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Distributed and Collaborative Tree Architecture: A Low-cost Experimental Approach for Smart Forest Monitoring

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Abstract. Distributed and collaborative CAD recently gained great attention as a digital geodesign information exchange and management ecosystem, operating in a reliable, transparent, and secure way (CAD-Blockchain integration). Temporal-sensitive tree simulation, in collaborative design environments, offers advantages in the context of smart planning for virtual parks and forests, while DLT/Blockchain technology significantly reduces overhead and tree-modeling transaction costs, eliminates the need for third parties or middlemen to verify transactions, and provides data integrity and information confidence. A proof-of-concept 2.5D tree architecture and Blockchain integration technique was presented as a low-cost distributed and collaborative engineering case study that affects the digital landscape architecture design and monitoring infrastructure. As important findings were recorded, the add-in planning intelligence, the superior data integrity, and confidence, the superiority in terms of time and cost, as well as the satisfactory tree modeling accuracy for smart forest and landscape architecture applications, compared to traditional 3D tree modeling methods (laser scanning, close-range photogrammetry, etc.). The tree-model engineering added new value to the CAD-Blockchain integration industry because a simple and scalable "Blockchain/Merkle hash tree" temporarily tracks tree-geometry-growth and texture change with simple parametric transactions. Hence, decentralized, autonomous, coordinated, and parallel design; same-data sharing; data validation; smart forest distributed surveillance; and contractual collaborative frameworks are effectively supported. Stratification based on forest types improved woody above-ground biomass estimation, especially when biomass was greater than 350 Mg/ha, using the proposed "Internet-of-tree-images" technique. Therefore, this research provides new insight into the woody above-ground biomass modeling and monitoring. Finally, performance evaluation testing validates the technique's robustness.

Keywords: Tree modeling architecture, distributed and collaborative CAD, smart forest monitoring, landscape architecture, woody above-ground biomass engineering, blockchain functionalities, geodesign ecosystem.

1. Introduction

Web-enabled big data (3Vs; Volume, Variety, and Velocity) and Cloud/Blockchain data structures lead to "smart products" (smart forest, smart contracts, etc.) operating in real-time and requiring real-time queries, evaluation, and action (Dounas and Lombardi, 2018). The design, implementation, and operation of these "smart applications" in distributed CAD environments are quite complicated, sophisticated, and usually operated with user-friendly interface issues (Lemeš and Lemeš, 2020; Nawari and Ravindram, 2019).

In the context of this reality, in smart digital documentation (forests, tree landscapes, monument landscapes), and landscape architecture applications, where the modeling accuracy is not so important, a need emerges for a user-friendly interface operating in near real-time with simple tree CAD modeling, planning intelligence and decentralized functionality (Deharam and Alksnis, 2022; Dzemyda et al., 2022). Distributed CAD-Blockchain integration based on 2D Internet-of-Tree images (IoTr-images), collaborative design efficiency, and easy-to-use customized GUI (Graphical User Interface), with dialogs hooked to event-driven dedicated CAD software tools, could be a practical solution to this need (Gspurning et al., 2022; Styliadis, 2007; Styliadis et al., 2003). In this case, the GUI dialogs and the event-driven routines must support *parametric* (design level/layer, color, weight, style, reference point, height, and width) and *relative-to-a-ground-reference-point* (geo-referenced tree-frame's CAD geometry deployment) tree CAD modeling.

Hence in the context of Web-enabled smart tree landscapes digital documentation with CAD modeling, where the 3D accurate representation of trees -as the core object in forests, landscapes, and IoTr-images with non-fungible tree-Images tokens (NFTs) ecosystems- is extremely time-consuming and costly, a less accurate representation with near 3D visualization is needed (e.g., 2.5D tree modeling). Compared with traditional digital collection systems and methods for tree form digitization (like Terrestrial Laser Scanners (TLS), close-range terrestrial photogrammetry, and videometry), a CAD modeling solution can maximize the "velocity" property in big data acquisition and in this way improve cultural, scientific, and economic values of digital documentation (Bournez et al., 2017; Vishwa and Hussain, 2018; Zhaofeng et al., 2018).

1.1. Concepts and Terms Definitions

"Internet-of-Trees (IoTr)" concept definition. This concept has been inspired by the "Internet-of-Things / IoT" one and means a Metaverse ecosystem with tree models and images as primitive blocks.

"Internet-of-Tree images (IoTr-images)" concept definition. This concept means a Blockchain with tree images as the blocks of the chain.

“Smart tree landscape” concept definition. This definition refers to a landscape rich in “smart” functionalities, like sustainability, flexibility, user-friendliness, planning intelligence, IoTr-images efficiency, etc.

“2.5D tree CAD model” term definition. A 2.5D tree CAD model is defined as a combined structure of two or more rectangular 2D tree-frames paired and centered perpendicularly to each other in 3D space, while a tree’s scalable vector image is assigned as material to each of these combined tree-frame structures. Obviously, in tree modeling reconstructions like that, the modeling (tree geometry) accuracy is poor, but the visualization (rendering efficiency) effect is acceptable in many applications (e.g., landscape architecture industry).

“WAGB” term definition. Woody above-ground biomass (with monitoring and engineering functionality, and carbon storage in living plant tissues located above the earth's surface). Living vegetation above the soil, includes stems, twigs, stumps, branches, barks, seeds, and foliage (Liordos et al., 2021).

“**Distributed and collaborative smart tree landscape**” framework definition. The proposed framework for digital landscape architecture and tree landscapes is defined as a “*Distributed and Collaborative smart tree landscape*”, i.e., “a *smart* 2.5D easy-to-design *parametric* and *relative* tree CAD modeling with metaverse tangible tree-image NFT accessibility”.

1.2. Research Background Gap Analysis

In the context of distributed and collaborative CAD modeling for digital documentation projects with many trees (landscape architecture, monument landscapes, tree landscapes, metaverse smart forests), the massive production of tree CAD models and the 3D accurate representation is cost and time prohibitive (Bournez et al., 2017; Vishwa and Hussain, 2018; Zhaofeng et al., 2018).

Thus, in the spirit of minimum cost in the shortest possible time, a simple (tree image as a texture), less accurate (2.5D), parametric, and relative tree representation is needed but keeping the visualization relatively satisfactory for projects and applications where modeling accuracy is not a basic prerequisite (Barzdins et al., 2022; Basdekidou and Papapanagos, 2023). At the same time, there is a demand for mass production and presentation of similar 3D models with an emphasis on visualization rather than modeling accuracy (e.g., 2.5D tree parametric and relative modeling).

Additionally, Web-enabled and coordinated design “smart products” (like smart forests or urban pocket parks) are significantly complicated, flexible, operate in real-time, and require same-data sharing, parallel design functionality, and real-time queries, evaluation, and action (Lemeš and Lemeš, 2020; Nawari and Ravindram, 2019). Hence, for smart 2.5D tree modeling, the need emerges for a user-friendly, adaptable, and CAD domain-independent modeling method, implemented in near real-time with easy-to-offline-code modeling commands hooked to CAD-dependent routines.

Gap Analysis - Open Cases

The design, implementation, and operation of Web-enabled "smart application environments" is not a simple and straightforward task (Zhang et al., 2021; Tychkov et al., 2019). For instance, even nowadays, smart forest applications operating in real-time and requiring real-time queries, evaluation, and action are still quite difficult, elaborate, and complex (Gabrys, 2022; Urzedo et al., 2022; Ribeiro et al., 2021; Sinoquet and Rivet, 1997).

CAD-Blockchain integration strategies, regarding digital infrastructures of the physical world, are still on a conceptual level mainly because the built environment ecosystem's geometry is quite complicated (Varveris et al., 2023; Dounas and Lombardi, 2018; Hasanagas et al., 2010a; Hasanagas et al., 2010b). In this domain, imbalanced data and fraudulent transactions threaten Blockchain's digitally distributed consensus, transparency, and data security (Breskuviené and Dzemyda, 2023; Dzemyda et al., 2022).

A parametric model contains information like dimensions, constraints, and relationships between various entities like edges, sketches, and features. Any design changes are made easily, and the parametric model updates and responds to those changes. A non-parametric model does not contain such relationships. It can be modified (dimensions), but it does not have the additional constraints and relationships to allow any update to affect other design elements (Wang et al., 2019; Aktaruzzaman et al., 2011). Parametric modeling is subjected to usability testing (design/modeling evaluation) (Awale and Murano, 2020) and allows users to automate repetitive changes, such as those found in families of product parts (e.g., tree species) (Klerk et al., 2019; Cottrill and Derrible, 2015; Caouder, 1992; Parametric Models, 2009).

3D tree reconstruction modeling is a challenging task (complex geometry). Even in urban environments, an important diversity of tree species and therefore of tree geometry might occur (Bournez et al., 2017). On-situ observations, metrics, and photography highlight the difficulty of tree data acquisition (3D tree form coordinates) and reliable 3D modeling (Sinoquet and Rivet, 1997; Caouder, 1992). Therefore, detailed 3D tree modeling faces many difficulties as it requires contact with the object (Wu et al., 2023; Li et al., 2023), manual and tedious procedures (Bentaher et al., 2013; Miranda et al., 2018), and a huge number of points of view (Rahman et al., 2014; Sharma et al., 2016; Wagner et al., 2009; Parveaud et al., 2008).

Gap Analysis – Results Weaknesses

Studying the research results and comments, from recent previous scientific studies related to web-enabled smart applications, the weaknesses (unfriendliness, dysfunction, complexity, domain-specific functionality, etc.) in the Graphical User Interface (GUI) are evident (Styliadis, 2007; Styliadis et al., 2003).

In detailed 3D tree modeling surveys, the point distribution in the point cloud cannot be uniform, because of the geometric complexity of tree architecture and the number of Terrestrial Laser Scanning (TLS) stations recorded around the tree. Thus, depending on the modeling (digital reconstruction) algorithm, the point distribution will have an impact on the skeleton, as well as on a good size, shape, texture, and volume estimation (Sharma et al., 2019; Bolton and Cora, 2021).

Finally, when there are lots of intersections and many branches (case of the pruned silver lime tree with shoots) none of the available data-capturing methods delivers accurate results. This is the common limit of the tested reconstruction algorithms for tree simulation frameworks, urban smart tree landscapes, and 3D tree modeling for cultural heritage and monument landscapes (Basdekidou and Styliadou, 2017; Seidl et al., 2010; Moss, 2022; Gspurning et al., 2022).

1.3. Article's Scope and Findings

This is a descriptive paper on a complex process regarding tree architecture and Blockchain. The descriptive nature of this paper does not allow for an in-depth discussion about the specifics of our approach. Instead, we focus on the application of the results in distributed and collaborative design and planning with metaverse Blockchain functionality. Here, we report the results of an experiential approach to applying spatially explicit tree modeling and environmental simulation to forests and urban parks monitoring in the design and planning process. In smart forest and digital landscape architecture projects, like tree landscapes, trees with complex geometry appear abundantly and, in these applications, visualization takes precedence over accurate 3D tree representation.

Accurate 3D tree modeling from mobile laser scanning, topography, and terrestrial close-range photogrammetry traditional techniques provides the necessary data for WAGB engineering, tree architecture, forest monitoring, and geometrical analysis (Nijhuis et al., 2023; Ma et al., 2022), while Blockchain in distributed CAD environments change how critical information is viewed and supports data integrity, distributed, collaborative, and validated digital design, and information confidence (Lemeš and Lemeš, 2020; Doumas and Lombardi, 2018; Deharam and Alksnis, 2022). Monitoring in nearly real-time 3D tree-geometry-growth and tracking WAGB-texture change temporarily is not competitive in distributed and collaborative environments due to cost, time, and the not-controlled complex "Blockchain/Merkle hash tree" scaling (Varveris et al., 2023; Nawari and Ravindran, 2019; Doumas and Lombardi, 2018).

This paper presents a proof-of-concept CAD-Blockchain integration implementation techniques. At the core of both techniques is a combined tree-frame 2D geometry but with an almost 3D visualization (2.5D tree model), with parametric (tree's geo-reference, height, width, etc.) and relative (georeferenced tree-frame modeling deployment) functionalities. The distributed and collaborative nature of the presented techniques guarantees coordinated design (between various participants: designers, clients), same-data sharing, and parallel design work; while the decentralized Blockchain integration promises data validation, fast transaction management, and several contractual frameworks in the digital landscape architecture industry, like smart contracts, and performance-based contracts. The proposed tree CAD modeling is characterized as "smart" due to the number of functionalities provided (near real-time design, redesign functionality, decentralized autonomous design, planning intelligence, and IoT/metaverse efficiency for the tangible tree-image NFTs).

The proposed technique, instead of the traditional tree modeling approaches, uses a customized graphical user interface (GUI) and event-driven CAD routines (design level/layer, color, weight, style, reference point, height, and width) for 2.5D parametric tree CAD modeling and relative-to-a-ground-reference-point (geo-referenced tree-CAD frame's) for tree CAD geometry deployment. Thus, with the proposed competitive technique, we greatly reduce costs, save time, and achieve the operation and maintenance of a simple and functional controlled "Blockchain/Merkle hash tree" scaling, with all that this implies at the level of distributed and collaborative design. Certainly, the proposed technique produces less accurate tree models, but this disadvantage does not affect urban landscape architecture projects or smart forest applications (Xudong et al., 2023; Barzdins et al., 2022).

Findings. Experimental data, as findings, proved the satisfactory performance in tree shape modeling of the proposed 2.5D tree modeling implementation techniques - compared to manual TLS and close-range photogrammetry methods- in time (15 min/tree CAD model vs. 72 h.) and expenditure (3€/tree CAD model vs. 864€) at a cost of modeling accuracy. In addition, many positives (user-friendliness, planning intelligence, design process modification ability, redesign functionality, safe-relaxed error-free design, and robust Blockchain/hash tree) and a few negatives (tree CAD modeling accuracy, visualization) were detected for the forest and the landscape design ecosystems.

1.4. Research Questions and Novelties

The proposed framework "*distributed and collaborative smart tree landscape*" is defined as "a *smart* 2.5D easy-to-design *parametric* and *relative* tree CAD modeling with metaverse tangible tree-image NFT accessibility". For the *distributed* and *collaborative* part of the framework's title, coordinated design, same-data sharing, and parallel design are required. Even more, the present work introduces, in the digital landscape architecture industry, innovative functionalities like data validation, fast transaction management, and contractual frameworks (smart and performance-based contracts between designers and clients).

As far as the definition is concerned, for the *smart* design, several functionalities (like time, flexibility, user-friendliness, planning intelligence, IoTr-images efficiency, etc.) are needed. For *2.5D* tree representation, a not-detailed 3D-like tree geometry is needed. For *parametric* tree CAD modeling, a generic CAD modeling routine is needed with the tree model frame's level/layer, color, weight, style, geo-reference, height, and width as parameters. For *relative* modeling, all design progress (progressive graphic design and modeling deployment) must be executed relatively to a ground reference point (i.e., without explicit tree geo-referenced coordinates) geometry development commands.

For the proposed framework referring to metaverse Web-enabled digital documentation of tangible tree-image and tree-model NFT collections in the IoTr-images (2D images) and IoTr-models (2.5D models) Blockchain ecosystems, a *digital collection* (tree NFT Wallet) must be established as a distributed DLT ledger and as a safe and efficient data exchange protocol between Web-enabled decentralized smart applications (e.g., smart tree landscapes, monument landscapes, etc.).

The proposed framework could develop into a system to protect the raster tree-image NFTs, the 2.5D tree-model NFTs, and the associated multimedia data (IoTr-images and IoTt-models tree NFT *collections*) and to regulate anomalies and even illegal behaviors during the exchange decentralized process. Obviously, digital *collections* can archive tree data in safe, stable, and efficient DLT Blockchain structures and exchange them in DLT networks without a central authority, but in CAD modeling projects the designer end-user (*regulator*) must monitor the transaction process and its data content and be interrupted in the event of data anomalies to realize in-transaction regulatory, post-transaction proof saving, and traceability.

Research Questions. For the proposed off-the-self technique ("smart tree landscape" concept) and the "Internet-of-Tree" Blockchain application case study (*smart, parametric, and relative 2.5D tree distributed and collaborative CAD modeling*) the research questions are described as follows:

- Describe a parametric and relative 2.5D easy-to-design tree CAD modeling methodology based on low-cost tree-images (e.g., smartphones' jpg format).
- Design of the IoTr-images and IoTr-models WAGB Blockchain data structures for tangible tree-image and 2.5D tree-model NFTs respectively.
- Define the relative datasets (metadata) and the "tree display file" of the Blockchain structure in DXF ASCII format.
- Define a trustworthy process (digitally distributed consensus) enabling activity transparency and data security enhancement.
- Design a user-friendly GUI (dialogs and thematic palettes) operating in near real-time with Web-enabled smart functionality (unique identifiers/UIDs, NFT tokens, or IP addresses for the tree images and the 2.5D generic tree models. The GUI dialogs refer to 2.5D tree modeling, as well as to building and maintaining the WAGB Blockchain structure (Yazdi et al., 2023).
- Describe the customized dialogs, clustered in thematic palettes, as GUI icon tools hooked to (a) dedicated CAD system s/w key-in routines, or to new event-driven procedures (CAD-programming coding is needed).

Aim. The article's main aim is to develop an experimental technique for integrating tree-images in mutually perpendicular 2D CAD frames and connecting them into a dedicated "Internet-of-Tree" Blockchain.

Research Objectives. After describing the general research questions, this article's specific research objectives are defined as:

- The implementation details of the (easy-to-design) 2.5D parametric and relative tree CAD modeling methodology.

- The implementation of the smart and user-friendly customized GUI with dialogs organized in thematic palettes and hooked to dedicated CAD-domain dependent key-ins (Bentley's MicroStation CAD platform was selected); and
- The implementation of the "Internet-of-Tree" Blockchain app case study (tangible tree-images NFT tokens). The tree-images and the 2.5D models are decentralized among several nodes that hold identical information, and at the same time, none (project manager, designer, or client) holds the complete authority (a fully digitally distributed consensus). This enables transparency of design activity, enhancement of 2.5D data security, and clients' confidence.

Novelties. (i) The proposed 2.5D tree model added new value to CAD-Blockchain integration industry, thanks to a very plain "Blockchain/Merkle hash Tree" that tracks tree-geometry-growth and WAGB-texture change temporarily with simple parametric transactions; (ii) Smart forest add-in app with simple Blockchain transactions (tracking tree-growth and WAGB-texture change temporarily); (iii) The innovative 2.5D tree CAD methodology for parametric, relative, and untagged geo-referenced tree modeling; (iv) The simple "Customized GUI" implementation technique, associated with system key-ins (domain-dependent dedicated CAD software tools) for 2.5D generic and parametric tree modeling; and (v) The simple, functional, and controlled scaling "Blockchain/Merkle hash tree" structure, storing the metadata of a DXF/ASCII representation of generic tangible tree-image NFTs (Xudong et al., 2023; Yazdi et al., 2023).

Purpose. The purpose of the conducted research is to develop a Web-enabled framework for distributed and collaborative smart digital documentation with tree-modeling applications, where modeling accuracy is not so important, and the easy-to-use interface is a necessity.

Applications. Potential applications could be associated with landscape architecture visualization, digital city infrastructures, smart forests, smart monument landscapes, smart tree landscapes, etc. Additionally, prospective applications are referred to as a living archive and virtual field-site method exploring how digital technologies are transforming cities (e.g., urban parks) and forests.

Implications. The proposed IoTr ecosystem platform includes open data from the "smart tree landscape" domain and provides tools for researchers, stakeholders, and the public to gather, explore, analyze, annotate, reflect on, and reimagine smart tree modeling knowledge and technologies. The proposed *distributed and collaborative smart tree landscape* framework investigates the social, political, and technological dimensions of the CAD-Blockchain integration that monitors and governs tree-based environments. Therefore, social implications are considered for the increasing use of digital technologies to monitor and manage forests and monument landscapes for addressing sustainable environmental change policies (Xofis et al., 2022; Liordos et al., 2023).

Hence, *smart tree modeling* asks not just how digital technologies remaking landscapes and forests are, but also investigates how *smart landscapes* consider social, political, and technological aspects as a dynamic factor addressing environmental policies.

Situated at the intersection of science and technology studies, political ecology, and digital media studies, the proposed research demonstrates how these technologies impact socio-ecological relations and constraints and proposes more equitable, decentralized, trustworthy, and democratic approaches to digital and environmental practice and policy (Basdekidou and Styliadou, 2017).

Significance. The particular significance of this study lies in the plain "Blockchain/Merkle hash tree" structure supporting distributed and collaborative tree architecture for monitoring landscape architecture, smart forest, and digital documentation apps where there are no requirements on the accuracy of the tree modeling dimensionality and visualization (Fox et al., 2023, Hasanagas et al., 2010a; Styliadis, 2007; Dzemyda et al., 2022). Finally, performance evaluation testing validates GUI friendliness and implementation robustness in an Internet-of-Tree Blockchain case study (an urban tree landscape).

1.5. Article's writing structure

The further article's writing structure is as follows. In Section 2 ("Method and Procedures") the proposed framework's (method and implementation technique) research methodology workflow, datasets and software tools, and customized GUI dialogs are presented. In Section 3 ("Results and Discussion") the outline design of the "IoTr-images" WAGB Blockchain (metaverse application for a smart forest rich in trees), a case study (figures, tables), experimental data that demonstrates the difference between a 3D tree with demanding accuracy/visualization, and a 2.5D tree with acceptable accuracy/visualization model, discussion matters, and the proposed framework's validation (usability testing) are covered. Finally, in Section 4 ("Conclusions") results, findings, and suggestions for further study are briefly presented.

2. Method and Procedures

Parametric modeling lets designers modify the entire shape of the design at once, not just individual dimensions one at a time. Additionally, a feature-based parametric modeling CAD software design tool saves time as it eliminates the need for a design engineer to constantly redraw a design every time one of the design's dimensions changes. MicroStation, AutoCAD, Pro/ENGINEER, and SolidWorks offer direct modeling CAD platforms on top of existing feature-based parametric modeling (Styliadis, 2007).

A direct modeling CAD software platform provides a geometric-based modeling strategy, rather than a feature-based format so that designers can quickly define and edit geometry. Direct modeling lets copy, move, split, replace, offset, push, and drag geometry in any way on need (Bournez et al., 2017). On the other hand, a feature-based parametric modeling CAD software design tool saves time as it eliminates the need for a design engineer to constantly redraw a design every time one of the design's dimensions changes. Parametric modeling lets designers modify the entire shape of the design at once, not just individual dimensions one at a time (Wang et al., 2019; Parametric Models, 2009).

There are some drawbacks to parametric modeling tools. Designers must often anticipate potential design changes and define features accordingly. Even more, the designer must define the relationships between features. For instance, in complex designs, capturing design intent can be a difficult challenge (Caouder, 1992). MicroStation, AutoCAD, Pro/ENGINEER, and SolidWorks offer direct modeling CAD platforms on top of existing feature-based parametric modeling (Styliadis, 2007; Styliadis et al., 2003).

2.1. Implementation Components

The three basic implementation components of the proposed 2.5D tree CAD modeling procedure are displayed in Figure 1. These components are the end-user; the implementation technique (the "Customized GUI" with thematic palettes and user-defined dialogs assigned to event-driven selected system key-ins); and the "tree display file" metadata structure defining the IoTr ecosystem, i.e., the IoTr-images and the IoTr-models Blockchains (Fig. 1).

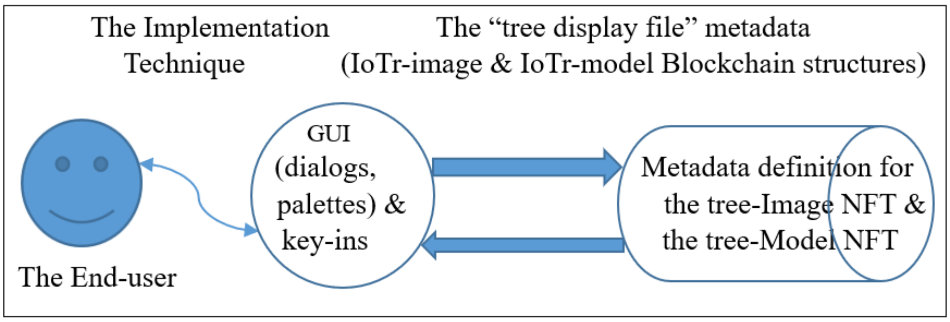

Figure 1. The basic implementation components of the proposed "2.5D tree architecture"

The block diagram, as a flow-chart, of the research methodology process (four stages), is presented in Figure 2.

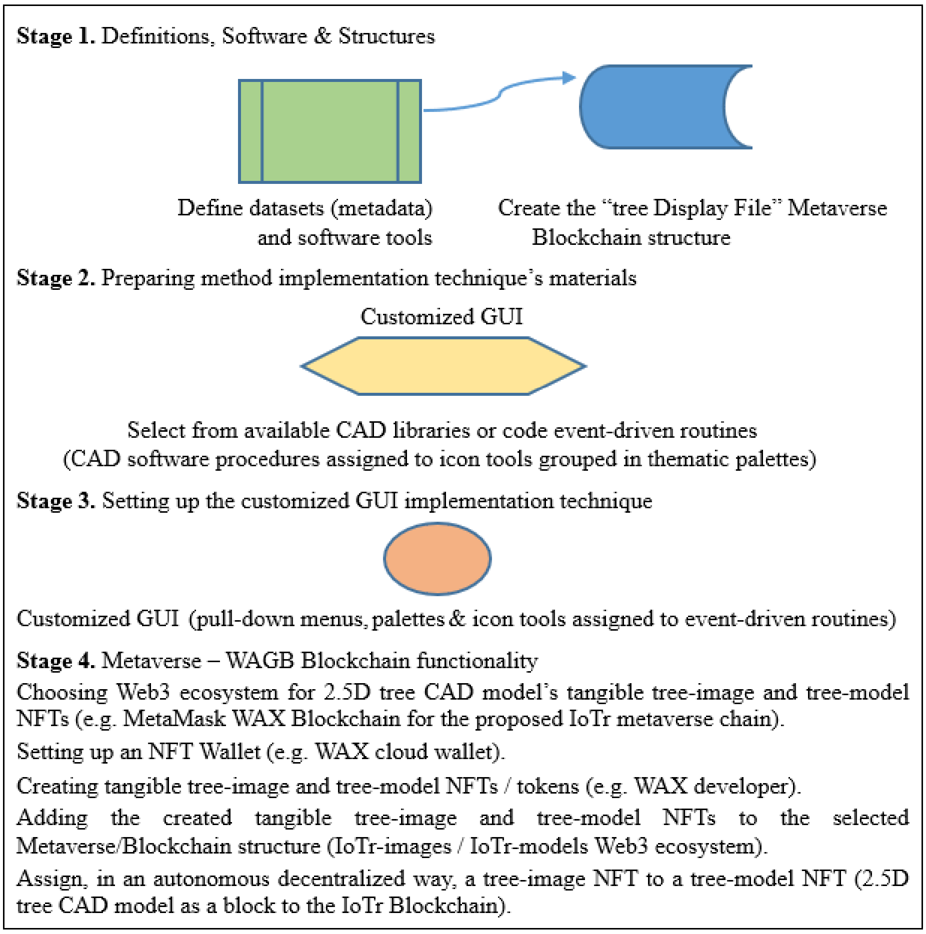

Figure 2. Research methodology workflow

2.2. Metadata tree-Image NFTs datasets (server) & CAD Software (client)

The metadata for the tree-image and tree-model NFT datasets (the *server* part in the proposed *smart tree landscapes* framework) and the CAD platform for the implementation software tools (the *client* part in the proposed *smart tree landscapes* framework) are defined as follows:

(A) Metadata tree-image & tree-model NFTs datasets

Three types of metadata datasets were used for the proposed IoTr ecosystem: tree species, tree dimensions, and geospatial data (Solodovnikova and Niedrite, 2020; Zhu et al., 2021; Larriba et al., 2021).

Metadata data sources: For the “tree species” metadata there are forty-nine (49) tree datasets available on “data.world” as data sources. Open data about trees species (types) contributed by thousands of users and organizations around the world (see https://data.world/datasets/tree).

For the “tree dimensions” metadata the tree’s “width” and “height” dimensions were used as the basic parametric parameters. There are 1.097 boundaries datasets available on data.world. Open data about trees boundaries contributed by thousands of users and organizations around the world (see https://data.world/datasets/boundaries).

Finally, for the “geospatial data” metadata there are 1.110 geospatial datasets available on “data.world”. Open data about trees geospatial data contributed by thousands of users and organizations around the world (see https://data.world/datasets/geospatial) (Patel et al., 2005; Qureshi and Jiménez, 2020; Barzdins et al., 2022).

Metadata data types and attributes: For the “tree species” the data type is string-alphanumeric. For the “tree dimensions” the data type is numeric. For the “geospatial data” the data type is numeric.

NFT (Unique Identifier): Finally, a unique identifier (UID) is needed. UID is a numeric or alphanumeric string that is associated with a single entity within a given system. In metaverse smart applications, like the proposed IoTr-images / IoTr-models, the UID is a tangible tree-Image/tree-Model NFT (tree token) and makes it possible to address Blockchain entities (i.e., raster tree Images / 2.5D generic tree CAD models), so that they can be accessed and interacted with decentralized.

(B) CAD software (source coding)

A few parametric modeling routines were implemented in MDL (MicroStation Development Library) and assigned to personalized icon tools as user-defined event-driven routines (Fig. 2). MDL code can be compiled using Microsoft Visual C++ as a native-code DLL. These parametric routines enhance programmer productivity with C++ object-oriented concepts and provide better performance in low-cost CAD modeling. For a *batch job control* these parametric modeling routines were grouped in a batch file as phrases from the English language (plain ASCII text data from an online text editor, e.g., Notepad).

CAD platform: The CAD platform MicroStation was used as the hosting software environment for the GUI, the event-driven procedures, and the command-line programming of the proposed framework. MicroStation® is Bentley Systems' CAD product and one of its many strengths is its adaptability. Inherent to that adaptability are tools to customize and extend MicroStation.

User Customization and Task-specific Tools: MicroStation lets an administrator modify its user interface and create custom menus, palettes (toolboxes), and icon tools (icon buttons) that provide a fast track to commands and functions used frequently.

2.3. Tree Display File Structure (IoTr Blockchain)

2.3.1. Display File structure definition

The "tree display file" structure, for the proposed IoTr ecosystem, is defined by twelve (12) data fields as follows: tangible tree-image NFT, tangible tree-model NFT, tree type, tree species, tree height, tree width, tree size, tree shape, tree texture, and tree's down-left corner X-, Y-, Z-geo-referenced coordinates. Qualitative and quantitative assessments of the raster tree image or the 2.5D tree model are performed using reference tree reconstructions and field measurements (TLS, close-range terrestrial photogrammetry, image acquisition techniques, etc.) (Bournez et al., 2017).

The structure characteristics of the "tree display file" (Styliadis et al., 2003) are described by:

- Tree species diversity (dataset). There are 49 tree datasets available on data.world (https://data.world/datasets/tree).
- Tree geometry complexity (height, width, size, and shape of branches).
- Tree texture.
- Tree geo-referenced positioning (3D coordinates of tree's lower-left corner point).
- A unique NFT identifier (Blockchain decentralized functionality).

Non-fungible tokens (NFTs) are one of the hottest intellectual property (IP) topics currently. NFTs can be used simply for marketing purposes, as a new form of asset to attract investment, or as part of the transfer of products and services into the metaverse.

Tangible NFTs are blockchain-based tokens that each represent a unique asset with a physical substance like a raster tree image or a 2.5D tree model. A tree NFT can be thought of as an irrevocable digital certificate of "ownership" and authenticity for a given tree (asset), whether digital or physical.

2.3.2. Display File structure setup

The steps for setting up the IoTr blockchain are described as follows:

Choose a Web3 ecosystem for NFTs (NFT Blockchain chain): The most popular NFT blockchain is Ethereum, which hosts thousands of NFT collections. Ethereum NFTs are created utilizing the ERC-721 standard, which stores the metadata of the NFT on the Ethereum blockchain. In addition, another useful for the proposed IoTrI ecosystem NFT Blockchain chain is the WAX (Worldwide Asset eXchange). It is a purpose-built blockchain and protocol token designed to make e-commerce transactions faster, easier, and safer. The WAX Blockchain uses Delegated Proof of Stake (DPoS) as its consensus mechanism and is backward compatible with EOS. WAX offers a purpose-built network for storing and transaction virtual items and collectibles like the raster tree images or the 2.5D tree CAD models.

Set Up an NFT Wallet: Once choosing a Blockchain, a digital wallet is needed that supports that Blockchain to store the tree-Image and tree-Model NFTs. To create a wallet, the *crypto wallet* app has to be downloaded (e.g., WAX Wallet or MetaMask popular crypto wallets that support a wide variety of cryptocurrencies, as well as WAX, Ethereum, and Solana Blockchains. They can be used as a mobile app or added as a browser extension, provide a username and password, and store private keys and recovery phrase offline for backup purposes.

Choose an NFT Platform for NFT creation: An ever-growing list of NFT platforms utilize NFT creation, but the best ones offer a full-service marketplace to list and sell NFTs. For the presented app case study (IoTr Blockchain) the WAX Developer platform is considered. The most popular NFT platform is OpenSea with more than $20 billion in trading volume since its launch in 2017 and more than 2 million NFT collections listed, OpenSea is the top platform for Ethereum-based NFTs.

Create the tangible tree-image and tree-model NFTs: Once the platform is chosen, creating a tree-image or a tree-model NFT is a pretty straightforward process. Here is an example of creating a tangible tree-image NFT on WAX Developer:

- Connect your Wallet: In the WAX Developer menu, select the wallet icon and choose which digital wallet you'd like to connect. This will require you to sign a verification on a wallet app.
- Select the "Create" option: This brings up a menu for the NFT creation process, including an upload section, NFT features, properties, and Blockchain.
- Upload the tree image file: This is the scalable vector tree image available for selling for 2.5D tree CAD modeling projects (decentralized environment). This image can be uploaded directly or linked to an externally hosted image file (jpg).
- Fill in the details: Name tree-Image NFT and fill in a description. Optionally add unique properties and additional perks like unlockable content, such as an invite to a private discord channel or discount codes to merchandise.

Select Metaverse/Blockchain structure: This will be the blockchain on which the tree-Image NFT resides, and it cannot be changed once minted.

2.4. 2.5D tree CAD Modeling Procedure

For the so-called 2.5D generic tree modeling, the relative design of two rectangular tree-frames, perpendicular to each other, starting with a ground-reference-point with coordinates 0,0,0 is preceded (geo-referenced functionality for a relative-to-a-ground-reference-point modeling deployment). Next is the assignment of the tree image in these frames and the storage of this generic tree format as a 2.5D tree CAD model (local disk) and as a tangible tree-image NFT token (IoTr-images metaverse chain). Customized GUI was used as the method's implementation technique (Nijhuis et al., 2023; Yazdi et al., 2023; Nawari and Ravindran, 2019; Awale and Murano, 2020; Sharma et al., 2019).

Hence, the proposed 2.5D tree CAD modeling procedure takes as parameters the CAD current drawing level (LV), frame's line color (CO), weight (WT), style (LC), frame's geo-referencing point coordinates (GRP), and tree's height (H) and width (W), and is developed as follows:

1. The tree-frame's CAD parameters LV, CO, WT, and LC are predefined.
2. In CAD platform/FRONT view a tree-frame is designed according to the tree's height parameter (H), and for a generic geo-referencing the ground reference point GRP is assigned to coordinates 0,0,0 (CAD universe space) (Fig.3).
3. In CAD platform/RIGHT view another tree-frame is designed according to the tree's width parameter (W) (Fig. 3).
4. The last tree-frame is relocated in such a way as both frames cross each other perpendicularly. In this way, a compound tree frame is designed starting from the ground reference point (0,0,0) (Fig. 3).

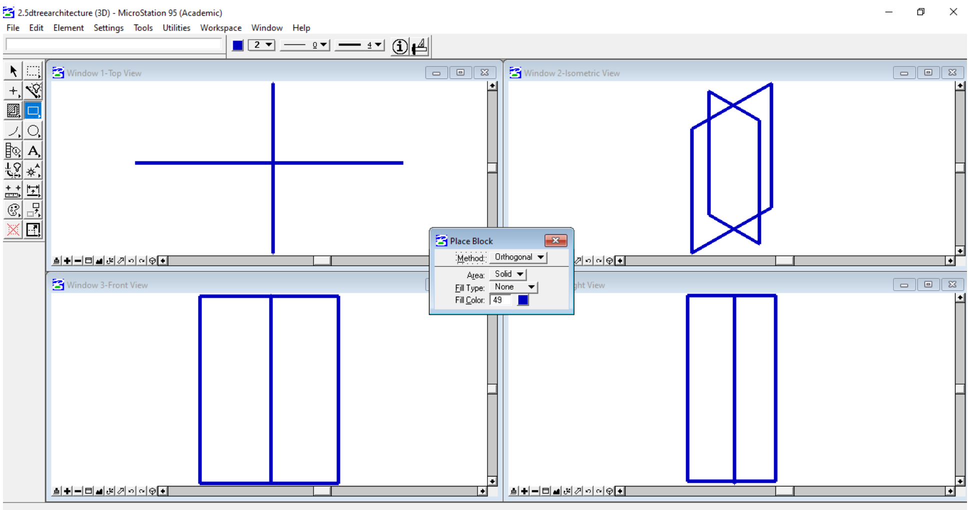

Figure 3. The two orthogonal tree-frames cantered perpendicularly (FRONT and RIGHT view)

5. A tree's scalable raster image (jpg) from (i) the CAD platform's system palette "Flora.pal" or (ii) user's noise-free photography or (iii) IoTr-image ecosystem, is assigned to both block frames utilizing a GUI's dialog setting box according to the predefined LV (e.g., level=2) and CO (e.g., color=8) parameters (Fig. 4).

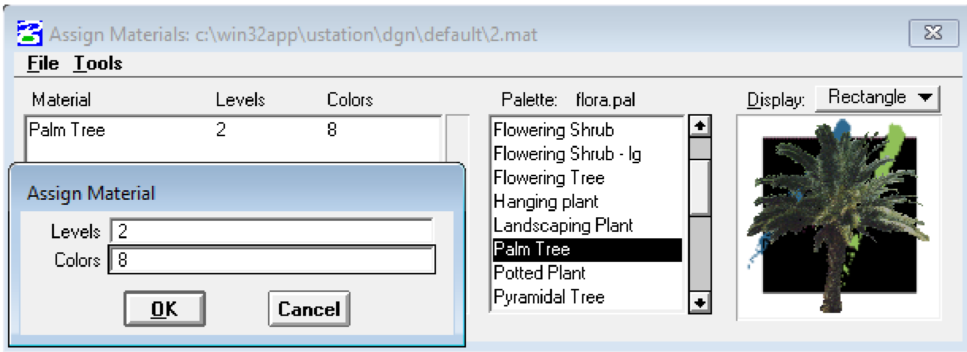

Figure 4. Tree WAGB-texture image assignment to FRONT and RIGHT view tree-frames

In this way, the modeling is referred to as "2.5D tree CAD modeling" and the visualization accuracy is adequate, sufficient, and satisfactory for digital documentation and visualization purposes regarding smart tree landscapes, smart forests, smart monument landscapes, and landscape architecture applications.

Figures 5A, 5B, and 5C present a 2.5D tree CAD model and tree landscapes (ISOMETRIC view). The modeling accuracy is adequate for smart forest projects and landscape architecture applications without special visualization requirements.

Figure 5A. A 2.5D tree CAD model

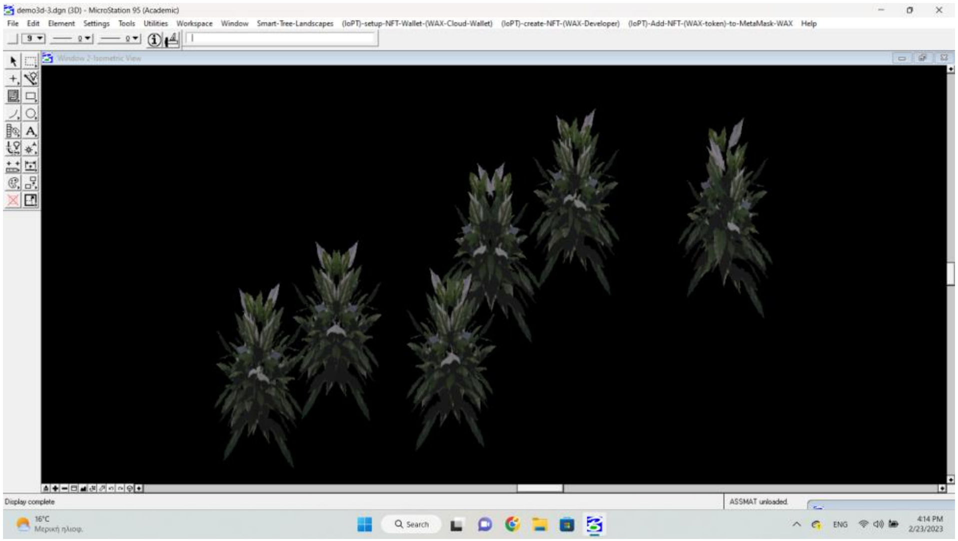

Figure 5B. A tree landscape (ISOMETRIC view, north-east eye position)

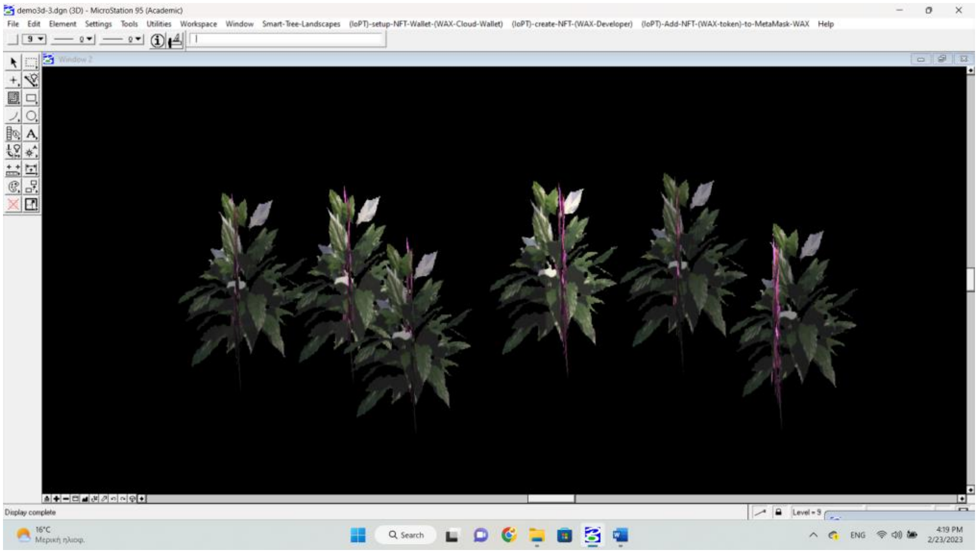

Figure 5C. The same tree landscape from a different point-of-view
(ISOMETRIC view, north-west eye position)

2.5. Customized GUI

The CAD platform MicroStation was used as the hosting software environment for the event-driven procedures and the proposed customized GUI framework. MicroStation® is Bentley Systems' CAD product and one of its many strengths is its adaptability. Inherent to that adaptability are tools to customize and extend MicroStation.

User customization and task-specific tools: MicroStation lets an administrator modify its user interface and create custom menus, palettes (toolboxes), and icon tools (icon buttons) that provide a fast track to commands and functions used frequently. The icon tools are grouped into modeling thematic palettes, and they are assigned to event-driven procedures (user-defined CAD s/w) or key-ins (CAD system s/w / Bentley's propriety MDL source code). Figure 6 demonstrates the development process for the WAGB-Modeling pull-down menu (WAGB-Modeling / Trees / 2.5D tree CAD geometry / FRONT frame setup).

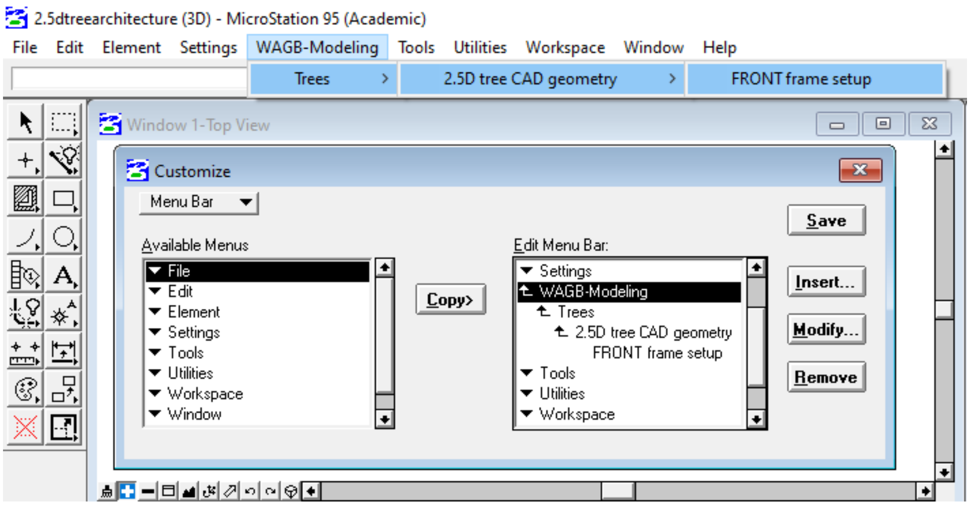

Figure 6. The development process for the WAGB-Modeling pull-down menu (WAGB-Modeling / Trees / 2.5D tree CAD geometry / FRONT frame setup)

Figure 7 presents the development process for the graphic representation of a new icon tool with a tool tip "PLACE Tree Frame" hooked to the user-defined key-in "PLACE Parametric Relative Tree Frame" (one of the few customized MDL-coding parametric event-driven routines). The modeling duty of this icon tool is to design a rectangular parametric and relative tree frame in any CAD design and modeling view (i.e., Front, Back, Right, Left, Bottom, Top, Right-Isometric, Left-Isometric, or a user-defined view).

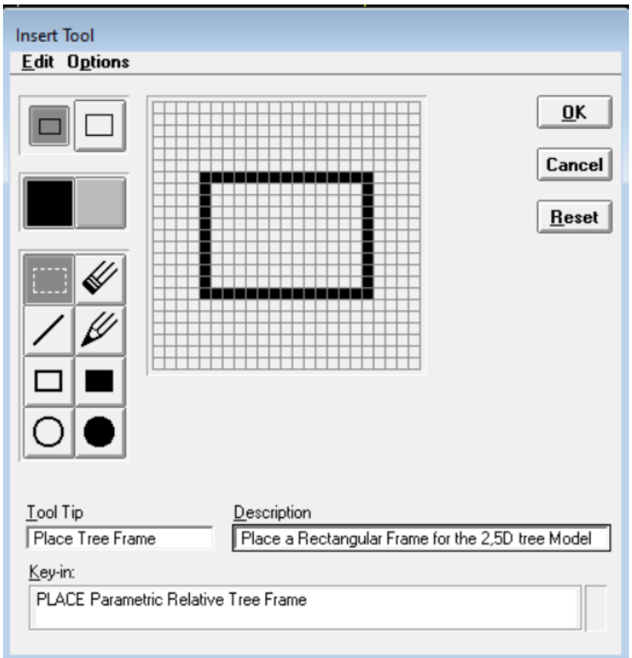

Figure 7. The "PLACE Tree Frame" icon tool: Graphic design and assignment to user-defined key-in "*PLACE Parametric Relative Tree Frame*"

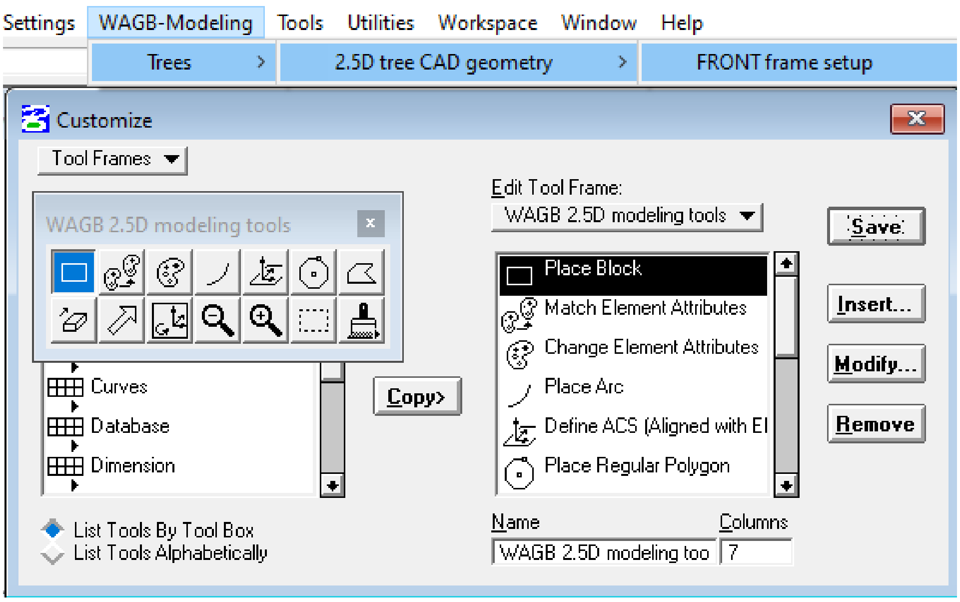

Figure 8. The thematic palette "WAGB 2.5D modeling tools"

The “PLACE Tree Frame” icon tool was named “Place Block” and has been grouped, as the 1st tool on the 1st row, into the thematic palette “WAGB 2.5D modeling tools”. Then, on a “left-button” event (i.e., a cursor hit activation) the relative dedicated key-in “*PLACE Parametric Relative Tree Frame*” is executed (Fig. 8).

The IoTr-images WAGB Blockchain (a Web/NFT-enabled procedure for the WAX Blockchain Web 3.0 ecosystem) is developed in four steps:

Step A: Create the 2.5D tree geometry (height, width) and add tree image, settings (size, shape, volume), and WAGB-texture (Figures 3 and 4).

Step B: Setup for the digital CAD tree model an NFT Wallet. See pull-down menu: “WAGB-Modeling / IoTr-images Blockchain / A. Setup NFT Wallet (WAX cloud Wallet)” in Figure 9.

Step C: Create a physically redeemable NFT (WAX token) for the parametric 2,5D tree CAD model. See pull-down menu: “WAGB-Modeling / IoTr-images Blockchain / B. Create NFT token (WAX Developer)” in Figure 9.

Step D: Add tree’s tangible NFT (WAX token) to MetaMask WAX using the vIRL®NFT technology (linktr.ee/TangibleNFTs). See pull-down menu: “WAGB-Modeling / IoTr-images Blockchain / C. Add tangible NFT (WAX token) to MetaMask WAX” in Figure 9.

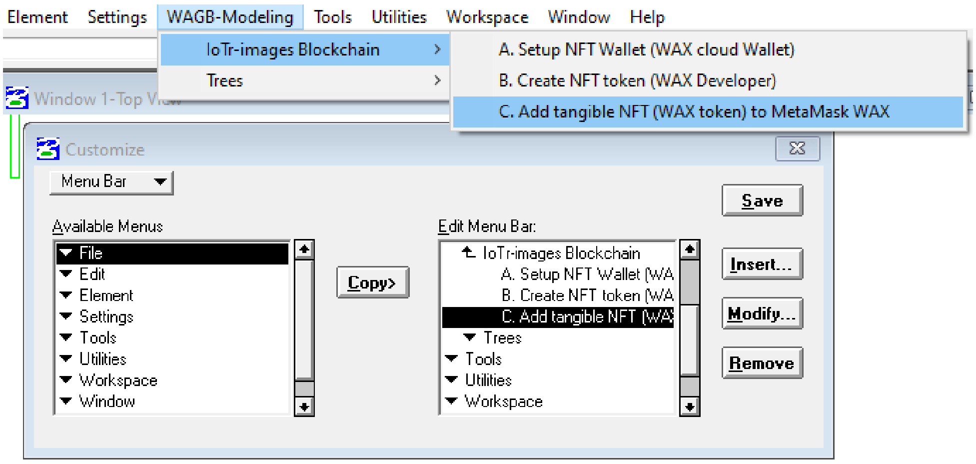

Figure 9. The pull-down menu “WAGB-Modeling / IoTr-images Blockchain”, for “A. Setup NFT Wallet”, “B. Create NFT token”, and “C. Add tangible NFT token” to MetaMask WAX Blockchain

A 2.5D tree CAD modeling with the introduced "Customized GUI" technique is a *smart CAD modeling* procedure because it operates in near real-time with planning intelligence (modeling and design process modification ability in near real-time) and metaverse efficiency. Additionally, it is flexible because it is performed offline in a friendly safety and relaxed way with simple user-designed dialogs (dialog boxes and palettes) hooked to domain-dependent CAD key-in routines.

3. Results and Discussion

For demonstration purposes of the introduced distributed and collaborative WAGB modeling framework, an "IoTr-images" WAGB Blockchain outline design for an urban landscape architecture project is presented in Figure 10. Follows a comparative analysis's usability test for validation purposes.

3.1. "Internet-of-Tree images" WAGB Blockchain: The outline design

The outline design of the "Internet-of-Tree" WAGB Blockchain case study (metaverse application for a smart forest rich in trees) is displayed in Figure 8. Each tree, as a block in the IoTr-images WAGB chain, is referred to by a hash value created by the SHA256 cryptographic algorithm. Hence, the "IoTr-images" Blockchain is composed of a linked list of blocks of transactions (tree-frame dimensions and raster image data in autonomous collaborative design) tracking tree-geometry growth and WAGB-texture change over time (Lemeš and Lemeš, 2020; Doumas and Lombardi, 2018).

The "*Root of Hash Tree*" points to a "*Merkle hash tree*" chain of transactions (Nawari and Ravindran, 2019). It is important to know that, in the discussed IoTr-images Blockchain the "*Merkle hash Tree*" is relatively compact in its extension and easily manageable with controlled small-scale magnification for great Blockchain functionality (Doumas and Lombardi, 2018; Awale and Murano, 2020; Sharma et al., 2019; Basdekidou and Papapanagos, 2023; Li et al., 2023) (Fig. 10).

3.2. Comparative validation analysis

(Tree shape modeling: "IoTr-images" usability testing)

3D data acquisition (3D modeling) vs. customized GUI (2.5D modelling)

For a comparative usability testing study, many "*time*" and "*user friendliness*" measurements were executed during the presented case study (risk management and analytics) (Awale and Murano, 2020; Basdekidou, 2019a; Basdekidou, 2019b; Basdekidou and Styliadis, 2018a; Basdekidou and Styliadis, 2018b). In addition, planning intelligence (Fang et al., 2022; Liordos et al., 2021), intelligence and IoT efficiency (Sanchez-Iborra et al., 2023), and image identification functionality (López et al., 2022) were estimated.

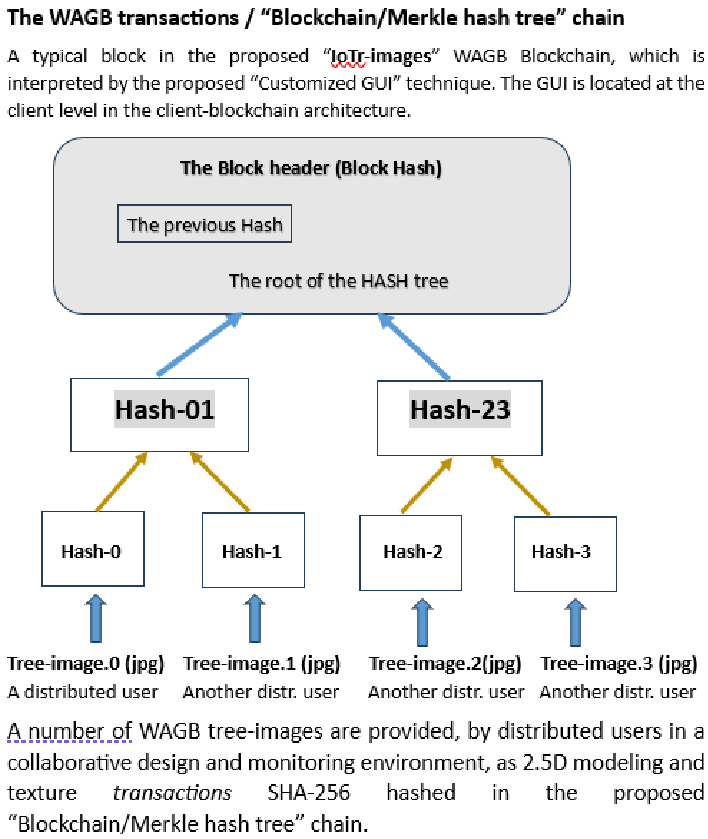

Figure 10. The proposed "Blockchain/Merkle hash tree"
(The "*Root of Hash Tree*" is pointing to a simple "*Merkle hash tree*" chain of WAGB transactions)

Notes

1. For the *hashing* (hash values Hash-0, Hash-1, Hash-2, Hash-3, Hash-01, and Hash-23) the hash function SHA256 (cryptographic algorithm) is proposed.

2. The *genesis block*, also known as "block 0", is the very first block upon which additional blocks in a blockchain are added. It is effectively the ancestor that every other block can trace its lineage back to since every block references the one preceding it. The *genesis block* of Bitcoin was mined by the anonymous entity known as Satoshi Nakamoto, who also holds the *genesis Bitcoin* address. The address has a wallet that contains 50 BTC mined from the *genesis block*, and they are not spendable in nature. The wallet's address is 1A1zP1eP5QGefi2DMPTfTL5SLmv7DivfNa. The hash of the *genesis block* is unique as it contains two additional leading hex zeros than required by other early blocks (000000000019d6689c085ae165831e934ff763ae46a2a6c172b3f1b60a8ce2 6f).

3. The reference to the *genesis Bitcoin* is made because in smart contracts, between designers and clients, the payments are usually made with Bitcoin.

Table 1. Tree data acquisition & shape modeling techniques – Usability test

Evaluation parameters	3D data acquisition (Manual Terrestrial Laser Scanning, Photogrammetry)	Customized GUI (Personalized dialogs and thematic palettes)
Time (tree modeling)	32 h. field-work & 40 h. office CAD design effort	10 min field-wok & 5 min CAD design effort
Expenditure*	864€	3€
User friendliness	No	Yes
Planning Intelligence	No	Yes
IoT efficiency	Yes	Yes
Image Identification	Yes	Yes
Design process Modification ability	Not very well (Perceivable)	Very well (Robust)
Redesign functionality	Poor	Excellent
Safety,	Safe	Safe
Relaxness,	Not relaxed	Relaxed
Error-free / Risk	Error-prone risky design	Error-free design
Tree Modeling accuracy	Very accurate 3D tree CAD model	Poor in accuracy tree CAD model
Visualization	Excellent!	Acceptable
Metaverse hash tree	Extremely scalable	Robust
Metaverse functionalities (coordinated parallel design, same-data sharing & validation, contractual frameworks, etc.)	Poor (an extremely scalable hash tree that tracks geometry, position, and texture tree changes over time)	Yes! (plain hash tree) - Simple parametric transactions (tree-frames geometry, raster image)
Applications	Architecture, rendering, demanding visualization. Smart forest & metaverse apps are not supported.	Landscape architecture, digital documentation, smart forest (temporal tree growth track) & metaverse apps.

* Germany's minimum wage is €12 per hour, pre-tax, since October 1, 2022.

The usability test is referred to as (a) an accurate 3D data acquisition-tree point clouds and tree shape modeling method, known as the manual 3D digitizing TLS and Photogrammetry method (Li et al., 2023; Rahman et al., 2014; Gspurning et al., 2022; Aktaruzzaman et al., 2011); and (b) the proposed customized GUI technique. From the comparative analysis of these two “tree architecture” approaches, the off-the-shelf “Customized GUI” technique is faster (time), much cheaper (expenditure), easier (user-friendliness), with planning intelligence, and in addition more flexible (design process modification ability and redesign functionality) (Table 1) (Klerk et al., 2019; Awale and Murano, 2020; Wagner et al., 2009; Sharma et al., 2019). The “cost” for these advantages is the poor tree CAD modeling accuracy and the medium-standard tree architecture visualization.

But the most important superiority is the simple, controlled, and functional “Blockchain/Merkle hash tree” scaling when transactions (tree-geometry growth and WAGB-texture change) are recorded to the chain.

The end-user, in the customized GUI implementation technique, end-users can modify offline and outside of the CAD/Modeling environment the GUI (dialogs, thematic palettes). The modification can be performed in a simple way (CAD graphic editor), offline (CAD platform), and without stress or the risk of a design accident (Caouder, 1992; Basdekidou, 2019a; Sanchez-Iborra et al., 2023). Hence, 2.5D tree CAD modeling with the introduced “Customized GUI” technique is a “smart 2.5D CAD modeling” procedure because it operates in near real-time and is flexible, because it can be performed offline (outside a CAD software platform), in safety, and in a friendly way with domain-independent dialogs nested in thematic palettes.

Comparative analysis for WAGB monitoring

A comparative analysis of different tree-datasets and modeling algorithms, between the proposed 2.5D technique and traditional 3D modeling methods (laser scanning, terrestrial close-range photogrammetry) for WAGB monitoring has been performed (Li et al., 2023; Liordos et al., 2021). Tree and forest type, as well as WAGB range, influence tree modeling and they are important factors in comparative analysis.

The results show the following: (i) laser scanning imagery provides more accurate WAGB estimates (RMSE values in about 25 Mg/ha) than the proposed “Customized GUI / IoTr-images” technique (about 83 Mg/ha); (ii) Overestimation for small WAGB values (<40 Mg/ha) and underestimation for large WAGB values (>300 Mg/ha) are major problems when using terrestrial close-range photogrammetry; (iii) Stratification based on forest types improved WAGB estimation, when AGB>350 Mg/ha, using the proposed technique; and (iv) The proposed technique provides collaborative risk management analytics, planning intelligence, and metaverse efficiency in nearly real-time. Thus, the presented low-cost experimental approach to collaborative tree modeling provides new insights into smart forest monitoring.

3.3. Discussion

Table 1 shows conducted research findings, positives, negatives (as accuracy and visualization issues), the "Merkle hash tree" simplicity and easy-of-maintenance novelty (Blockchain transactions) resulting in several metaverse functionalities, and potential applications (smart forest, metaverse, etc.). The proposed "distributed and collaborative smart tree landscape" framework, compared with accurate 3D tree modeling approaches (like terrestrial laser scanning and close-range photogrammetry), is characterized by:

Speed and Convenience (it is faster & easier than 3D tree modeling). The proposed distributed and collaborative smart tree landscape framework, as graphically presented in Figures 9-17, is a safe process and much faster and easier than the traditional manual electromagnetic digitizing, close-range photogrammetry, and laser scanning techniques (Bournez et al., 2017; Tychkov et al., 2019, Urzedo et al., 2022). Even more, as is visible in Figures 5A, 5B, and 5C, the quality of the visualization of the 2.5D parametric tree model is satisfactory and suitable for smart forest, landscape architecture, digital documentation, and metaverse applications.

The plain "Merkle tree model" means additional Traceability (a CAD-Blockchain with 3D tree models as blocks leads to an extremely scalable "Merkle tree model", i.e., impossible for practical use). The ownership and the token metadata stored on the WAX blockchain of the digital collection NFT can be publicly identified. With the CID label (content identifier used to point to material in IPFS), the IPFS (the distributed system for storing and accessing the IoTr 2.5D parametric tree models, files, websites, applications, descriptive tree data, etc.) can verify if the data have been tampered with and the storage and redundancy status of data.

The plain "Merkle tree model" means additional Transparency. As the world of non-fungible tokens (NFTs) continues to grow and evolve, so too do the collections that WAX enthusiasts are amassing. From digital art and crypto games to music and sports, there are now NFTs available for just about any interest or hobby. The whole process of the proposed WAX digital NFT collection for the 2.5D parametric tree modeling (IoTr NFT collection), from casting to on-chaining to exchange, is transparent, whereas the storage of the NFT metadata and the collected data is not. No possibility exists that the NFTs cannot be published and interacted with as long as they are cast, given that the on-chain systems on which digital collections interact will not crash.

The plain "Merkle tree model" means additional Tamper Proof. Once validated, NFT's metadata and complete transaction records are stored permanently, allowing only new information to be added, with no past data that can be modified. Tamper-proof due to the employing of the IPFS documentation system. The information seen in each 2.5D tree CAD model is instantly updated, straightforward, and easy to circulate, eliminating the traditional information barriers between the data contributor and the data acquirer.

Less flexible algorithms, not suitable and sufficient for Architectural Visualization. Apart from the metaverse and smart tree domains, where the superiority of the proposed framework is evident as described above, the biggest disadvantage of the 2.5D tree parametric methods is that the assumptions made may not always be true. For instance, it was assumed that the form of the "tree-shape function" is linear, whilst it is not. Therefore, the proposed 2.5D parametric tree technique involves a less flexible algorithm not suitable and sufficient for complex modeling problems, architectural rendering projects, and visualization applications (Styliadis et al., 2003; Li et al., 2023).

4. Conclusions

The described experimental approach was a conceptual metaverse case study that supports coordinated and parallel design, same-data sharing, and a trustworthy collaborative design process (digitally distributed consensus), enabling activity transparency and data security enhancement. The proposed 2.5D tree model added new value to CAD-Blockchain integration industry, thanks to a plain, controlled, and functional "*Blockchain/Merkle hash Tree*" that tracks tree-geometry growth and WAGB-texture change temporarily with simple parametric transactions. Therefore, smart forest surveillance, decentralized, autonomous, coordinated and parallel design, same-data sharing, tree modeling data validation, design files transaction management with analytics functionality, and contractual frameworks (e.g., smart and performance-based contracts) are effectively supported.

Results: A simple 2.5D parametric and relative tree CAD modeling methodology has been described in detail and the IoTr-images and IoTr-models Blockchain data structures have been designed for tangible tree-images and 2.5D tree-models NFT tokens respectively. Additionally, the relative datasets (metadata) and the "tree display file" of the Blockchain structure in DXF ASCII format have been defined.

A smart, safe, adaptive, and user-friendly "Customized GUI" has been implemented with a number of event-driven tree CAD modeling selected system software procedures assigned to Icon tools organized in thematic palettes. This GUI supports Web-enabled smart functionality (unique identifiers/UIDs, NFT tokens for the raster tree images for the IoTr-images Blockchain). In addition, several customized GUI icon tools (clustered in thematic palettes) have been assigned as dedicated system software Key-in routines or event-driven Procedures.

The described conceptual case study ("IoTr-images" WAGB Blockchain), as a low-cost metaverse application, supports the coordinated and parallel design, same-data sharing, and a trustworthy collaborative design process (digitally distributed consensus) enabling transparency of activity and enhancement of data security. The proposed framework facilitates trees and smart forests distributed design and collaborative monitoring.

Findings: Experimental data (findings) proved the satisfactory performance in tree shape modeling of the proposed 2.5D tree modeling implementation technique, compared to manual terrestrial laser scanning and close-range photogrammetry methods, in *time* (fieldwork and design effort/tree CAD model: 15 minutes vs. 72 hours) and *expenditure* (charge/tree CAD model: 3€ vs. 864€) at a cost of modeling accuracy.

A personalized GUI, embedded into the host CAD platform, with thematic Palettes/Icon tools, can operate an implementation technique for the IoTr Blockchain in near real-time. This simple easy-to-design methodology can produce 3D-like tree representations with redesign flexibility, planning, and great visualization functionality. A customized GUI with simple, adaptable, and user-friendly dialogs (thematic palettes and icon tools), as an interpretation tool for the IoTr-images WAGB Blockchain, can support near real-time 2.5D tree modeling operations in a safe, relaxed, and error-free CAD environment, with redesign flexibility, planning, and design functionality.

The proposed IoTr-images Blockchain technique supports coordinated and parallel design, and same-data sharing, i.e., characterized by decentralized and autonomous design efficiency, and can be operated as a CAD s/w gateway to the metaverse.

Suggestions for further study: Future research should study distributed and collaborative "smart tree landscapes" reconstructed from 3D tree CAD models instead of raster tree images and 2.5D tree models ("IoTr-models"). In this case, terrestrial videometry can provide periodically (e.g., monthly) the necessary 3D data acquisitions/point clouds for the modeling.

Additionally, an open research issue is an IoTr-image WAGB Blockchain with GIS functionality in near real-time for a secure and decentralized autonomous spatial analysis. Finally, further research should develop the proposed "*smart tree landscape*" concept and the "*decentralized and collaborative smart tree landscape*" framework into a well-defined and documented decentralized design ecosystem working with tangible raster tree-image and 3D tree-model NFTs.

Abbreviations

AI – Artificial Intelligence.

ASCII – American Standard Code for Information Interchange.

CAD – Computer-Aided Design.

CID – Content Identifier.

DLT - Distributed Ledger Technology.

DLL – Dynamic Link Library. A library that contains code and data that can be used by more than one program at the same time.

DXF - Drawing Exchange Format or Drawing Interchange Format. It is a type of vector file.

Etherscan - Etherscan is a block explorer and analytics platform for Ethereum, a decentralized smart contracts platform.

IoT - Internet of Things.

IoTr – Internet-of-Trees.

IoTrI - Internet-of-Tree (raster) Images.

IoTrM - Internet-of-Tree (2.5D) Models.

IP - Internet Protocol. IP addresses are the identifier that allows information to be sent between devices on a network: they contain location information and make devices accessible for communication.

IP - Intellectual Property.

IPFS - PFS stands for InterPlanetary File System, and it is a p2p protocol for storing and sharing data in a distributed file system. IPFS doesn't rely on a server, so it makes it decentralized and easy to deploy and use, for instance in web3 as it is a decentralized protocol. IPFS is not just for blockchain developers, it's also for web developers, content creators, etc. The artwork files are stored on IPFS and a unique hash to the metadata (including a hash URL to the downloadable image on IPFS) is generated each time and stored in the metadata (which can be viewed on Etherscan).

NFT – Non-Fungible Tokens. An NFT can be anything from photos and video sequences to audio and 3D models. One example of 3D NFTs are those minted by a metaverse named 'Wilder World', which is a platform that's created its own entire world, in which the assets used inside of it, are all minted as 3D NFTs on the Ethereum blockchain.

MDL – MicroStation Development Library (a CAD development programming language). From the introduction of MicroStation V8, MDL code can be compiled using Microsoft Visual C++ as a native-code DLL. This both enhances programmer productivity through the use of C++ object-oriented concepts and provides better performance.

Smart MFG – A 3D NFT marketplace and Blockchain supply chain, where the 3d CAD models, as 3d assets, are converted to a tangible 3D NFT (smartmfg.io). Smart MFG is focused on making 3D assets interoperable across all metaverses and enabling creators and industrial designers to own, market, sell and authenticate their digital assets (CreatorFi), and gamers to accelerate their play-to-earn opportunities (GameFi).

STS - Science and Technology Studies.

TLS – Terrestrial Laser Scanning.

UID – Unique Identifier.

WAGB – Woody Above-Ground Biomass.

WAX – Worldwide Asset eXchange.

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