Smart Urban Tree Valorization: An AI-Blockchain-Based Application for the Preservation of Remarkable Trees

Hajer Nabli[1,a], Issra Jegham[1], Yasmine Zorgati[1], Rania Ajmi[2], Raoudha Ben Djemaa[1] and Layth Sliman[3]

[1]University of Sousse, Higher Institute of Computer Science and Communication Technologies of Sousse/Miracl Lab, Sousse, Tunisia

[2]University of Sousse, High Institute of Agronomic Science of Chott Mariem, Sousse, Tunisia

[3]Paris Pantheon-Assas University, Efrei Research Lab, Villejuif, France

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Abstract: Urban trees contribute significantly to the well-being of city dwellers by improving air quality, reducing heat, and offering psychological and cultural value. Among them, remarkable trees—due to their rarity, size, age, or symbolic importance—deserve special attention, yet they often remain poorly documented or undervalued. This paper introduces a smart application that uses artificial intelligence (AI) and blockchain to enhance public awareness and long-term recognition of these trees. The system features an AI-driven chatbot that interacts with users by asking questions about tree types or suggesting trees based on their desired benefits—such as relaxation, biodiversity, or carbon absorption—thus guiding users toward relevant and meaningful discoveries. In parallel, each remarkable tree is assigned a blockchain-based digital certificate in the form of a non-fungible token (NFT), ensuring that its identity, characteristics, and location are securely recorded and verifiable. By combining participatory exploration with digital certification, this approach offers a novel tool for cities to promote biodiversity, support environmental education, and foster citizen involvement in urban green heritage. The proposed system fills a gap between static tree mapping platforms and dynamic, secure, and intelligent urban biodiversity applications.

1 INTRODUCTION

Urban ecosystems are vital for sustainable development, providing ecological, health, and social benefits. Among these, urban trees help filter air pollutants, mitigate heat islands, sequester carbon, support biodiversity, and contribute to well-being and cultural identity (Torres and McDonald, 2021). Remarkable trees—distinguished by age, size, rarity, or symbolic value—hold particular ecological and heritage importance but are often under-identified or overlooked in urban planning (Yoon and Fischer, 2023).

Existing digital platforms for urban tree management rely on static inventories or geographic information systems (GIS), offering basic information but lacking personalized, interactive features. They rarely engage citizens in discovering, monitoring, or preserving urban tree heritage, limiting opportunities for public participation and environmental education (Mullaney et al., 2015; Li and Wu, 2022).

Advances in Artificial Intelligence (AI) and Blockchain can address these gaps. AI enables natural language understanding, personalized recommendations, and context-aware interaction (Radhakrishnan et al., 2022), while Blockchain ensures transparent, immutable, and verifiable data records (Treiblmaier, 2018; Abdelghani et al., 2023; Abdelhamid et al., 2024).

This paper presents a smart AI- and blockchain-based system for valorizing and preserving remarkable urban trees, comprising two main components:

- An AI-powered chatbot that allows citizens to explore trees via natural language queries and receive personalized suggestions based on ecological, recreational, or carbon-sequestration criteria.
- A blockchain-backed certification mechanism that Assigns each tree a non-fungible token (NFT)

[a] https://orcid.org/0000-0002-3603-251X

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storing its identity, characteristics, and geolocation in a secure, tamper-proof format.

By combining intelligent interaction with secure digital certification, the system promotes urban biodiversity, environmental education, and citizen engagement.

The remainder of the paper is structured as follows: Section 2 reviews related work, Section 3 details the system architecture, Section 4 presents implementation and evaluation, and Section 5 concludes with key findings and future directions.

2 RELATED WORK

The integration of digital tools in the monitoring and preservation of urban trees has gained traction in recent years (Varveris et al., 2023; Nandhini et al., 2021). This section reviews existing works across three key dimensions relevant to our application: (1) urban tree mapping platforms, (2) AI-powered chatbots for environmental engagement, and (3) blockchain and NFTs for ecological and cultural heritage certification.

2.1 Urban Tree Mapping Platforms

In recent years, a growing number of digital platforms have been developed to document, share, and promote urban tree inventories. These tools support biodiversity awareness, engage local communities, and often aim to inform urban planning and conservation efforts.

Among the most notable is Moabi[1], a French mobile application specifically designed for the participatory referencing of remarkable trees. Moabi empowers both citizens and professionals to geolocate trees, upload photographs, and contribute descriptive information such as species, dimensions, or historical anecdotes. The platform seeks to build a nationwide, crowdsourced inventory of ecologically and culturally significant trees, thus fostering broader public involvement in environmental heritage preservation.

Other important initiatives include TreeMap LA, developed by TreePeople[2], which enables users in Los Angeles to view, add, and update data related to street and park trees. It emphasizes civic participation in tree maintenance and urban forestry. Similarly, TreeTalk London[3] provides interactive green walking routes, combining cartographic interfaces with biodiversity data to enhance public engagement with the urban forest. On a broader scale, OpenTrees[4] aggregates tree inventory datasets from over 60 cities worldwide and offers an API for basic visualization and data access.

While these platforms clearly demonstrate the benefits of community engagement and geospatial visualization in urban ecology, they present several limitations in the context of long-term heritage recognition and digital certification. Most systems:

- Lack of interactive or intelligent educational components: these platforms do not include features like conversational agents or other tools that encourage user learning and exploration
- Lack of data verification or authentication mechanisms: there are no reliable processes to confirm tree uniqueness, origin, or historical significance
- Absence of user feedback or annotation options: users cannot provide input or add notes, limiting engagement and the dynamic nature of environmental storytelling
- Lack of durable, tamper-proof records: these systems fail to maintain persistent, secure identities for trees over time

These limitations reduce their effectiveness for supporting institutional recognition, long-term traceability, and the symbolic valorization of individual trees — particularly in cases where trees are considered urban natural heritage assets. In contrast, our proposed platform introduces a proactive AI chatbot and a blockchain-backed certification system, enabling more secure, informative, and user-centered interaction with urban trees.

2.2 AI Chatbots for Agriculture and Environmental Awareness

AI-driven chatbots are increasingly adopted in agriculture to provide farmers with real-time information, facilitate crop management, and support informed decision-making (Pravinkrishnan et al., 2022; Ong et al., 2021; Niranjan et al., 2019; Chathurya et al., 2023). These systems typically combine natural language processing (NLP) techniques to interpret user queries, classification algorithms to detect crop-related issues or suggest interventions, and rule-based methods to organize domain knowledge and generate context-aware responses.

AgronomoBot (Mostaco et al., 2018) is developed to assist farmers by retrieving real-time data from

[1]https://www.moabi.re/
[2]https://www.treemap.in/#home
[3]https://www.treetalk.co.uk/
[4]http://opentrees.org/

wireless sensor networks deployed in vineyards. Using the Telegram messaging platform, it interacts with users via natural language and leverages IBM Watson services for intent recognition. Its goal is to facilitate fast and context aware access to environmental data, including soil and climate conditions, thus enhancing agricultural decisions. However, it is highly domain-specific, lacks entity-level interactions, and does not support static, descriptive data like botanical attributes or historical context. It also lacks integration with web platforms or map-based visualization, which are key to our project.

Similarly, Agribot (Arora et al., 2020) employs an LSTM-based conversational model combined with CNNs for plant disease detection and weather forecasting. Though technically advanced, it is built for broad agricultural tasks and lacks support for user-generated feedback, location-specific recommendations, or interactive interfaces beyond Telegram.

A third system, AgroBot (Marla et al., 2023), trained on India's Kisan Call Center data, is a voice-enabled chatbot designed to answer farming-related questions using RNNs and deep learning. However, it is based on a closed dataset, produces pre-scripted responses, and provides no interface for visualizing or contextualizing environmental entities, making it less suitable for heritage or educational goals.

Adding to these, (Usip et al., 2022) propose a mobile chatbot using ontologies and similarity algorithms to assist Nigerian farmers. While effective for localized knowledge retrieval, it lacks multimodal interaction, emotional or well-being-based inputs, and does not manage individual entities with rich metadata (such as specific trees).

Despite their contributions, current agricultural chatbots share key limitations in the context of our goals:

- No support for entity-specific interaction: These systems do not manage individualized, georeferenced environmental objects like remarkable trees
- Absence of user well-being perspective: They are focused on factual problem-solving, not on proposing nature-based recommendations tied to emotional or ecological benefits
- Lack of participatory or community layers: Existing chatbots do not engage citizens in co-producing data or contributing to environmental heritage awareness
- Minimal interface diversity: Most are mobile- or Telegram-based with no map-based, web-integrated experiences.

Our chatbot addresses these gaps by reversing the interaction flow: it asks users about their desired benefits (e.g., shade, air purification, relaxation), then recommends specific remarkable trees that match those goals. This design supports exploratory environmental learning, enhances citizen engagement, and aligns with broader urban biodiversity and well-being objectives.

2.3 Blockchain for Digital Environmental Certification

In recent years, blockchain technology has emerged as a powerful tool for ensuring the transparency, traceability, and authenticity of data in agricultural and environmental contexts (Kamble et al., 2020; Slama et al., 2024; Nabli et al., 2025). Several blockchain-based frameworks have been proposed, particularly in the domains of organic certification, supply chain tracking, and customer engagement through tokenization. While these systems have shown technical and conceptual maturity, their design and goals differ significantly from applications intended to valorize urban natural heritage, such as remarkable trees.

One notable contribution is the SAFE platform (Tegeltija et al., 2022), designed to automate and secure organic agriculture certification by combining IoT sensors and blockchain smart contracts. By streamlining data collection and validation, SAFE reduces administrative burdens and enhances consumer trust. However, the platform focuses on standardized certifications in agricultural production and does not address subjective or cultural valuation, which is central to heritage tree recognition. Additionally, it lacks support for non-fungible digital identities like NFTs that can uniquely represent individual natural entities.

Another approach by Santos et al. (Santos et al., 2023) introduces a blockchain-based system for certifying agri-food harvests through ERC-standard NFTs. Their solution emphasizes fine-grained traceability and anti-fraud measures within the food supply chain. Yet, it assumes tokens are consumable and temporary, as they are burned post-sale—an approach incompatible with the long-term tracking and preservation needed for the digital identity of heritage trees. Furthermore, the model focuses on fungible products, whereas urban trees require rich, non-fungible representations embedded with ecological, historical, and visual data.

A third work explores smart agriculture assurance through blockchain and IoT integration (Hasan et al., 2024). It proposes an architecture involving real-time sensors, oracles, IPFS, and permissioned blockchain for sustainability certifications (e.g., organic, non-GMO). While technically robust, the system targets dynamic agricultural conditions, not static environmental assets. Its reliance on costly hardware, complex infrastructure, and continuous data streams makes it poorly suited for urban biodiversity valorization, where the emphasis is on accessibility, longevity, and public interaction rather than real-time monitoring.

Finally, Hosseinalibeiki and Zaree (Hosseinalibeiki and Zaree, 2023) present a model for NFT-based loyalty programs in agribusiness, leveraging smart contracts to reward customer behavior. Their NFTs include metadata (photos, certificates) to reinforce personalization and trust. While conceptually closer to symbolic valorization, their system remains rooted in commercial use cases and lacks features critical to environmental education, public engagement, or urban planning integration. The absence of interactive maps, botanical classification, or user-centered ecological narratives limits its relevance to urban tree heritage.

Across these studies, several limitations emerge in relation to our objectives:

- Context mismatch: Most works focus on agriculture and product certification, not on natural, static assets like urban trees or their cultural and ecological importance
- Temporal design: Many systems rely on ephemeral tokens tied to transactions or seasonal data, whereas our NFTs must persist over time to reflect ongoing tree status and legacy
- Lack of rich metadata: Existing NFTs often lack botanical, historical, or geographic attributes, which are essential for tree valorization
- No citizen engagement layer: The reviewed systems do not include interactive, participatory platforms involving municipal authorities, citizens, or educators
- Overly complex architecture: Several solutions rely on heavy technical stacks (e.g., IoT, IPFS, CRM), which are ill-suited for lightweight, educational, and publicly accessible web/mobile platforms.

In response, our work introduces a blockchain-based system for certifying remarkable urban trees through NFTs enriched with multi-dimensional metadata (e.g., age, species, photos, location, cultural stories). Certification is triggered by a smart contract upon validation by municipal authorities and stored immutably on the blockchain. Unlike agricultural systems, this framework is not designed for economic traceability but for heritage recognition, citizen awareness, and digital conservation.

3 SYSTEM DESIGN AND ARCHITECTURE

The proposed application is a modular, AI- and blockchain-based system designed for the digital valorization of remarkable urban trees. Its architecture integrates three complementary technological pillars, each addressing a critical aspect of the valorization process. Figure 1 illustrates the high-level architecture and interaction between system components.

- Web-Based Interface: This component provides an interactive map interface allowing users, citizens, urban planners, and environmentalists, to explore and contribute geo-referenced data on remarkable urban trees. It supports dynamic visualization of tree locations, species, and health status, fostering community awareness and engagement.
- AI-Driven Recommendation Chatbot: Integrated with the geographic interface, the AI chatbot offers personalized recommendations and informative responses regarding tree care, species identification, and environmental benefits.
- Blockchain-Powered Certification Engine: To ensure the integrity and transparency of tree-related data, a blockchain certification engine registers and certifies remarkable trees on a decentralized ledger. Each certified tree is represented as a Non-Fungible Token (NFT), enabling trusted digital recognition and long-term data preservation.

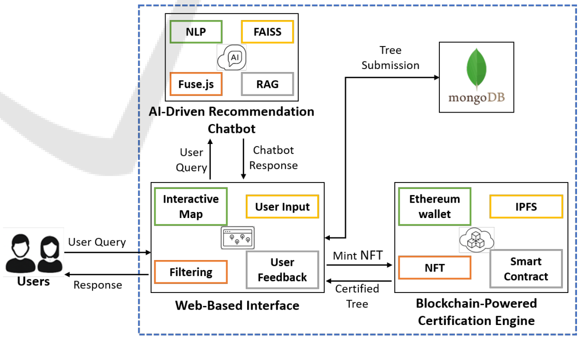


Figure 1: Smart Urban Tree Valorization System Architecture.

3.1 Web-Based Interface

The web-based interface serves as the central module of the platform, offering users a structured, interactive, and intuitive environment to explore and engage with remarkable urban trees. Designed as a responsive web-mobile application, this interface supports the valorization, management, and digital certification of ecologically or culturally significant trees. It bridges the gap between citizens, urban planners, and municipal authorities by providing accurate botanical data, geolocation tools, and participatory features within a unified interface.

Upon launching the platform, users are welcomed by a public homepage presenting the goals of the project and its environmental importance. Authenticated users are granted access to personalized dashboards, with functionalities that vary depending on their assigned roles (Regular User, Admin, Super Admin). To clarify the interactions between the system and its different user types, Figure 2 presents a use case diagram illustrating the functionalities available to each role.

Three primary actors are defined: User, Admin, and Super Admin, as well as two external components: an AI Chatbot and a Blockchain Platform. Each actor interacts with the system through a set of functionally distinct use cases.

The *Regular User* interacts with the system through several core functionalities, each corresponding to specific use cases within the system's architecture:

- Register and Authenticate use cases: Users can create a personal account and securely authenticate themselves using standard login procedures. This ensures personalized access and enables participation in interactive features such as reviews and chatbot queries.
- Explore Trees use case: The user can browse the complete inventory of remarkable urban trees through two complementary interfaces: an interactive map view (Explore Trees on Map use case) and a structured list view (Explore Trees on List use case). The map supports both OpenStreetMap and satellite layers, with each tree represented by a clickable marker that reveals detailed profile information, including the common names, botanical family, age, and height (See Figure 3). In the list view, users can apply search and filtering options to refine the inventory based on various criteria, such as species, age, or name.
- Submit Review use case: After exploring a tree, users can submit a rating and review through the system. Each review allows users to assess several aspects, including perceived air quality, ambient noise level, cleanliness of the surroundings, accessibility and visibility of the tree, and its apparent health and maintenance status. Users can also provide open comments and suggestions (See Figure 4). This participatory use case encourages public engagement and contributes to the collective knowledge about remarkable urban trees.
- Ask Question use case: This use case introduces a generative *AI chatbot* that enables users to ask natural language questions about remarkable urban trees. Through the included Respond to Tree Inquiry use case, the chatbot interprets user intent and generates context-aware responses, ranging from factual information about specific trees (e.g., species, age, ecological value) to personalized recommendations (e.g., quiet spots, accessible trees). This interactive feature fosters public engagement in the preservation and appreciation of urban natural heritage.

In addition to the regular user's core functionalities, the system provides dedicated use cases for the *Admin* role, including:

- Manage Tree Data use case: The *Admin* can add, update, or delete tree profiles within the system. This includes managing detailed information such as scientific and common names, species, age, height, trunk circumference, location, and uploading representative photos to ensure accurate and up-to-date tree records.
- Manage Users use case: The *Admin* oversees user accounts by creating, updating, or removing users.
- Certify Tree use case: The *Admin* submits a certification request for a tree by verifying its attributes and confirming it meets preliminary criteria for recognition as a remarkable urban tree. The final validation and approval of the certification are performed by the *Super Admin*, ensuring the credibility of the system's inventory.

Beyond *Regular User* and *Admin* functionalities, the system includes specialized use cases reserved for the *Super Admin* role, responsible for high-level management tasks, including:

- Manage Admins use case: The *Super Admin* oversees admin accounts by creating, updating, or removing admin users.
- Validate Tree Certification use case: The *Super Admin* reviews and approves tree certification requests submitted by admins. The certification process involves a secure interaction with the *Blockchain Platform*, represented by the Create Tree Certificate use case.

3.2 AI-Driven Recommendation Chatbot

The AI-driven chatbot module constitutes a key component of the proposed system, designed to assist users in discovering remarkable urban trees according to their preferences, location, or well-being in-

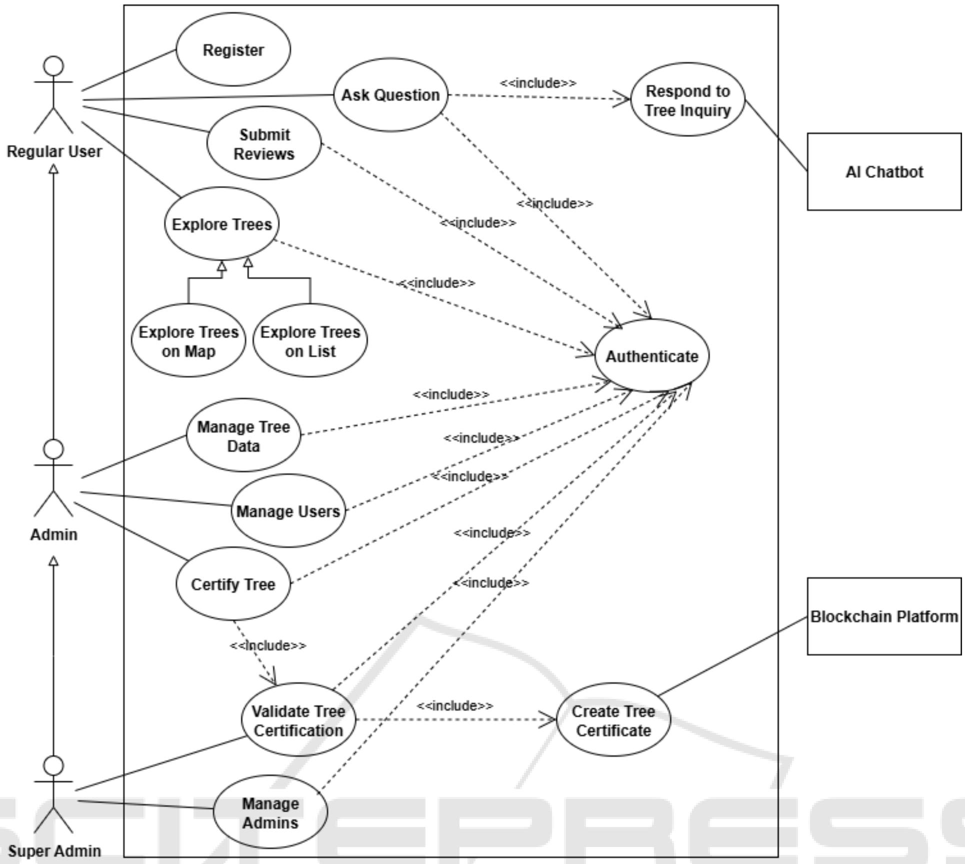


Figure 2: Use Case Diagram: Functionalities by User Role.

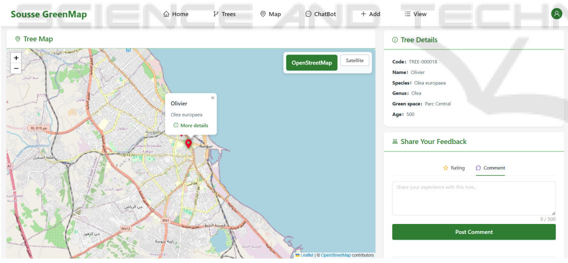


Figure 3: OpenStreetMap Interface Displaying Details of a Selected Tree.

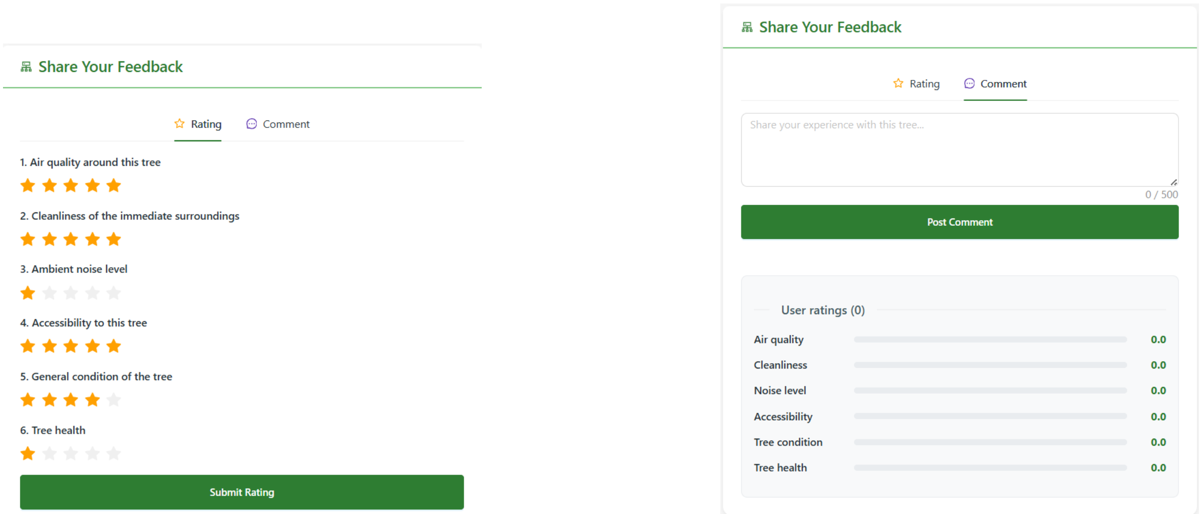
tentions. Unlike traditional static query interfaces, this chatbot dynamically interprets natural language input, offering interactive and personalized suggestions (Nabli et al., 2024). As illustrated in Figure 5, the chatbot adopts a hybrid, multi-layered architecture combining three intelligent modules: a Natural Language Processing (NLP) module for understanding user intent, a fuzzy keyword-based retrieval system powered by Fuse.js, and a semantic vector search integrated with a Retrieval-Augmented Generation (RAG) pipeline.

3.2.1 Natural Language Processing (NLP)

The NLP module functions as the chatbot's interpretive front-end, transforming informal, often ambiguous natural language into structured representations compatible with downstream search and retrieval mechanisms. This transformation unfolds across several stages:

Preprocessing and Normalization: The user input is first normalized through lowercasing, whitespace trimming, and punctuation removal. These preprocessing steps reduce lexical variance and ensure uniformity, enabling robust matching against both keyword and semantic indices.

Lexical and Syntactic Analysis: The system performs tokenization (splitting input into words or meaningful subunits) and applies part-of-speech tagging to understand grammatical structure. Optional named entity recognition (NER) identifies geographical areas (e.g., "City Center"), common tree names (e.g., "Jacaranda"), or well-being-related expressions (e.g., "calm", "shady").



(a) Rating component (b) Comment submission section

Figure 4: User interface elements displaying the rating component (left) and the comment submission section (right).

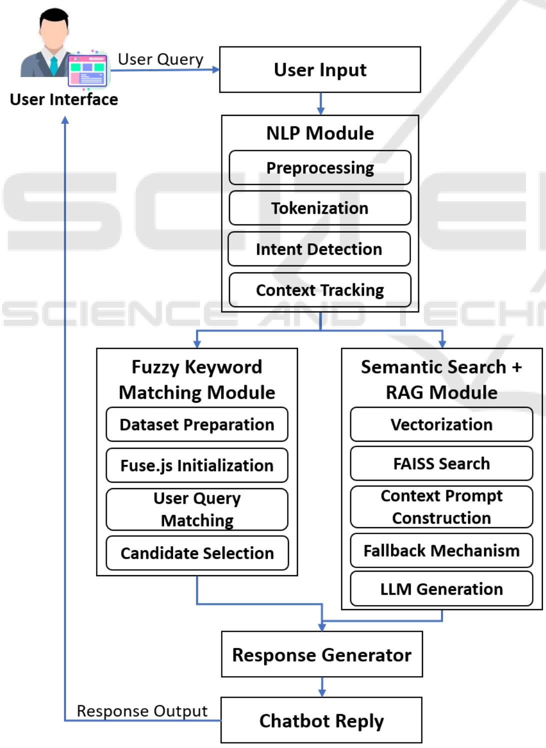


Figure 5: Hybrid architecture of the AI-driven recommendation chatbot.

Intent Detection and Slot Filling: The NLP engine determines the user's intent (e.g., search for shade, locate a specific tree, get a recommendation) using a lightweight rule-based or statistical classifier. From this intent, semantic slots are filled with extracted values such as tree features (e.g., shade, beauty), user goals (e.g., relaxation, walking), and locations.

Context Tracking: For multi-turn conversations, a memory buffer can be maintained to carry forward unmentioned context. For instance, if a user first asks about "shady trees in Boujaafar" and later asks "and in Sousse?", the module infers that the user is still interested in shady trees.

This module ensures that linguistic diversity in user queries is faithfully mapped to the chatbot's internal data schema, enabling accurate and consistent processing.

3.2.2 Fuzzy Keyword Matching

This module addresses one of the practical challenges in real-world chatbot systems: dealing with noisy, imprecise, or misspelled user inputs. Unlike exact keyword matching, which fails when there are spelling errors or lexical variations, fuzzy matching algorithms tolerate such inconsistencies by allowing approximate matches.

Dataset Preparation: The system defines a structured dataset comprising frequently asked questions, common tree attributes, and predefined recommendation intents. Each item in the dataset is represented as a JSON object with searchable fields, such as `title`, `description`, or `species`.

Fuse.js Initialization: Fuse.js[5] is a popular JavaScript library for efficient fuzzy searching over a predefined corpus. A Fuse.js instance is instantiated using the prepared dataset, with configuration options

[5]https://github.com/krisk/Fuse

tailored to the domain. The `keys` parameter specifies which fields to search, while the `threshold` value controls the sensitivity of the fuzzy matching. A lower threshold yields more precise matches, while a higher value allows greater tolerance for variation.

```
const fuse = new Fuse(treeDataset,
keys:  ['title', 'description'],
threshold:  0.4 );
```

User Query Matching: Once the user's input is processed by the NLP module, the remaining query string is passed to the Fuse.js search function. Fuse.js computes similarity scores between the input and dataset entries using approximate string matching algorithms (e.g., Levenshtein distance).

Candidate Selection and Ranking: The output of the search is a ranked list of candidate items with associated confidence scores. The chatbot selects the top match (or top-*k*) if the score falls below a predefined relevance threshold, ensuring that only meaningful results are presented to the user.

Response Generator: The best-matched item is mapped to a corresponding response template or action, such as displaying detailed information about a tree species or suggesting trees based on environmental filters. If no sufficiently relevant match is found, the system gracefully prompts the user to rephrase the query.

3.2.3 Semantic Search and RAG Engine

When user queries are abstract, personalized, or emotionally expressive, the chatbot escalates to a semantic retrieval pipeline underpinned by Retrieval-Augmented Generation (RAG) techniques (Lewis et al., 2020).

Semantic Vectorization: The user query is encoded into a dense vector representation using a pre-trained transformer-based model (e.g., Sentence-BERT or OpenAI embeddings) that captures the semantic meaning of the query (Reimers and Gurevych, 2019)).

FAISS-Based Similarity Search: The chatbot maintains a FAISS (Facebook AI Similarity Search) index populated with vector embeddings of curated knowledge chunks from environmental reports, tree guides, and urban ecology texts (Johnson et al., 2019). The semantic vector of the user query is compared against this index using approximate nearest neighbor search.

Context Prompt Construction: If relevant documents are retrieved, they are concatenated with the original query to form a prompt for the language model. This grounding ensures that generated responses are factual and context-specific, reducing the likelihood of hallucinated or vague output (Shuster et al., 2021).

Fallback Mechanism: In cases where no relevant chunks are retrieved (e.g., ambiguous or out-of-scope queries), the system invokes a fallback mode, allowing the LLM to generate responses from its internal pretrained knowledge without retrieved context.

Local LLM Response Generation: The structured prompt is fed into a local language model (e.g., using the Ollama API with LLaMA or GPT models) for final response generation. The model produces fluent and semantically relevant responses that reflect the user's intent and contextual data.

Response Generator: The output is reformatted for display and sent back to the user interface. Optional modules adjust tone, verbosity, and terminology for clarity and appropriateness.

3.3 Blockchain-Based NFT Certification Engine

To enhance the credibility, traceability, and long-term preservation of remarkable trees in urban environments, the proposed system integrates a blockchain-based certification engine. This module employs the Ethereum blockchain and the ERC-721 token standard to issue a non-fungible token (NFT) for each tree officially validated by authorized entities (e.g., municipal or environmental authorities). Each NFT serves as a verifiable, immutable digital certificate that encapsulates the tree's scientific, cultural, and spatial attributes, thereby promoting transparent ecological governance and public engagement (Taherdoost, 2022).

3.3.1 NFT Smart Contract Design

The smart contract is written in Solidity and built upon the OpenZeppelin implementation of the ERC-721 standard. It defines a minting function restricted to the contract owner (i.e., the certifying authority) and includes URI management to associate NFTs with their corresponding off-chain metadata. Figure 6 illustrates the smart contract used to mint tree certification NFTs.

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.0;

import "@openzeppelin/contracts/token/ERC721/extensions/ERC721URIStorage.sol";
import "@openzeppelin/contracts/access/Ownable.sol";

contract TreeNFT is ERC721URIStorage, Ownable {
    uint256 private _tokenIds;

    constructor() ERC721("TreeNFT", "TREE") {
        _tokenIds = 0;
    }
    function mintNFT(address recipient, string memory tokenURI) public onlyOwner returns (uint256) {
        _tokenIds += 1;
        uint256 newTokenId = _tokenIds;

        _mint(recipient, newTokenId);
        _setTokenURI(newTokenId, tokenURI);

        return newTokenId;
    }
}
```

Figure 6: Solidity Smart Contract for Minting Tree Certification NFTs Using the ERC-721 Standard.

Each time a tree is validated, a transaction is submitted by the authority, triggering the *mintNFT()* function. This function mints a new NFT and links it to a metadata URI hosted on IPFS. The smart contract is deployed on Sepolia using test ETH.

The certification engine is deployed on the Sepolia testnet, a publicly accessible Ethereum test network, and supports interaction via MetaMask[6], a widely adopted browser-based cryptocurrency wallet. Metadata describing the tree is stored off-chain using the InterPlanetary File System (IPFS), while the corresponding URI is permanently linked on-chain within the NFT contract.

3.3.2 Metadata Structure and Off-Chain Storage

The NFT metadata follows a JSON schema and includes both botanical and contextual information, such as location, species, dimensions, historical significance, and issuer identity. This data is uploaded to IPFS using decentralized pinning services (e.g., Pinata), and the resulting content identifier (CID) is used to construct the metadata URI. A typical NFT metadata structure is shown in the following JSON Figure 7.

```
{
  "name": "Olivier",
  "genus": "Olea",
  "species": "Olea europaea",
  "family": "Oleaceae",
  "order": "Lamiales",
  "type": "Arbre",
  "greenSpace": "Parc Central",
  "district": "Sousse",
  "neighborhood": "Centregggg-ville",
  "plantingDate": "2020-05-15",
  "age": 5,
  "height": 4.5,
  "circumference": 0.8,
  "location": {
    "type": "Point",
    "coordinates": [10.6333, 35.8256]
  },
  "images": ["https://gateway.pinata.cloud/ipfs/QmbkrrhR1W4JLtDZQbZhaSkAd7SsvsofFxMQWVxJgSMSG4"]
}
```

Figure 7: Example of NFT Metadata Structure Representing a Certified Tree (in JSON Format).

The metadata is publicly accessible through the generated IPFS gateway link and linked permanently to the on-chain token via its *tokenURI*.

3.3.3 Certification Workflow

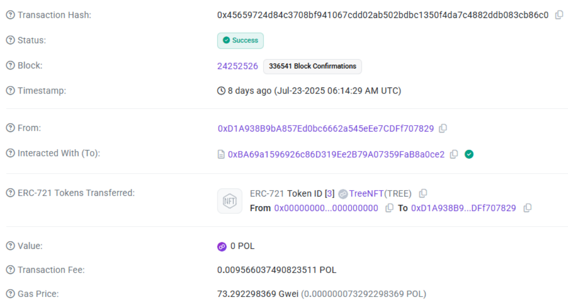
The NFT certification process follows a multi-stage workflow:

Tree Submission: A tree is submitted via the system interface by a verified user, such as a municipal agent or environmental researcher. The submission includes geolocation, physical attributes, photographs, and cultural or historical context. The tree information is stored in a MongoDB database, ensuring persistence and efficient querying. Upon successful submission, a certification notification is automatically sent to the authorized administrators.

Expert Validation: Authorized administrators evaluate certification submissions based on predefined criteria (e.g., age, rarity, aesthetic or historical value). Upon validation, a structured metadata JSON file is generated and securely uploaded to the IPFS for decentralized storage.

NFT Minting: Using MetaMask, the administrator connects to the Ethereum Sepolia network and signs a transaction to mint the NFT using the smart contract. The IPFS metadata URI is passed to the *mintNFT()* function, and the token is issued to the municipality's digital wallet.

Figure 8 displays the detailed record of the minting transaction on Etherscan, illustrating the successful execution of the *mintNFT()* function, including the transaction hash, block number, sender and recipient addresses, gas fees, and the status of the operation, providing transparent and verifiable proof of NFT creation on the blockchain.



Transaction Hash:	0x45659724d84c3708bf941067cdd02ab502bdbc1350f4da7c4882ddb083cb86c0
Status:	Success
Block:	24252526 336541 Block Confirmations
Timestamp:	8 days ago (Jul-23-2025 06:14:29 AM UTC)
From:	0xD1A938B9bA857Ed0bc6662a545eEe7CDFf707829
Interacted With (To):	0xBA69a1596926c86D319Ee2B79A07359FaB8a0ce2
ERC-721 Tokens Transferred:	ERC-721 Token ID [3] TreeNFT(TREE) From 0x00000000...000000000 To 0xD1A938B9...DFf707829
Value:	0 POL
Transaction Fee:	0.009566037490823511 POL
Gas Price:	73.292298369 Gwei (0.000000073292298369 POL)

Figure 8: Transaction Details of Tree NFT Minting on Sepolia Etherscan.

[6]https://metamask.io/

Public Certification Access: The certified tree is displayed on the application's map interface with a "Verified" badge. The blockchain certificate is accessible through a link to Sepolia Etherscan and may also be viewed in MetaMask or compatible NFT explorers.

4 IMPLEMENTATION AND EVALUATION

To assess the feasibility and effectiveness of our approach, we conducted preliminary experiments evaluating both the AI chatbot and blockchain certification components.

4.1 Implementation Insights

The proposed system is implemented using a modern web technology stack designed for modularity, scalability, and user interactivity. The frontend interface is developed with React.js, a widely adopted JavaScript framework that facilitates dynamic user interfaces and seamless chatbot interactions. The AI chatbot module combines Python with the Transformers library (Hugging Face) and Ollama for local deployment of large language models, enabling natural language understanding, intent classification, and response generation. To support flexible keyword-based retrieval, it incorporates Fuse.js, allowing fuzzy matching between user input and the indexed urban tree dataset. The backend API is built using Node.js with Express.js, handling business logic, database interactions, and coordination with blockchain services. For data persistence, MongoDB is used to store non-sensitive tree information and user interaction logs. The blockchain layer is developed using Solidity smart contracts deployed on the Ethereum Sepolia test network, with IPFS employed for decentralized storage of tree metadata linked to NFTs. Development and testing workflows utilize Visual Studio Code as the primary IDE, with Remix IDE[7] used for smart contract coding and verification. Figure 9 illustrates the overall software system architecture, highlighting the interactions between the user interface, AI chatbot, backend services, blockchain network, and data storage components.

[7]https://remix.ethereum.org/

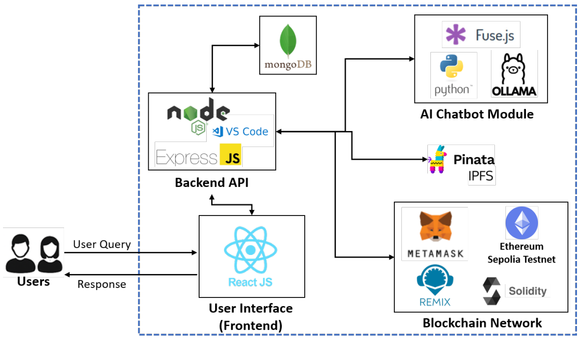


Figure 9: Overall software system architecture.

4.2 Evaluation

4.2.1 Evaluation of Chatbot Response Relevance

The AI module is evaluated based on its ability to accurately understand and respond to user queries. The evaluation used 250 test queries spanning informational and action-oriented requests, reflecting ecological, recreational, and emotional user intents to simulate realistic chatbot interactions. To measure the chatbot's effectiveness in matching user intents and retrieving relevant tree information, we use standard metrics including Precision (the proportion of relevant trees correctly returned among all retrieved results), Recall (the proportion of relevant trees correctly identified among all actual relevant items), and F1-Score (the harmonic mean of precision and recall, reflecting overall performance). Table 1 compares the performance of our AI-driven tree recommendation system against a keyword-only retrieval baseline, highlighting the added value of our approach.

- $Precision = \frac{TP}{TP+FP}$
- $Recall = \frac{TP}{TP+FN}$
- $F1-Score = 2 \times \frac{Precision \times Recall}{Precision+Recall}$

Where: TP = True Positives, FP = False Positives, FN = False Negatives

Table 1: Comparison between AI-driven Tree Recommendation System and Keyword-only Retrieval Baseline.

Metric	AI-driven System	Keyword-only Retrieval
Precision	0.91	0.58
Recall	0.87	0.62
F1-Score	0.89	0.60

4.2.2 Evaluation of Personalization and User Satisfaction

To evaluate the chatbot's personalization capacity and user experience, we conducted a user study with 30 participants. The results are derived from post-interaction surveys and behavior logs, using metrics such as Click-Through Rate (CTR), which indicates how often users interacted with tree suggestions, and the User Satisfaction Score (USS), which reflects the perceived usefulness and relevance of the responses.

- $CTR = \frac{NumberofClicks}{NumberofRecommendations}$
- $USS = \frac{\sum(UserRatings)}{TotalUsers} \quad (scale: 1to5)$

Table 2: User Interaction and Satisfaction Metrics.

Metric	Value
CTR	0.68
USS	4.3 / 5

4.2.3 Evaluation of Blockchain Certification Integrity

The blockchain mechanism is evaluated based on its ability to ensure data authenticity, traceability, and resistance to tampering. We employ metrics such as Data Immutability Rate (the proportion of certificates that remain unaltered after issuance), Transaction Latency (the average time between submission and successful on-chain registration), and Certification Uniqueness (ensuring that each remarkable tree is uniquely represented on-chain through a NFT).

- Data Immutability Rate $= \left(\frac{ImmutableRecords}{TotalRecords}\right) \times 100$
- Transaction Latency $=$ Average time taken to validate and store a certificate
- Certification Uniqueness $= \frac{\#ofUniqueNFTs}{\#ofCertifiedTrees}$

Table 3: Blockchain-Based Certification Evaluation Metrics.

Metric	Value
Data Immutability Rate	100%
Transaction Latency	$\sim$ 12 seconds
Certification Uniqueness	1.00

4.2.4 Discussion

The evaluation shows that the proposed system provides highly relevant and personalized responses through its chatbot, achieving strong performance metrics (Precision 0.91, F1-score 0.89), which indicate the reliability of AI-generated recommendations. Compared to a keyword-only retrieval baseline (Precision 0.58, F1-score 0.60), the AI-driven approach demonstrates a clear improvement, highlighting the value of personalized AI recommendations over simpler query-matching methods. The relatively high CTR and satisfaction scores suggest that users found the interaction both intuitive and valuable. On the blockchain side, the system demonstrates full immutability and uniqueness of tree certificates, ensuring data trust and accountability. The average latency ($\sim$ 12 seconds) is within acceptable thresholds for public blockchain networks. These results validate the integration of AI and blockchain as an effective and trustworthy solution for urban tree valorization.

5 CONCLUSION

This paper presented an innovative AI- and blockchain-based system designed to enhance the preservation, visibility, and citizen engagement surrounding remarkable urban trees. By combining an intelligent conversational agent that guides users through personalized interactions with a secure blockchain-powered certification process, the proposed application bridges the gap between technological innovation and ecological heritage valorization. The integration of non-fungible tokens (NFTs) ensures traceability and digital permanence of each tree's unique identity, while the AI module fosters awareness and user participation by recommending trees based on specific ecological or emotional benefits. Implementation insights and evaluation confirmed its feasibility and user acceptance as a participatory urban ecology tool.

Future research will extend this study with a larger participant pool to enhance the generalizability of the findings and provide more robust evidence for the observed effects. Additionally, integrating supplementary environmental data sources—such as IoT sensors for real-time monitoring of tree health or microclimatic conditions—could further enrich the system's insights. Enhancements to the AI module, including multimodal interactions (e.g., voice or image input), could improve accessibility and foster greater user engagement.

REFERENCES

Abdelghani, S. B., Nabli, H., Djemaa, R. B., and Sliman, L. (2023). Blockchain-integrated technologies to address counterfeit drugs in the pharmaceutical supply chain. In *International Conference on Hybrid Intelligent Systems*, pages 292–301. Springer.

Abdelhamid, M., Sliman, L., Djemaa, R. B., and Perboli, G. (2024). A review on blockchain technology, current challenges, and ai-driven solutions. *ACM Computing Surveys*, 57(3):1–39.

Arora, B., Chaudhary, D., Satsangi, M., Yadav, M., Singh, L., and Sudhish, P. (2020). Agribot: a natural language generative neural networks engine for agricultural applications. In *International Conference on Contemporary Computing and Applications (IC3A)*, pages 28–33. IEEE.

Chathurya, C., Sachdeva, D., and Arora, M. (2023). Agriculture chatbot (agribot) using natural language processing. In *2023 14th International Conference on Computing Communication and Networking Technologies (ICCCNT)*, pages 1–5. IEEE.

Hasan, H., Musamih, A., Salah, K., Jayaraman, R., Omar, M., Arshad, J., and Boscovic, D. (2024). Smart agriculture assurance: Iot and blockchain for trusted sustainable produce. *Computers and Electronics in Agriculture*, 224:109184.

Hosseinalibeiki, H. and Zaree, M. (2023). A blockchain based solution to improve loyalty program with nft in agribusiness. *Journal of Smart Environments and Green Computing*, 3(4):127–146.

Johnson, J., Douze, M., and Jégou, H. (2019). Billion-scale similarity search with gpus. *IEEE Transactions on Big Data*, 7(3):535–547.

Kamble, S., Gunasekaran, A., and Sharma, R. (2020). Modeling the blockchain enabled traceability in agriculture supply chain. *International Journal of Information Management*, 52:101967.

Lewis, P., Perez, E., Piktus, A., Petroni, F., Karpukhin, V., Goyal, N., Küttler, H., Lewis, M., Yih, W., Rocktäschel, T., et al. (2020). Retrieval-augmented generation for knowledge-intensive nlp tasks. *Advances in neural information processing systems*, 33:9459–9474.

Li, X. and Wu, J. (2022). Public engagement in urban green infrastructure planning: A critical review. *Landscape and Urban Planning*, 225:104412.

Marla, A., Paul, R., Saha, A., Basha, N., and Anandhakrishnan, B. (2023). An agrobot: Natural language processing based chatbot for farmers. In *4th International Conference on Smart Electronics and Communication (ICOSEC)*, pages 1235–1241. IEEE.

Mostaco, G., Souza, I. D., Campos, L., and Cugnasca, C. (2018). Agronomobot: a smart answering chatbot applied to agricultural sensor networks. In *14th international conference on precision agriculture*, volume 24, pages 1–13.

Mullaney, J., Lucke, T., and Trueman, S. (2015). The benefits of large species urban trees: A review of ecosystem services. *Urban Forestry & Urban Greening*, 14(4):607–614.

Nabli, H., Djemaa, R. B., and Amor, I. B. (2024). Improved clustering-based hybrid recommendation system to offer personalized cloud services. *Cluster Computing*, 27(3):2845–2874.

Nabli, H., Ghannem, A., Djemaa, R. B., and Sliman, L. (2025). How innovative technologies shape the future of pharmaceutical supply chains. *Computers & Industrial Engineering*, 199:110745.

Nandhini, J., Anuratha, K., Sangeetha, K., and Jaswant, K. (2021). Smart tree management with biodiversity preservation using image processing and blockchain technology. In *2021 International Conference on System, Computation, Automation and Networking (ICSCAN)*, pages 1–6. IEEE.

Niranjan, P., Rajpurohit, V., and Malgi, R. (2019). A survey on chat-bot system for agriculture domain. In *2019 1st International Conference on Advances in Information Technology (ICAIT)*, pages 99–103. IEEE.

Ong, R., Raof, R., Sudin, S., and Choong, K. (2021). A review of chatbot development for dynamic web-based knowledge management system (kms) in small scale agriculture. In *Journal of Physics: Conference Series*, volume 1755, page 012051. IOP Publishing.

Pravinkrishnan, K., Balasundaram, P., and Kalinathan, L. (2022). An overview of chatbots using ml algorithms in agricultural domain. *International Journal of Computer Applications*, 975(11):15–22.

Radhakrishnan, R., Tripathi, A., and Singh, V. (2022). Chatbot-based citizen engagement in smart cities: A framework for personalized urban services. *Journal of Urban Technology*, 29(1):3–22.

Reimers, N. and Gurevych, I. (2019). Sentence-bert: Sentence embeddings using siamese bert-networks. *arXiv preprint arXiv:1908.10084*.

Santos, R. D., Pantoni, R., and Torrisi, N. (2023). Blockchain tokens for agri-food supply chain. *Journal of Engineering Research and Sciences*, 2(2):15–23.

Shuster, K., Poff, S., Chen, M., Kiela, D., and Weston, J. (2021). Retrieval augmentation reduces hallucination in conversation. *arXiv preprint arXiv:2104.07567*.

Slama, W. B., Charroux, B., Sliman, L., and Djemaa, R. B. (2024). Towards blockchain like soa. In *International Conference on Web Information Systems Engineering*, pages 301–311. Springer.

Taherdoost, H. (2022). Non-fungible tokens (nft): A systematic review. *Information*, 14(1):26.

Tegeltija, S., Dejanović, S., Feng, H., Stankovski, S., Ostojić, G., Kučević, D., and Marjanović, J. (2022). Blockchain framework for certification of organic agriculture production. *Sustainability*, 14(19):11823.

Torres, K. and McDonald, R. (2021). Urban trees and human health: A scoping review. *International Journal of Environmental Research and Public Health*, 18(9):4645.

Treiblmaier, H. (2018). The impact of blockchain on the supply chain: A theory-based research framework and a call for action. *Supply Chain Management: An International Journal*, 23(6):545–559.

Usip, P., Udo, E., Asuquo, D., and James, O. (2022). A machine learning-based mobile chatbot for crop farmers. In *International Conference on Electronic Governance with Emerging Technologies*, pages 192–211. Springer.

Varveris, D., Styliadis, A., Xofis, P., and Dimen, L. (2023). Distributed and collaborative tree architecture: A low-cost experimental approach for smart forest monitoring. *Baltic Journal of Modern Computing*, 11(4):653–685.

Yoon, J. and Fischer, J. (2023). The importance of culturally significant trees in urban biodiversity strategies. *Urban Forestry & Urban Greening*, 80:127828.