our business use case.

2.1.5 NON FUNGIBLE TOKEN (NFT)

NFT is a unit of any type of data which is unique in nature and cannot be modified. NFTs are stored on the blockchain and are used to represent and certify digital assets. One of it's biggest advantages is that it is extremely easy to transfer, track and access as compared to other entities on the blockchain [7].

By utilizing NFTs, the process of exchange of goods could be made more reliable, efficient and user friendly. NFTs could ensure that information on every single good is trustworthy and easily accessible, with even end-users acquiring all knowledge about the products.

2.1.6 INTERPLANETARY FILE SYSTEM (IPFS)

IPFS is a protocol and peer-to-peer network for storing and sharing data in a distributed file system (Fig 3.). IPFS uses content-addressing to uniquely identify each file in a global namespace connecting all computing devices[19]. IPFS enables users to store and retrieve content based on a "fingerprint" of the content itself (a cryptographic hash called a CID). By putting an IPFS CID in an NFT, that NFT directly references the data itself rather than a brittle HTTP link. This ensures that the NFT data:

- Can be publicly accessed from any location in the world with no centralization
- Is tamper and censor proof due to its decentralized nature
- Can be accessed faster than other data solutions

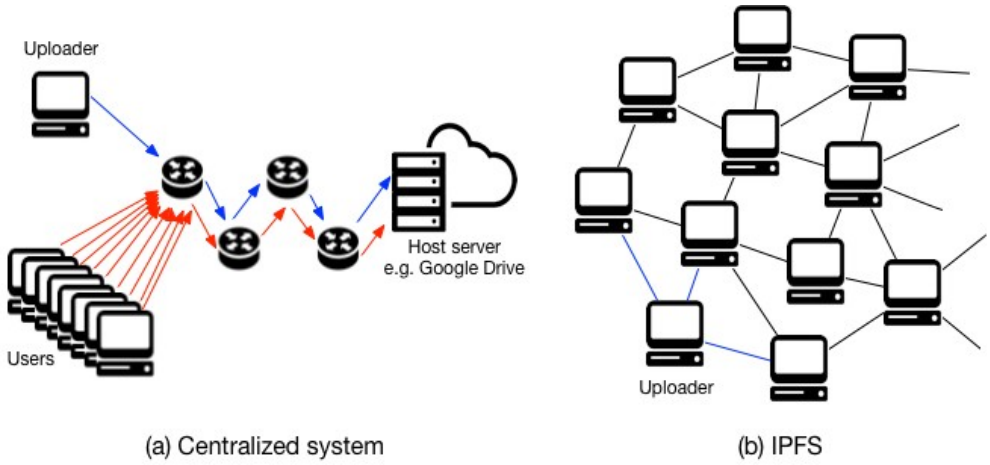

Fig. 3. Centralized data solution vs IPFS

2.2 RELATED WORKS

As mentioned above in section 1, there are many existing solutions in the market which would be competing with our product. These solutions are using different methodologies to track and authenticate the goods and are further segregated into two categories - centralised solutions and blockchain based solutions. The following subsections will give a high-level overview of these solutions including the technology used, implementation and drawbacks. Furthermore, Table 2.1 demonstrates the similarities and differences in the implementation summarizing the major features of all solutions, including our team's.

2.2.1 CENTRALIZED SYSTEMS

The exchange of the goods in centralised solutions is either documented using physical paper-contracts or through rudimentary technological solutions which include tracking and transferring the bill of lading agreement (a receipt issued to the shipper including details such as size, weight, count of the shipments used to denote legal responsibility of the goods) [8]. There are many issues with the current system of tracking goods, because of which the process becomes complicated, time consuming and expensive. One of the biggest issues is the lack of a standardized system, due to which stakeholders implement different technologies to collect, process and share their data. Moreover, the data gathered is not easily accessible which leads to many manual back office tasks [4].

2.2.2 BLOCKCHAIN BASED SYSTEMS

Companies like IBM have utilised the features of blockchain mentioned in section 1.1.1, which provides users with solutions such as the IBM Blockchain Transparent Supply eliminating the issues arising with the usage of centralised systems [9].

However, there are two major problems with this implementation. Firstly, even though the database is decentralized and immutable, the information posted onto it could be non vercious in nature. During an exchange, false information could be easily reported and fed into the immutable database which could lead to potential issues. The second issue is that all exchanges and transactions in the blockchain network are implemented using smart contracts. These smart contracts are traceable, however are difficult to access due to its extensivity and lack of user friendliness.

The SCM using Blockchain & NFT software proposed by our team would be solving all issues of existing solutions by utilizing NFT technology and by taking a customer-centric approach to user-friendly applications. Table 1 illustrates the key differences between the three possible solutions to the problem mentioned in section 1.1. Through Table 1 it can be inferred that the SCMTT software outperforms its competitors entirely by preventing voracious data inputs into

the system and by providing consumers with full access to supply chain information in a decentralized manner.

Table 1: Comparison between existing solutions and proposed solution

	Centralised Systems	**Blockchain Systems**	**SCMTT**
Counterfeiting	Limited Prevention	Completely Prevented	Completely Prevented
Trackability	Not efficient	Efficient	Efficient
Authentication	Not efficient	Efficient	Efficient
Voracious Data Input	Possible	Possible	*Not Possible*
Consumer Access	No access	No access	*Full access*

3 METHODOLOGY

This section explains the product workflow of the SCM software system proposed by our team. It further elaborates on multiple tools and technologies that will be used to realise this product.

3.1 PLATFORM WORKFLOW

Fig 4. below provides a high-level overview of the workflow of our product through a flowchart. The custom workflow is entirely based on our blockchain based web application.

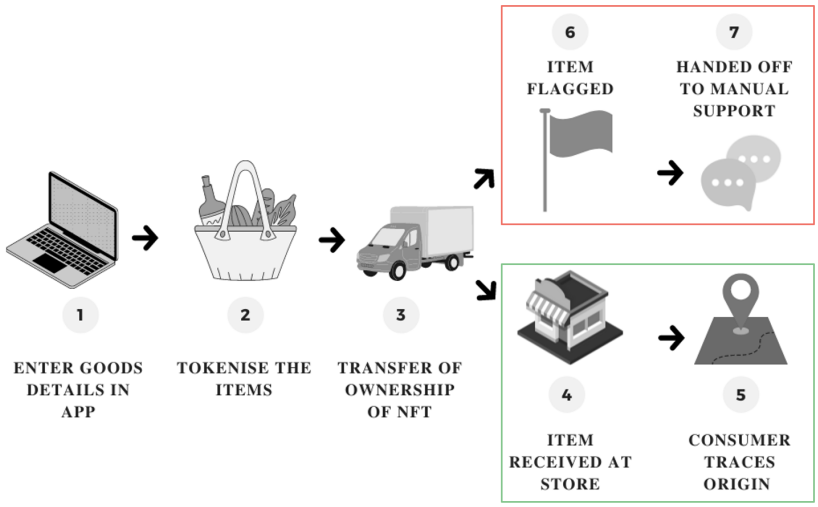

Figure 4. High-level overview of the product workflow.

With reference to Fig 4, the first step is for company management to enter details of the goods through the interface. They have the option to record varying characteristics such as quantity, weight, type of the goods. The second step involves the tokenization of items into NFTs. These NFTs act as an alias for the physical goods. On transfer of goods, the NFT is also transferred to the respective stakeholders. Third step involves the transfer of ownership of goods between all intermediaries which is represented by the transfer of NFTs. The stakeholder in possession of the NFT is liable for the goods associated with it. On successful transferring of goods across all intermediaries, the goods along with the NFT is received by the retailer (step four in Fig 4) with all information about the product easily accessible to the consumers through an NFT reader mobile application (step five in Fig 4). On a dispute of transferring of NFTs the system automatically reports the case (step six in Fig 4) and it is further escalated towards manual intervention (step seven in Fig 4).

3.2 IMPLEMENTATION AND FEASIBILITY

The following section provides an overview of different technologies used to realize the product. These are presented in an orderly manner discussing each technology's implementation and feasibility.

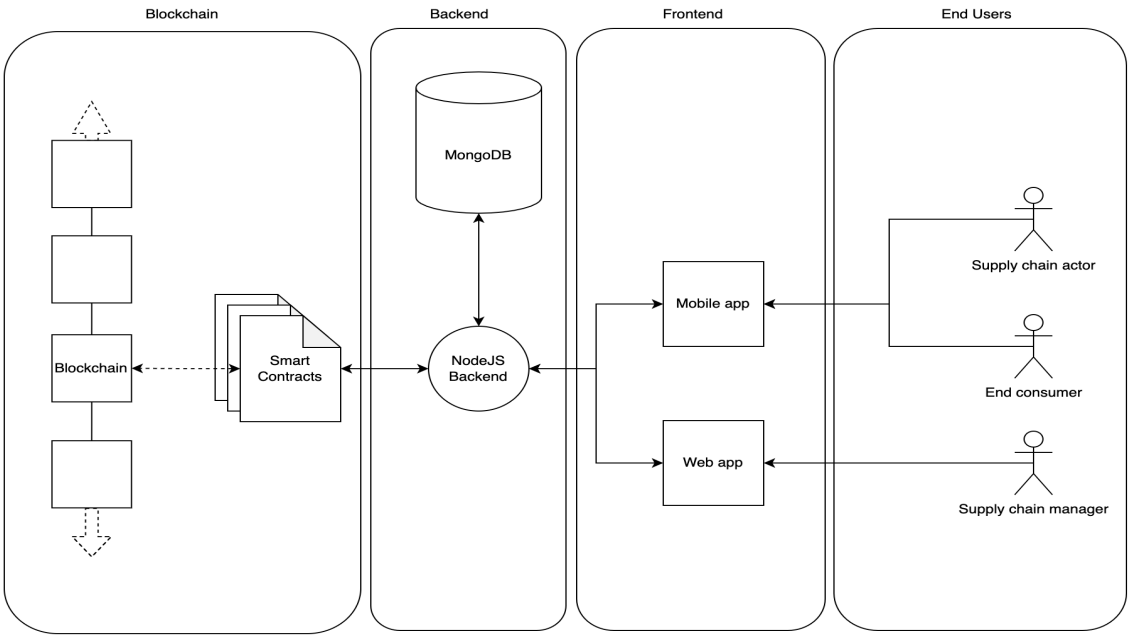

Fig 5. A high-level overview of the system architecture

3.2.1 BLOCKCHAIN: ETHEREUM

Blockchain forms the base of the application. We needed to decide between a custom or an existing blockchain. After extensive research, Ethereum was chosen. The primary selling point was its large and established ecosystem which is very well suited for decentralized application dApp development. Additionally, the ethereum network is one of the most secure networks having more than 300,000 nodes or validators along with having a rapidly growing developer community.

3.2.2 BLOCKCHAIN SCALING SOLUTION: POLYGON

Polygon is a Layer-2 scaling solution created to help bring mass adoption to the Ethereum platform. It caters to the diverse needs of developers by providing tools to create scalable decentralized applications (dApps) that prioritize performance, user experience (UX), and security [20]. Polygon was chosen as the preferred Layer 2 scaling solution as it efficiently solves the two main issues of ethereum - low TPS and expensive gas fees. Due to the underlying technical architecture of its Proof-of-Stake (PoS) Commit Chain and large developer community, polygon supports 10,000 TPS as compared to only 12-15 of ethereum and has attracted over 7000 dApps as of January 2022 [21]. With all gas fees being in its native token MATIC, the average fee for any transaction on the polygon network is 0.01 USD as compared to a highly volatile range of 20- 50 USD on the ethereum network [22].

3.2.3 BLOCKCHAIN DEVELOPMENT ENVIRONMENT: HARDHAT

The modules for tokenization of goods and further transactions based on it have been built using the Hardhat development environment. Hardhat is a development environment to compile, deploy, test, and debug Ethereum software [23]. It helps developers manage and automate the recurring tasks that are inherent to the process of building smart contracts and dApps, as well as easily introducing more functionality around this workflow. It has a rapidly growing developer community and is introducing integrations, additional features regularly to further optimize the development process.

3.2.4 BACKEND: NODEJS, EXPRESS, MONGODB

The backend server will be created using Express, a Javascript framework based on NodeJS, a server-side programming language with vast built-in functionality. With the routing functionality, it simplifies the organization and development of servers and RESTful application programming interfaces (APIs) written in Node [24].

MongoDB is a non-relational database that will be used to store all information including users, products, shipments etc. It is highly flexible and has seamless integration with NodeJS and Express. For project development, the team has used MongoDB Atlas, a database-as-a-service on the cloud provided by MongoDB itself, that assists in streamlined deployment and management of databases

3.2.5 FRONTEND: REACT NATIVE AND REACTJS

In line with the backend and blockchain being built upon a javascript framework. The team has chosen ReactJS for the web-application and React Native for mobile-application development, both being Javascript based.

ReactJS is an open-source front-end javascript library developed by Facebook which is used to make web user interfaces through components which are rendered as HTML on the browser. React native is an open source framework used to build cross platform mobile applications in a very streamlined and efficient manner [13].

The driving factor for choosing React native and ReactJS as the framework for our product are:

- Cross platform feature which allows applications on it to run on different operating systems which includes iOS and Android. As a result, only one code base needs to be maintained thereby saving time and money.
- Easy integration with backend and blockchain components
- Large developer community and high adoption in the industry.

These are flexible and cost effective framework which satisfies most key requirements of our product, thereby making it an adequate choice for our team to implement.

3.3 GOODS TOKENIZATION WORKFLOW

Each good is tokenized into an ERC-721 token which is minted from a custom made smart contract (skeleton of NFT) consisting of ownership access, transfer details and the minting functionality. This smart contract which shall represent the NFT collection shall be deployed on the blockchain network using a service such as Alchemy. (Alchemy is a microservice providing APIs to developers with easy-to-access Ethereum-based infrastructure to build dApps)[25].

The first step for tokenizing the goods involves creating the NFT metadata containing all vital information about the good. This metadata file is uploaded onto the IPFS using an uploading service such as Pinata.cloud (Pinata.cloud is a pinning service that allows users to host files on the IPFS network)[26].

The second step consists of calling the NFT minting function of the smart contract after passing the metadata uploaded on IPFS as a parameter. The result of which is an NFT token minted onto the blockchain network, easily trackable and visualizable via NFT marketplaces.

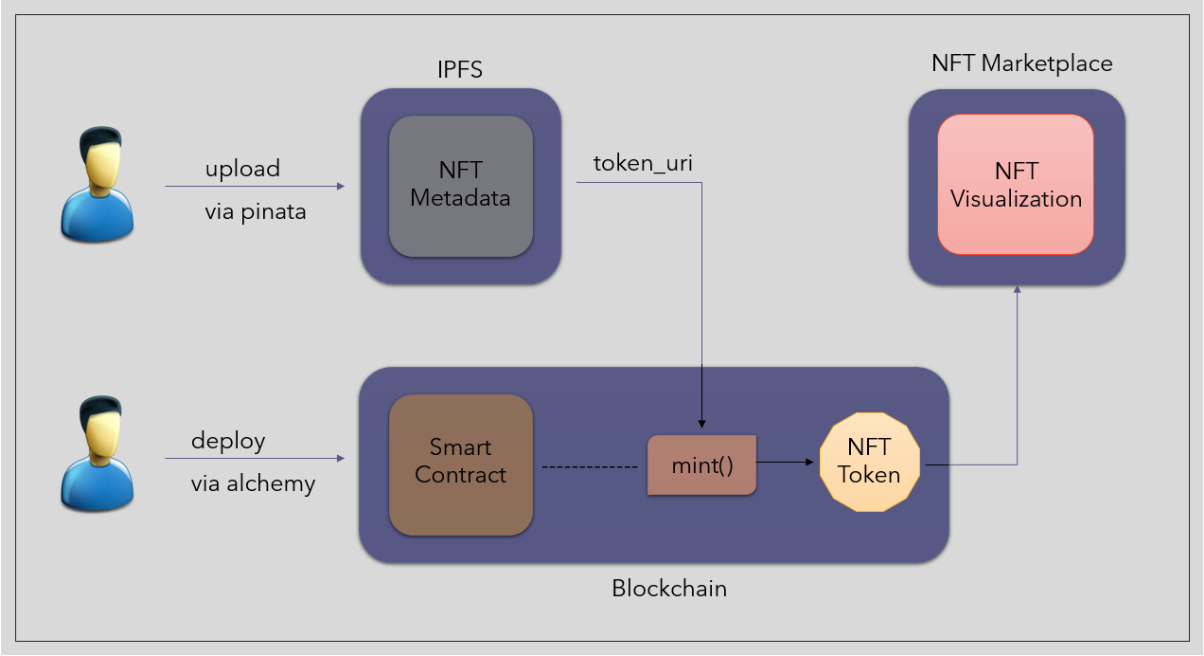

Fig. 6. NFT Minting Architecture [27]

4 PROJECT DEVELOPMENT

This section introduces the development plan of the project. It then states the results of the application implementation.

4.1 SCHEDULE

The project is divided into six different stages where each stage is considered an iteration to adhere to an Agile development process (Table 2). Every stage marks the completion of an important task essential for starting future tasks.

Table 2. Schedule of Project Development

Stage	Task	Timeline
Stage 1	Research on the feasibility of different blockchains with respect to throughput and gas fees and further study on various NFT standards	4th - 29th October
Stage 2	Develop a module to tokenize goods based on information	1st - 15th Nov
Stage 3	Develop a pipeline to create and transfer NFTs across a blockchain network	16th Nov - 30th Dec
Stage 4	Develop a web and mobile interface which allows the initialization, transfer and tracking of NFTs	3rd Jan - 14th Feb
Stage 5	Build an interface for consumers using which the origin can be tracked and the authenticity can be verified.	15th Feb - 14th March
Stage 6	Test the entire product in iterative sprints and improve the UI/UX of interfaces.	15th March - 15th April

4.2 PLATFORM DEVELOPMENT

As shown in Fig 5, the platform infrastructure is composed of 4 major parts: Blockchain, Backend, Database and Frontend. The following aspects played a major role in completing the platform development.

4.2.1 BLOCKCHAIN DEVELOPMENT

The blockchain development was done in a node.js project environment such that the future integration between front-end/ back-end of the mobile and web applications becomes simplified. The main dependencies of the project includes "@openzeppelin/contracts" and @alch/alchemy-web3" providing the skeletal ERC-721 smart contracts and blockchain connection infrastructure respectively.

The code base contains different sections responsible for the tokenization of goods as shown in (Fig. 7). Some of the most crucial parts are:

- **Contracts:** Contains all solidity files (smart contracts) used to make migrations and interact with the blockchain network.
- **Scripts:** Helper javascript files used to interact with alchemy to deploy contracts onto blockchain networks.
- **NFT.js:** Javascript file containing the function to mint the NFT, requires owner details and metadata as parameters.
- **NFT-Transfer.js:** Javascript file containing the function to transfer the NFT from one account to the other, requires owner details, intended target details and NFT token id as parameters.

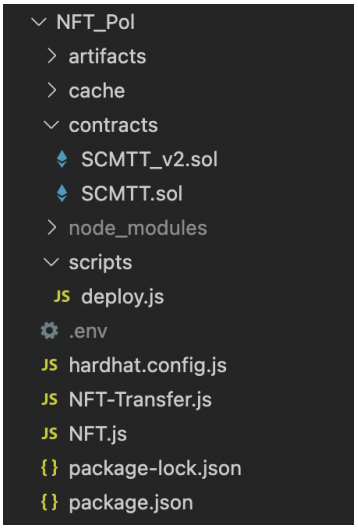

Fig. 7. Overview of Tokenization structure

4.2.1.1 SMART CONTRACT DEPLOYMENT

The smart contract is built using solidity. Solidity is an object-oriented programming language created specifically for constructing and designing smart contracts on Blockchain platforms. Programs in solidity run on the ethereum virtual machine platform. A snapshot of the solidity smart contract is below in Fig 8.

NFT_Pol > contracts > SCMTT_v2.sol

```
// SPDX-License-Identifier: MIT

pragma solidity >=0.8.0 <0.9.0;
import '@openzeppelin/contracts/token/ERC721/ERC721.sol';
import '@openzeppelin/contracts/utils/Counters.sol';
import '@openzeppelin/contracts/access/Ownable.sol';

contract SCMTT_v2 is ERC721, Ownable {
    using Counters for Counters.Counter;
    Counters.Counter private _tokenIds;
    using Strings for uint256;
    mapping(uint256 => string) private _tokenURIs;
    // Base URI
    string private _baseURIextended;
    constructor() ERC721('SCMTT_v2', 'SCMTT_v2') {}
    function setBaseURI(string memory baseURI_) external onlyOwner {
    _baseURIextended = baseURI_;
    }
    function _setTokenURI(uint256 tokenId, string memory _tokenURI)
    internal
    virtual
    {
    require(
    _exists(tokenId),
    'ERC721Metadata: URI set of nonexistent token'
    );
    _tokenURIs[tokenId] = _tokenURI;
    }
    function _baseURI() internal view virtual override returns (string memory) {
    return _baseURIextended;
    }
```

Fig. 8. ERC-721 token contract

This smart contract is deployed onto the polygon-mumbai blockchain network by utilizing the microservice Alchemy's pre-built APIs. Each interaction with the blockchain network is processed through the Alchemy microservice. The API-calls and interaction volume can be tracked using the Alchemy visualization service as shown in Fig 9.

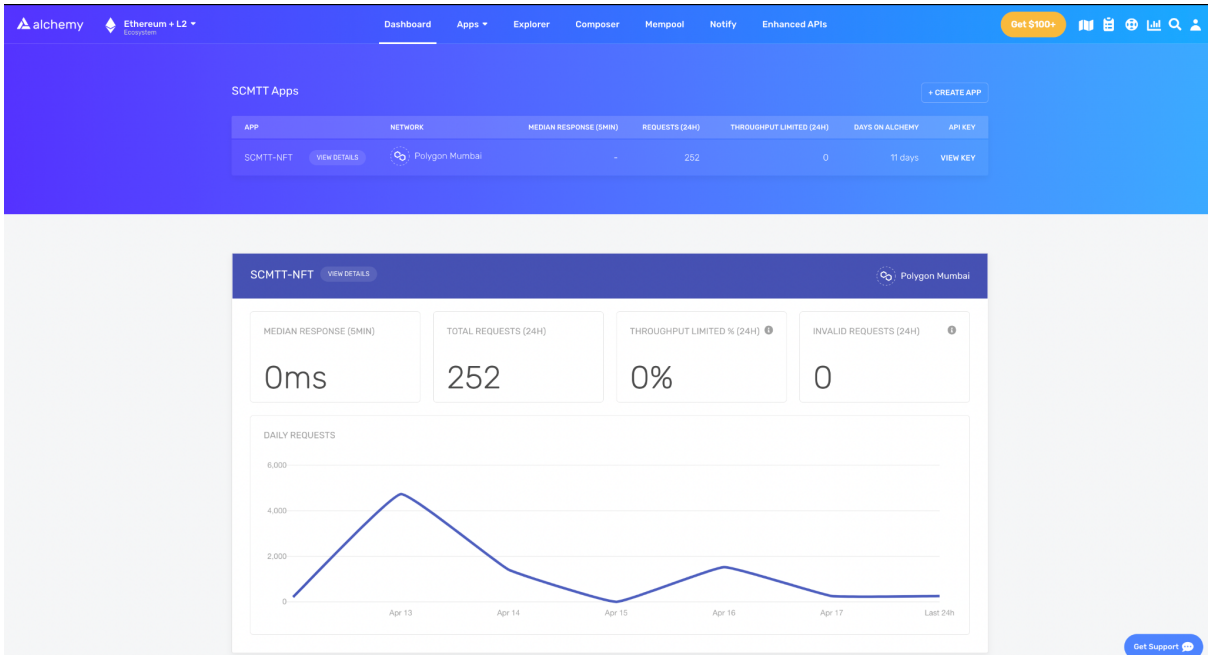

Fig. 9. Alchemy Dashboard

Post connecting with the blockchain network and interacting with it to deploy the smart contract, a transaction hash is received which can be tracked using mumbai.polygonscan.com, which is a block explorer and analytics platform that allows access to details on any Polygon blockchain transactions that are pending or confirmed. For example Fig 10. shows the contract creation and deployment on the network.

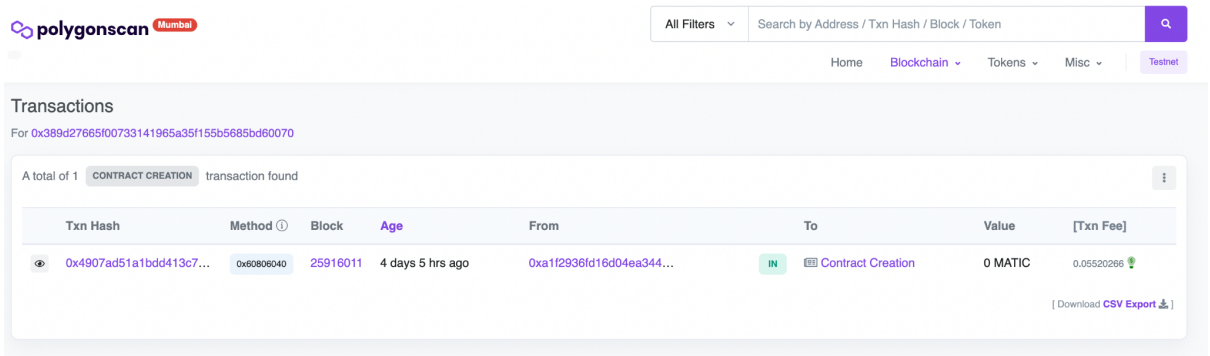

Fig. 10. Polygonscan Tracker

4.2.1.2 NFT METADATA PREPARATION AND STORAGE

The NFT metadata is a JSON object or file containing all details of the NFT to be minted. This includes the name, description, and many other attributes describing the specificity of the NFT. An example metadata is shown below in Fig 11.

```
const metadata = {
  name: "Shipment",
  description:
    "NFT representing a shipment, owner of the NFT claims ownership to the physical goods",
  attributes: [
    { trait_type: "Origin", value: "35 Produce Drive, Melbourne Market, Australia" },
    { trait_type: "Aussie Raspberries", value: "60" },
    { trait_type: "Australian Mandarins", value: "40" },
  ],
};
```

Fig. 11. Local NFT Metadata

This NFT metadata is then uploaded onto the IPFS data storage system by using Pinata.could services. Below in Fig 12, is the code to connect to Pinata.cloud services through APIs.

```
const authResponse = await axios.get("https://api.pinata.cloud/data/testAuthentication", {
        headers: {
          pinata_api_key: PINATA_API_KEY,
          pinata_secret_api_key: PINATA_SECRET_KEY,
        },
});

console.log(authResponse);

const data = new FormData();

const pinataJSONBody = {
      pinataContent: metadata
};
const jsonResponse = await axios.post("https://api.pinata.cloud/pinning/pinJSONToIPFS", pinataJSONBody, {
    headers: {
      'Content-Type': `application/json`,
       pinata_api_key: PINATA_API_KEY,
       pinata_secret_api_key: PINATA_SECRET_KEY,
    },
 });
 const { data: jsonData = {} } = jsonResponse;
 const { IpfsHash } = jsonData;
 const tokenURI = `https://gateway.pinata.cloud/ipfs/${IpfsHash}`;

 console.log(IpfsHash);
 console.log(tokenURI);
```

Fig. 12. Metadata uploading script

All NFT metadatas uploaded to IPFS by our users can be tracked and accessed using Pinata.cloud pinmanager service as shown in Figures 13 and 14.

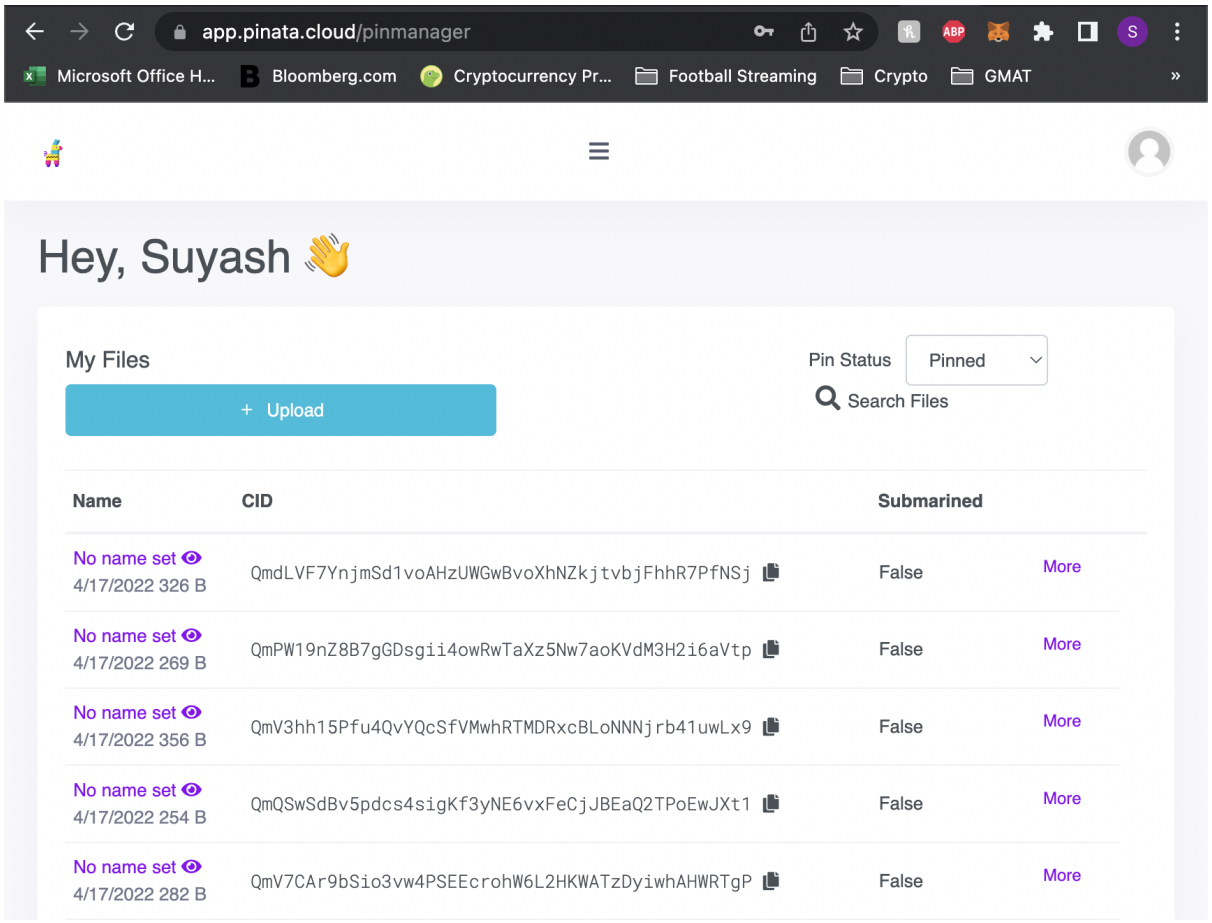

Fig. 13. Pinata Cloud Manager

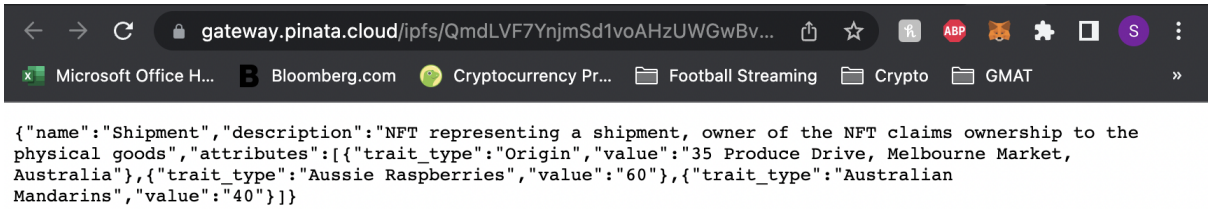

Fig. 14. NFT Metadata on IPFS network

4.2.1.3 NFT MINTING AND TRANSFER

The minting and transfer of NFT is carried out by the help of two scripts namely NFT.js and NFT-Transfer.js. The NFT.js file contains a function mintNFT which requires the NFT metadata, owner private key and owner public address as the parameters. On being called, it connects to the blockchain network, mints the NFT according to the deployed contracts specific and returns the transaction hash and token ID through which the token can be perpetually tracked as shown in Fig 15.

```
  data: {
    message: 'Congratulations! You are communicating with the Pinata API!'
  }
}
QmdLVF7YnjmSd1voAHzUWGwBvoXhNZkjtvbjFhhR7PfNSj
https://gateway.pinata.cloud/ipfs/QmdLVF7YnjmSd1voAHzUWGwBvoXhNZkjtvbjFhhR7PfNSj
Your Transaction Hash is: 0x3cd5e25a7bfcbaf1d42f41bc9d9ac924b09668026773ffcf9e82785c2c25d238
Token ID minted: 38
```

Fig 15. Console post calling mintNFT function from NFT.js

The NFT-Transfer file similarly contains a function transferNFT which requires the tokenID of NFT, sender's private key, sender's public address and receiver's public address as parameters. On being called it connects to the blockchain network and transfers the token as specified and returns a transaction hash through which the transfer can be verified. Both the minting and transfer activities of the NFT can be visualized using the open sea platform (Fig. 16)

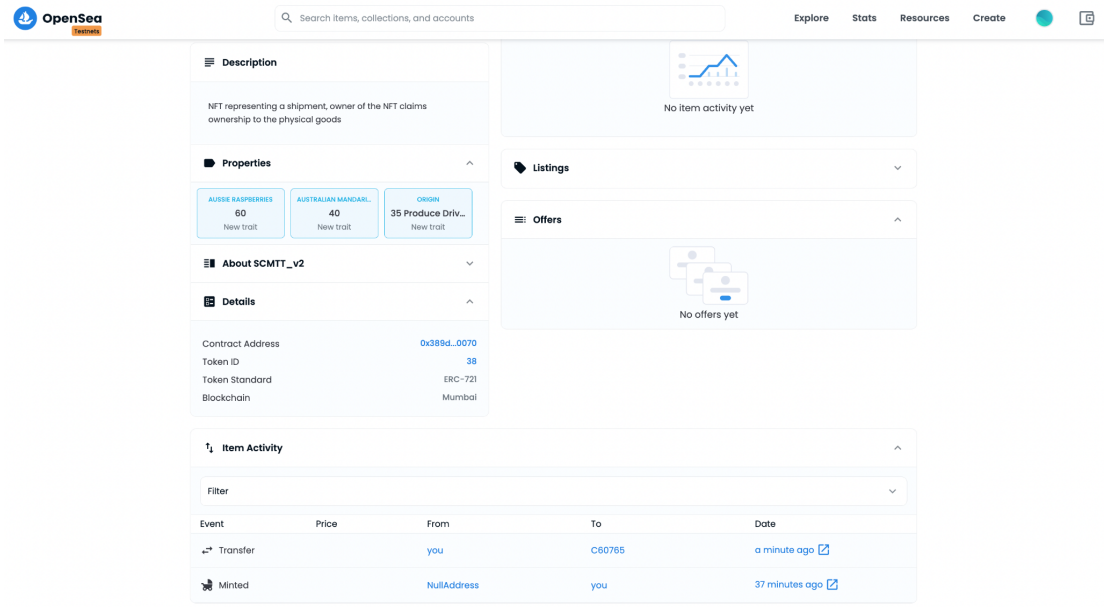

Fig.16. OpenSea - NFT visualization platform

4.2.2 MOBILE APPLICATION FRONTEND DEVELOPMENT

The mobile application has two types of users as shown in (Fig. 17): namely the employees in the companies supply chain and the general public acting as end-consumers.

- Supply chain members: Shall require a login using assigned credentials and can create,transfer and accept/reject tokenized shipments.
- End Consumers: Shall not require any login, can simply public view trace of origin of products and other details in a store.

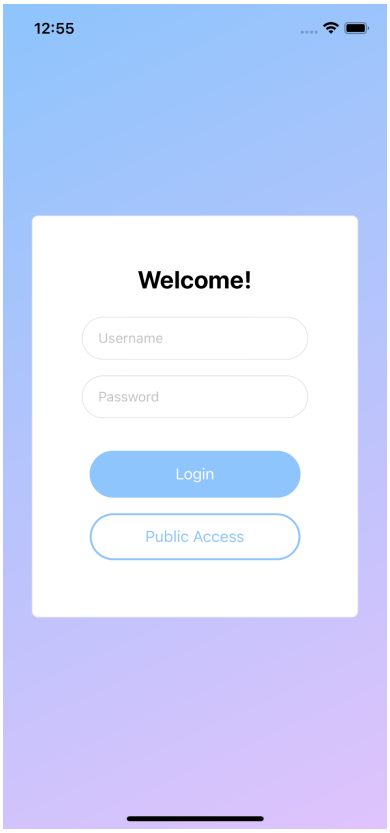

Fig.17 . Login Page

4.2.2.1 SCREENS: SUPPLY CHAIN MEMBERS

The supply chain members consist of the stores as well as the employees. Different types of users have access to different screens as shown in Fig 18. The screens are as follows:

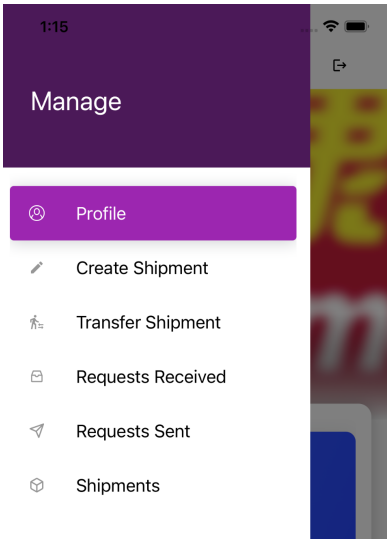

Fig.18 . Mobile menu bar

- **Profile Page:** Homepage for all features of the application. Employees have the additional functionality to create and transfer and view his/her shipments as compared to accepting/rejecting shipments function of stores.

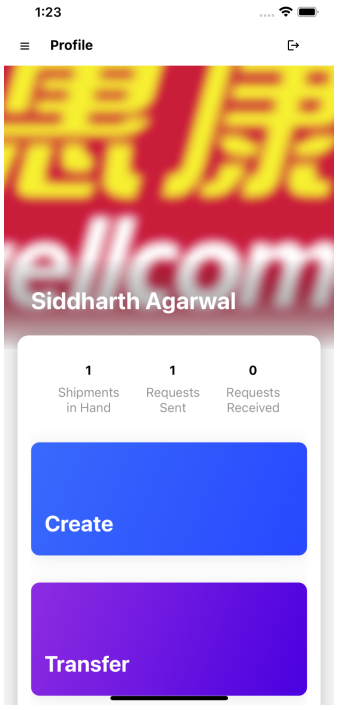

Fig.19 . Employee Profile Page

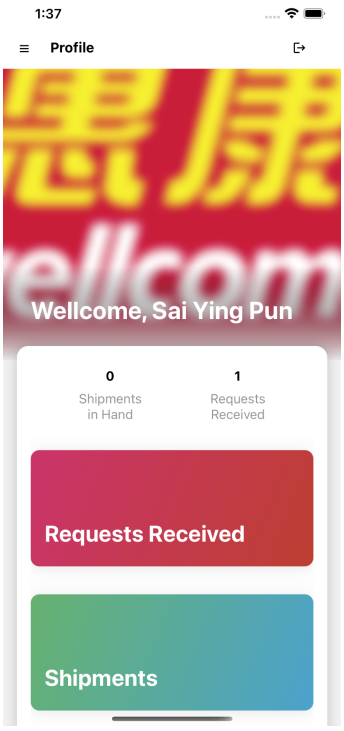

Fig.20 . Store Profile Page

- **Create Page:** This page allows employees to create a shipment representing the tokenized goods. Users can choose products, enter quantity and tag geo-location, which is then converted into the metadata of the NFT. Post minting, the employee is redirected to the profile page (Fig.23).

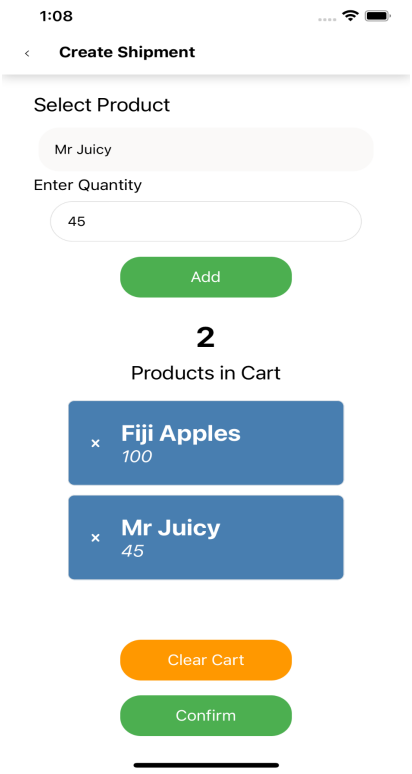

Fig.21. Create Page

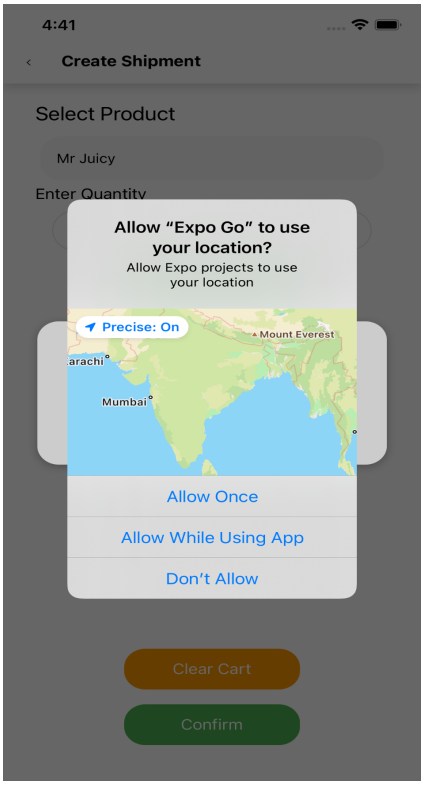

Fig.22. Mobile Location

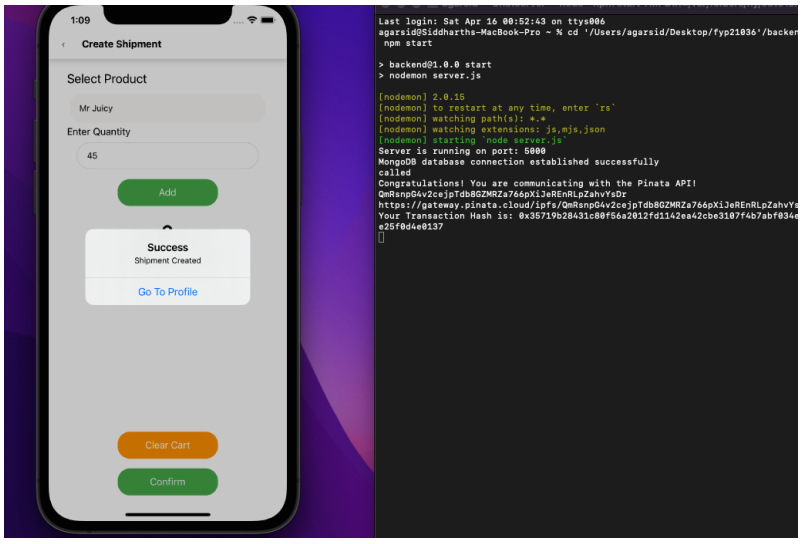

Fig.23. NFT Creation through Mobile App

- **Transfer Page:** Page to transfer a shipment owned by a user to another employee or store. On selecting the shipment id, the list of products in that shipment are displayed to prevent any error (Fig. 24).

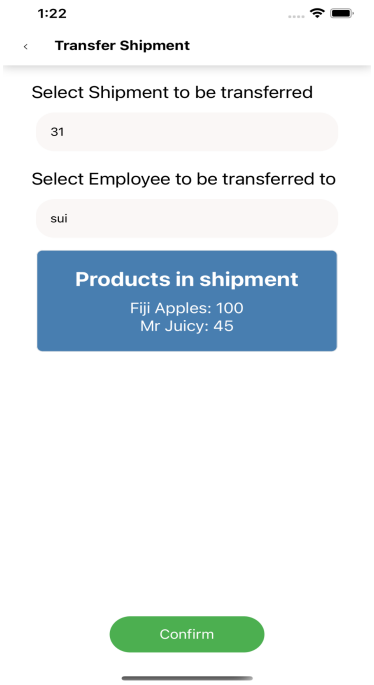

Fig.24. Transfer Page

On confirming, the transfer process is initiated wherein the relevant shipment is shown on the Requests Sent and Requests Received Pages of the sender and receiver respectively (Fig.25).

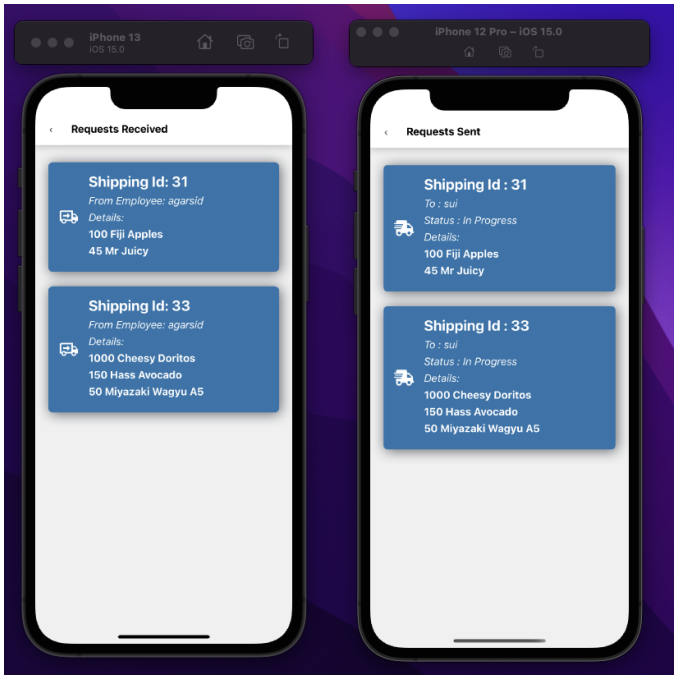

Fig.25. Requests Received (Left; user: sui) & Requests Sent (Right, user: agarsid)

- **Requests Received:** Both employees and stores have this functionality. As seen in Fig. , it displays all the shipments received from other employees. The user gets an option to accept or reject the shipment on clicking on the card (Fig.26). On acceptance, the NFT is transferred from the sender to the receiver. However, on rejection, the shipment remains with the sender.

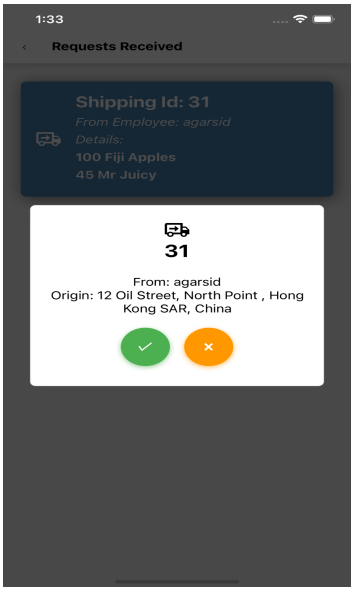

Fig.26. Handle Requests Received Page

- **Requests Sent:** Displays all shipments with its details that are sent to other users. Each shipment is tagged with a status field representing the status of NFT.
    - Accepted: NFT has been transferred and cleared from current page
    - Rejected: Issue sent to administrator, which needs to be manually resolved using web-dashboard.
    - In Progress: Waiting for receiver to accept/reject transfer request

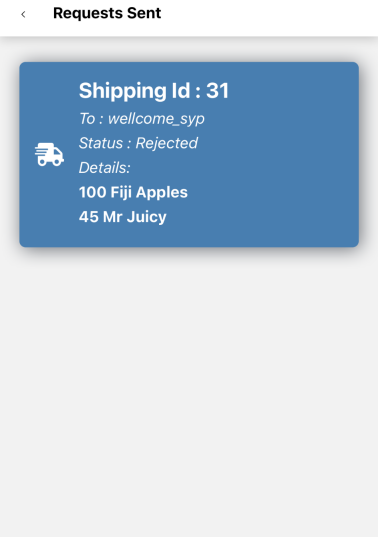

Fig.27 . Rejected Requests Sent Page

- **Shipments:** Displays all shipments owned by the user as shown in Fig 28.

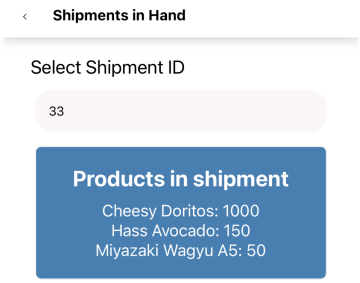

Fig.28 . Handle Requests Received Page

4.2.2.2 SCREENS: CONSUMERS (GENERAL PUBLIC)

The mobile application provides the consumers with three basic screens to trace the origin and confirm the authenticity of items.

- **Stores:** Users can search and select for stores as shown in Fig 29.

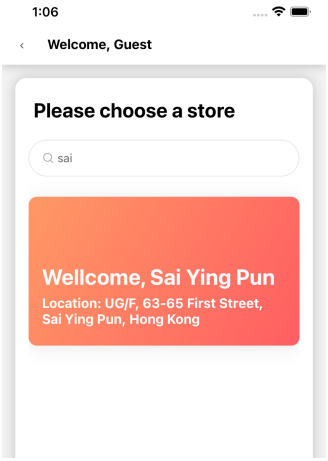

Fig.29. Select Store Page

- **Products:** Users can search and select for products in the selected store as shown in Fig 30.

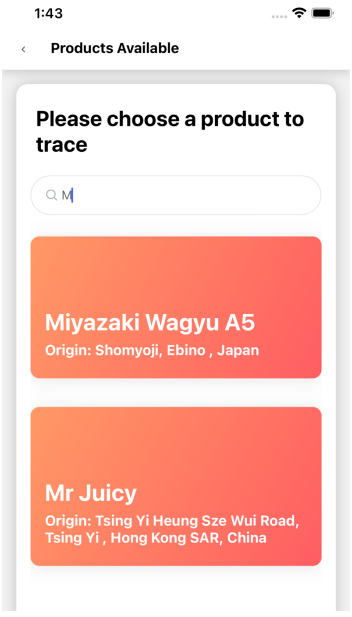

Fig.30 . Select Products Page

- **Product Trace:** Users can select a product and view the timeline of movements alongside a map with exact coordinates and address of the location as shown in Fig 31 & 32 below. This page helps to authenticate a product's origin and provides complete supply chain transparency to end-consumers.

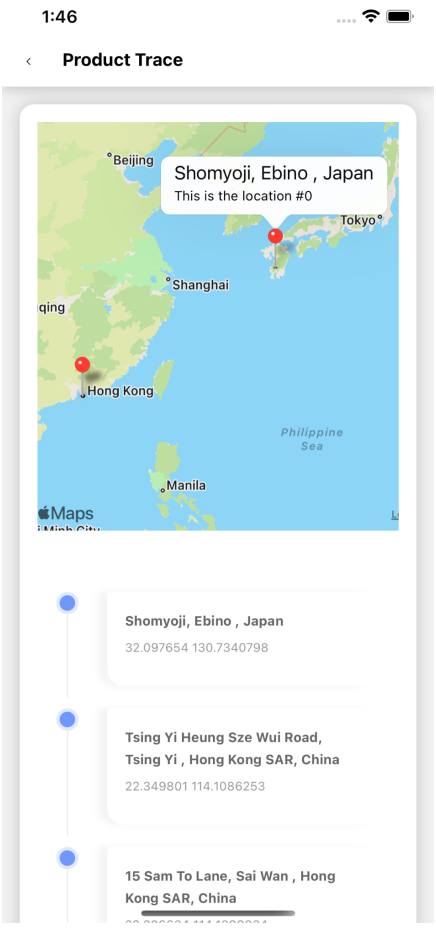

Fig.31 . Tracing Page 1

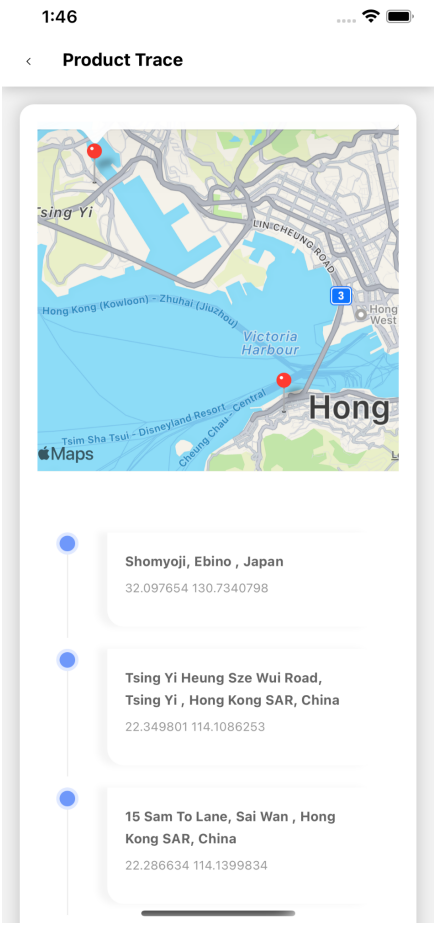

Fig.32. Tracing Page 2

4.2.3 WEB APPLICATION FRONTEND DEVELOPMENT

The Web application (Fig. 33) is designed to be used by company managers/ supply chain administrators.

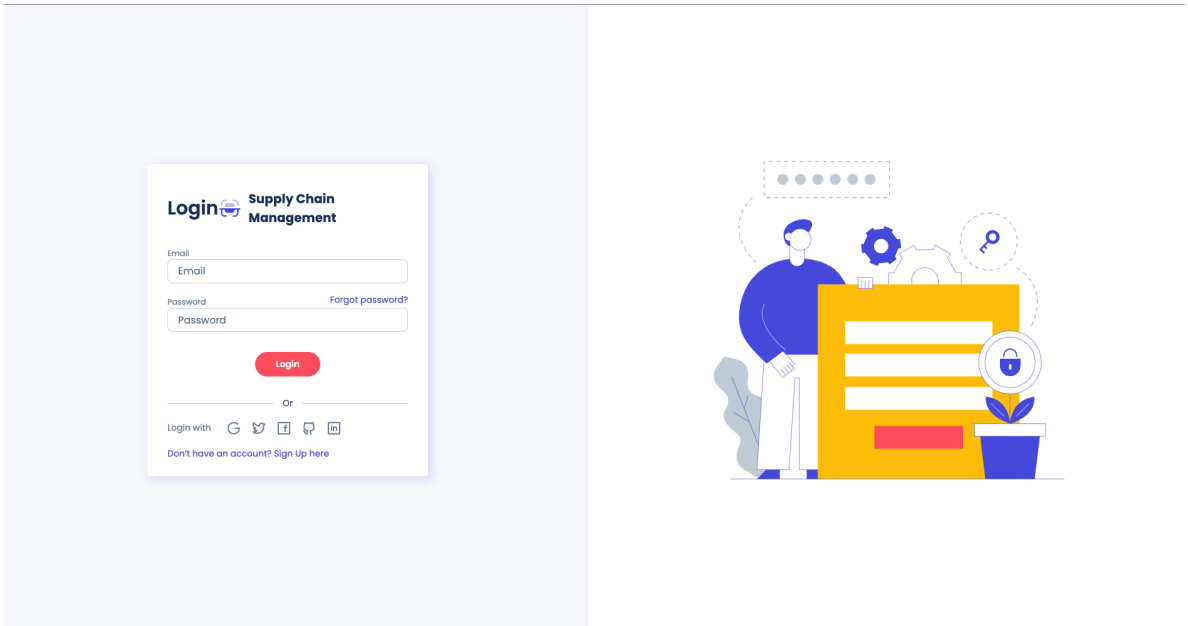

Fig 33. Web Application Login

4.2.3.1 SCREENS

The web application consists of three major pages each corresponding to an administrative function to be used by company managers:

- **User Management Page (Home Page):** Administrators can create new users and manage existing users through here. (Fig 34.)

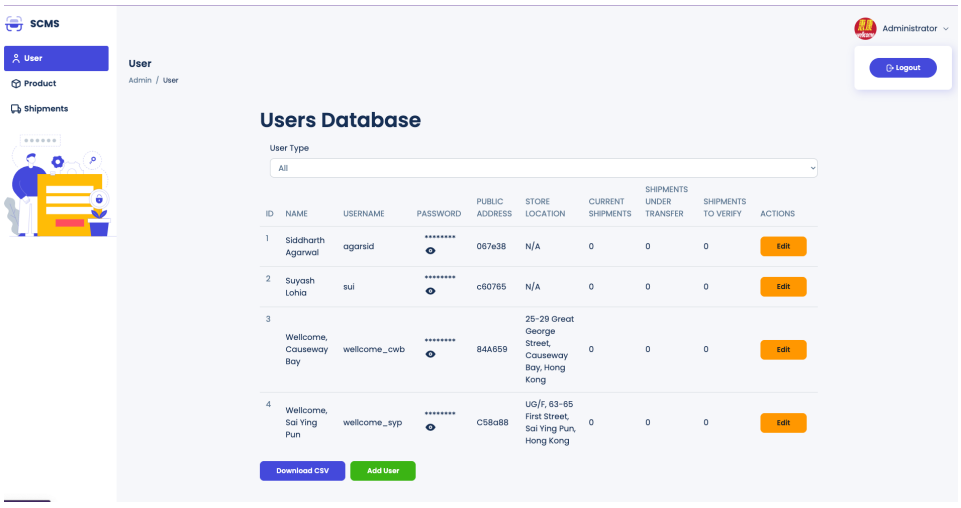

Fig 34. User Management Page / Homepage

They can also filter the view of the existing users into stores and employees (Fig. 35).

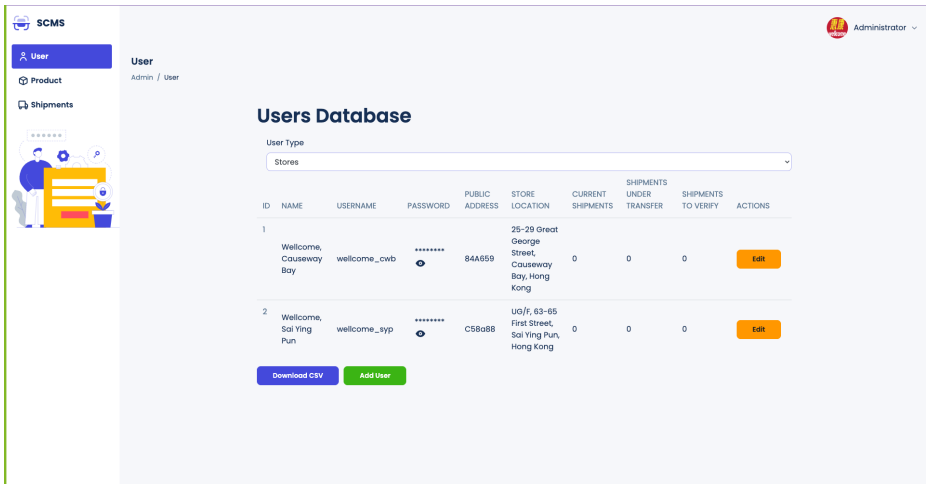

Fig 35. Filtered View of only Stores

New users are created to give them access credentials for the mobile application and to link their accounts to a company-managed cryptocurrency wallet which will hold all the tokenized shipments they own (Fig. 36).

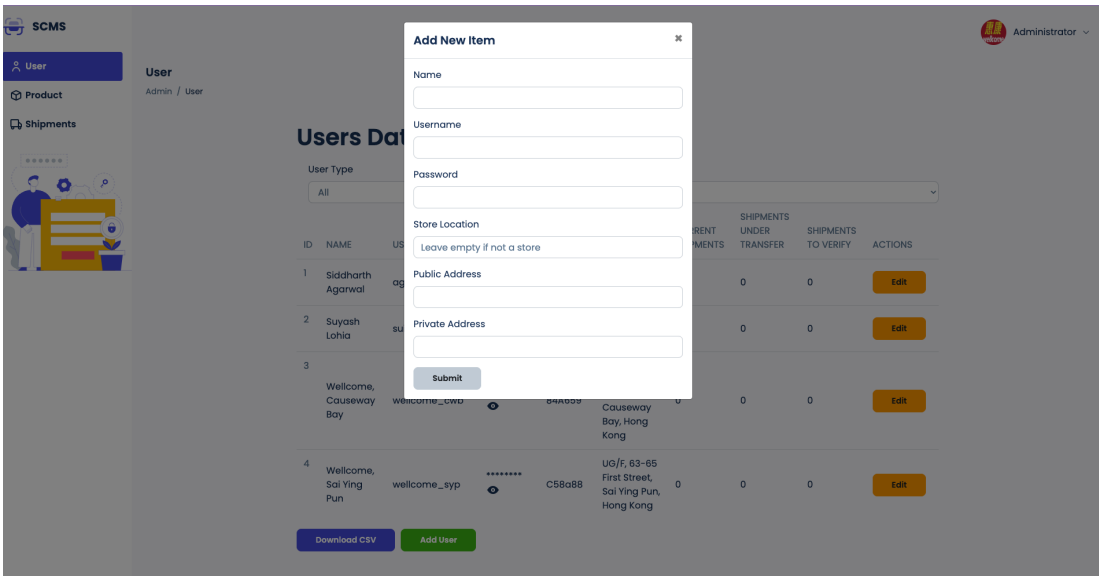

Fig 36. Add a new user

- **Products Management Page:** Administrator can manage the products database via this page. Each tokenized shipment in the platform consists of the products from this

database.

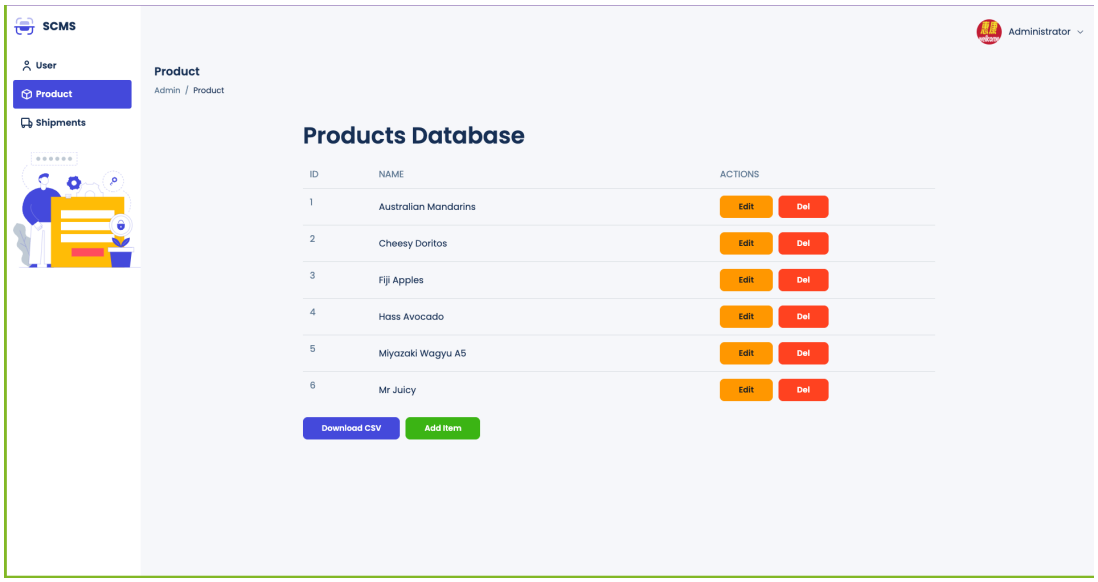

Fig 37. Products Management Page

- **Shipments Management Page:** Administrator can manage the shipments database via this page and solve shipment issues within the system.

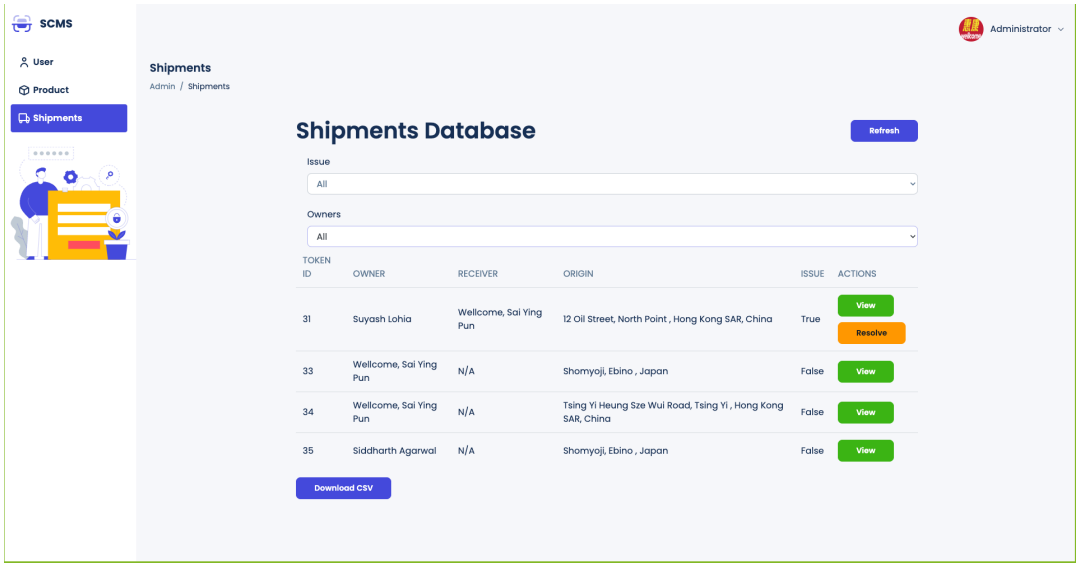

Fig 38. Shipments Management Page

Managers can view details about the products in the shipment, trace location history (Fig. 41) and also trace ownership history (Fig. 40). They are also provided with an OpenSea link to visualize the NFT.

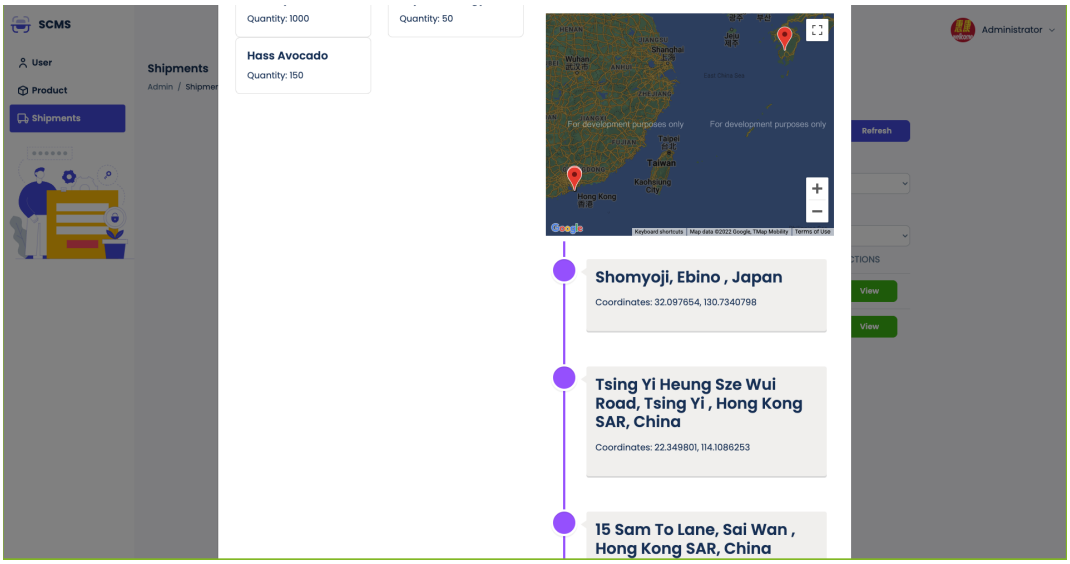

Fig 39. Shipment modal showing products and location history

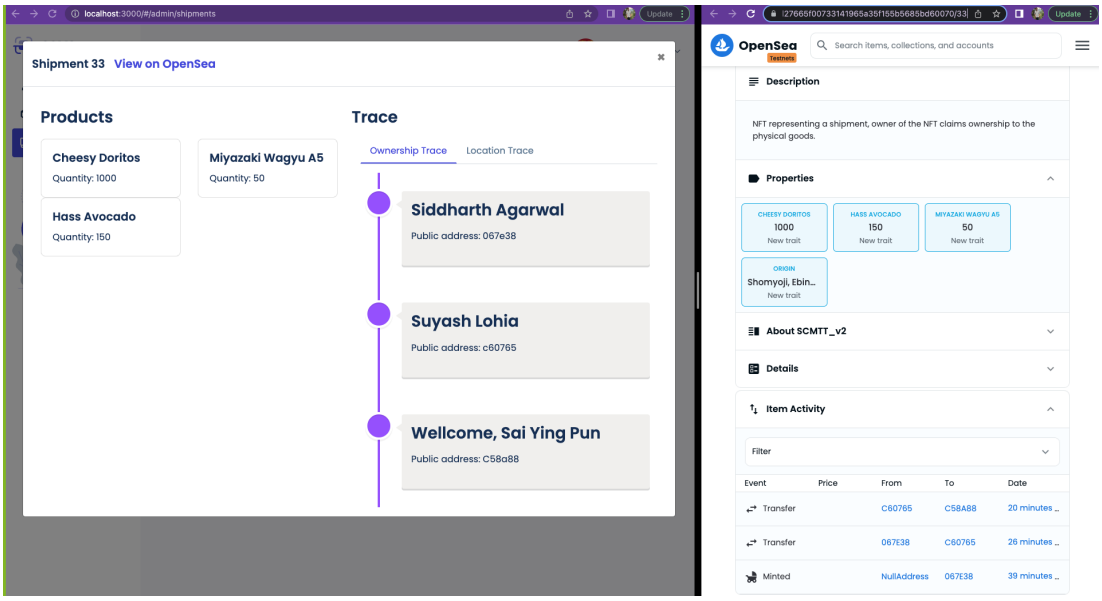

Fig 40. Ownership tracing in the modal (left) and shipment opened in OpenSea (right)

The page also provides a shipment resolution mechanism. Managers can edit quantities of products within the faulty shipment, post which a new NFT with updated metadata is minted having a link to the old shipment. (Fig. 41).

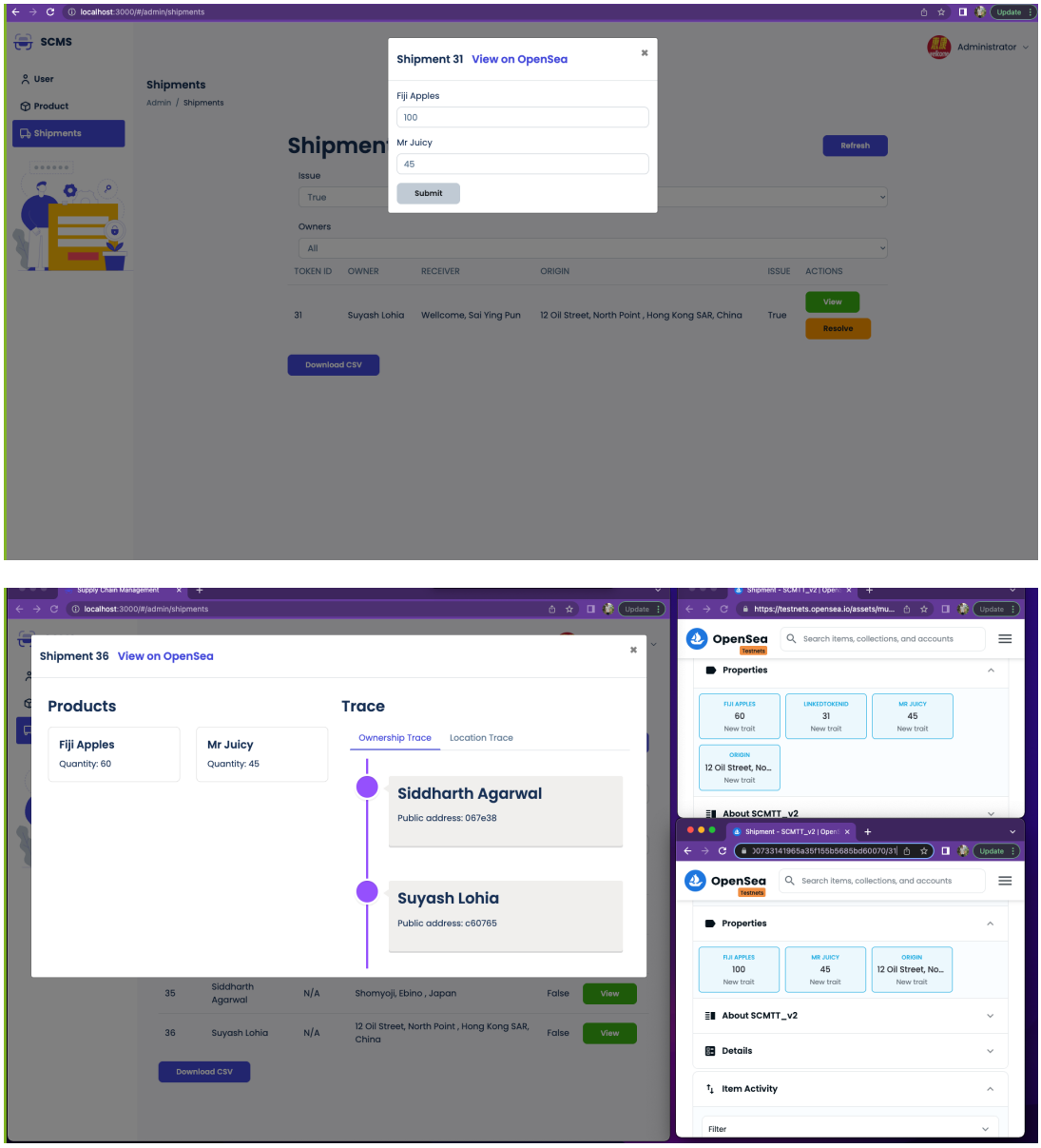

Fig 41. Shipment resolution modal (top) and new tokenized shipment with correct information based on the previous shipment (bottom)

4.2.2 BACKEND AND DATABASE DEVELOPMENT

As mentioned in section 3.2.2, Node.js and Express have been used for backend server-side development and MongoDB Atlas has been used for databases. All communication between frontend, backend, database and blockchain has been conducted through RESTful APIs.

To facilitate communication and achieve seamless operation of the above screens, different API routes have been developed. Table 3. Explains routes interacting with the blockchain network by calling the minting NFT and transfer NFT functions.

Table 3. Shipment-related routes

Protocol	Route	Description
POST	/create-shipment/:username	Mints an NFT for the shipment object and on successful creation adds the object to the current shipments of the specified username.
POST	/transfer-shipment/:username	Initiate the transfer process of the shipment from the specified username to the specified user in the request body as a requested shipment

The database solutions contain models such as ‘products’, ‘users’, ‘sentShipments’, ‘reqShipments’ storing data essential for communication and product workflow. The metadata for the NFT is generated from these databases and further sent over for uploading on IPFS.

5 DISCUSSIONS

This section includes the limitations of the product developed, the challenges encountered while building the product as well as the future steps.

5.1 LIMITATIONS

The biggest limitation for this product is that it requires a smartphone and constant connection to the internet for the transactions to take place and the data to render. With high and growing adoption rates, we believe that it shouldn't be a barrier for industry adoption. Any blockchain based product has a steep environmental impact even after adopting the best practices. However, we expect these costs to be reduced with constant development in the technology to reduce environmental impact. Apart from these, if the quality of goods degrades in the supply chain due to external factors like weather, the application can detect the point of degradation but not determine the exact reason for it.

5.2 CHALLENGES

One of the biggest challenges we faced was the high gas and transaction fees in blockchain solutions. However, we overcame this barrier by researching into a Layer 2 scaling solution and implementing the Polygon technology. Another challenge faced, includes the aspect of human error while creating and transferring these shipments being irreversible due to the nature of blockchain technology. We have tried our best to mitigate this issue by developing a very high quality UI and asking for multiple confirmations before posting the transactions. Lastly, if a consumer wants to trace homogeneous goods, it can be done so by implementing a QR-code system in the entire supply chain which can then be added onto the shipment data. This solution, however, requires the cooperation of business to ensure the practice is followed rigorously.

5.3 FUTURE PLANS

The team aims to further launch a beta version of the product on app marketplaces such as Appstore, Playstore and further approach businesses to try out the product and receive client feedback. The team shall be adopting a continuous research and development approach to better the product through innovations. These include integrating QR codes solution to tackle traceability of homogeneous goods, building an analytics dashboard to provide business managers with interesting insights, and lastly integrating with existing ERP solutions to transform into a fully functional SaaS (Software as a Service) company.

6 CONCLUSION

There are various existing solutions to facilitate the tracking and authentication of goods in the SCM and Logistics industry, however, all of them are inefficient and do not prevent loss of goods entirely. The SCM system proposed by our team aims to solve this problem by utilising NFT and blockchain technology, while providing a foolproof, transparent and traceable service of tracking goods across the supply chain.

The team has finished the development of the project, having extensively researched and ideated on various fronts. The team will be progressing towards the next phase of the project which is mentioned in section 5.3 including building the analytics dashboard, integrating with ERP solutions and further trying to maximize client onboarding and setup a feedback and maintenance mechanism. With the ultimate aim of becoming a company with an industry applicable product, the team shall be looking to convert into a fully functional startup raising funds and simultaneously aggressively acquiring clients to grow our market share.

In the future, after the culmination of our product development and release, there is scope for industry wide expansion through potentially expanding the functionality of our product. The team plans to research into this avenue and further explore other use cases facilitating expansion from the SCM system to other industries.

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