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Original paper

A technical workflow for building a VRGIS-based system to promote rice products using drone imagery, 3D modeling, and immersive visualization

Sach Thanh Nguyen[1], Le Hung Trinh[1]*, Van Trung Nguyen[2], Van Phu Le[1]

[1]Le Quy Don Technical University, Hanoi, Vietnam
e-mail: thanhns.geo@lqdtu.edu.vn; ORCID: http://orcid.org/0000-0002-7712-6109

e-mail: trinhlehung@lqdtu.edu.vn; ORCID: http://orcid.org/0000-0002-2403-063X

e-mail: phule.ktqs.53@gmail.com; ORCID: http://orcid.org/0009-0002-0066-4694

[2]Hanoi University of Mining and Geology, Hanoi, Vietnam
e-mail: nguyenvantrung@humg.edu.vn; ORCID: http://orcid.org/0000-0002-3032-6808

*Corresponding author: Le Hung Trinh, e-mail: trinhlehung@lqdtu.edu.vn

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Abstract: Agriculture is an important sector of Vietnam's economy, providing livelihoods for 60% of the rural population, accounting for 30% of the national workforce, and contributing nearly 12% to the GDP. In the context of rapid developments in science, technology, and digital transformation, the application of modern technologies, including Virtual Reality Geographic Information System (VRGIS), in agriculture has become an urgent issue in Vietnam. This paper presents a technical workflow for developing a VRGIS to support the promotion of agricultural products through immersive 3D environments. The research focuses on rice, a key agricultural product of Hung Yen Province (which has now been merged into Hung Yen Province), in northern Vietnam. The proposed method integrates multiple technologies into a systematic processing pipeline: (1) aerial image acquisition using drones, (2) 3D reconstruction using photogrammetry and Blender, (3) scene optimization for real-time rendering, and (4) immersive environment deployment using Unity. The system enables users to virtually explore the ThaiBinh Seed Crop Research Institute in a simulated environment. Experimental results demonstrate that the workflow can produce highly interactive and realistic 3D models, suitable for digital product promotion and agricultural education. This workflow proves effective in combining open-source solutions with commercial technologies to facilitate digital transformation in the agricultural sector.

Keywords: unity 3D, blender, VRGIS, drone imagery, immersive visualization

1. Introduction

The integration of Virtual Reality (VR) into Geographic Information Systems (GIS) has given rise to a powerful new paradigm known as Virtual Reality Geographic Information Systems (VRGIS) (Haklay, 2001; Pavelka and Landa, 2024). This approach merges the spatial data handling capabilities of GIS with the immersive, interactive experiences offered by VR environments (Keil et al., 2021; Rahman et al., 2024). In VRGIS systems, users are not limited to static map visualizations but can freely navigate complex 3D representations of real- world spaces, explore geospatial relationships, and engage with digital environments as if physically present (Sermet and Demir, 2022). As such, VRGIS has seen increasing adoption across various domains, including urban planning, environmental education, disaster management, cultural heritage preservation, and agriculture and rural development (Boulos et al., 2017; El Halabi et al., 2019; Kumar and Suresh, 2025).

In the context of agriculture, especially in developing countries, effective communication and promotion of agricultural products remain a challenge (Liu et al., 2011; Abdul et al., 2024). Conventional promotional methods often rely on printed brochures, still images, short videos, or static 2D maps (Lin et al., 2020; Devasia and Sanoop Kumar, 2022). These module provide only limited insight into the richness of agricultural landscapes, the complexity of farming practices, and the socio-economic values of local products (Vasilescu et al., 2023). Additionally, as global agricultural markets become more competitive, stakeholders are looking for innovative ways to differentiate their products, communicate unique value propositions, and engage with both domestic and international consumers (Devaux et al., 2018; Saranya et al., 2024). This calls for more compelling and immersive storytelling module, which is where VRGIS systems can offer a transformative solution (Ghosh and Kumpatla, 2022).

In recent years, several attempts have been made to visualize agricultural data in 3D, utilizing techniques such as 3D GIS, digital elevation models (DEMs), and drone-based photogrammetry (Fareed and Rehman, 2020; Sohl and Mahmood, 2024). Researchers have used unmanned aerial vehicles to capture high-resolution imagery of fields and orchards, which are then processed into textured 3D models using photogrammetry software (Anifantis et al., 2019; Sinha et al., 2022). These models can then be visualized on desktop screens or embedded into web-based platforms for public engagement (Dambruch and Krämer, 2014). Some projects have gone further to embed agricultural 3D scenes into interactive game engines, providing users with virtual tours of farms or crop demonstration areas (Bigonah et al., 2024).

Moreover, many existing implementations rely on commercial software ecosystems, which can be costly and difficult to access for local communities or small-scale agricultural organizations (Dhillon and Moncur, 2023). There is therefore a pressing need for a standardized, open-source-based workflow that is not only technically sound but also replicable and cost-effective (Lele, 2013; Salleh et al., 2014). Such a system should enable local users including farmers, researchers, students, and policy makers to document, model, and virtually present their agricultural spaces and practices in a manner that is both visually engaging and scientifically informative (Janssen et al., 2017).

To address these gaps, this study proposes a complete technical workflow for building a VRGIS-based system specifically designed for the promotion of rice products in Hung Yen province, Vietnam. The proposed workflow integrates four main components: (1) aerial imagery acquisition using affordable consumer-grade drones; (2) 3D reconstruction via photogrammetry, followed by modeling and optimization in Blender; (3) real-time scene rendering and interaction design in Unity; and (4) immersive deployment through virtual tours or standalone applications for education and promotion. This paper contributes to the growing body of knowledge on immersive GIS applications in agriculture by offering a replicable and adaptable pipeline using primarily open-source or free module. It also highlights the benefits of combining modern technologies for agricultural communication, rural tourism promotion, and digital heritage preservation. The results of the study demonstrate how the final VRGIS environment allows users to virtually explore the rice production area, interact with digital assets, and gain a deeper appreciation for the local agricultural ecosystem.

2. Materials and methodology

2.1. Study area and materials

2.1.1. Study area

ThaiBinh Seed Crop Research Institute, established in 2004, is the first private crop breeding institute in Vietnam. The institute is headquartered in Bac Dong Hung commune, Hung Yen province, covering a research area of 13.5 hectares, and specializes in rice, crop varieties, and biotechnology research. Over its 20 years of operation, the institute has developed many high-yielding, resilient crop varieties, most notably the BC15 and TBR225 rice varieties. The institute also applies biotechnology and genetic techniques to improve agricultural product quality, making a significant contribution to the sustainable development of Vietnamese agriculture.

The ThaiBinh Seed Crop Research Institute has received large-scale investment, with a total experimental research area of 152 hectares, spread across various ecological zones in Hung Yen province. It is one of the largest crop research centers among private enterprises in Vietnam. The institute is fully equipped with greenhouses, net houses, field experimental farms, biological and genetic testing laboratories, and internationally standardized seed storage systems. These facilities enable the institute to simultaneously implement multiple breeding, testing, and quality evaluation projects under different ecological conditions.

Fig. 1. Overview of ThaiBinh Seed Crop Research Institute

2.1.2. UAV Device

As part of the data collection on the current status of crop production areas at the ThaiBinh Seed Crop Research Institute, UAV-based aerial imaging activities were conducted to obtain accurate spatial data.

Fig. 2. UAV aerial survey at ThaiBinh Seed Crop Research Institute

2.1.3. Time and Location of Operation

The flight operation was conducted at 9:30 a.m. on March 4, 2025, at the ThaiBinh Seed Crop Research Institute. Weather conditions during the operation were favorable, with mild sunshine, few clouds, and light winds at level 2-3 on the Beaufort scale, providing a stable environment for flight activities.

2.1.4. Device

The survey was conducted using the DJI Mavic 3 Enterprise (M3E) UAV – one of the professional drones designed for topographic surveying and agricultural mapping.

Fig. 3. Image of the DJI Mavic 3 Enterprise (M3E) device

Table 1. Key technical specifications of the M3E device

Component	Specification
Product Name	DJI Mavic 3 Enterprise (M3E)
UAV Type	Foldable, 4 rotors
Flight Time	Up to 45 minutes
Flight Speed	Up to 21 m/s (75.6 km/h)
Maximum Flight Range	15 km (OcuSync 3.0 Enterprise)
Wind Resistance	Level 6 (12 m/s)
GNSS Positioning	GPS, Galileo, BeiDou, RTK (optional)

2.2. Methodology

The development of the VRGIS system for agricultural product promotion involved a multi-stage workflow that integrated UAV-based spatial data acquisition, 2D/3D geospatial data processing, and immersive visualization using modern game engine technologies. Figure 4 illustrates the complete technical workflow adopted in this study, demonstrating the integration between traditional GIS components and advanced 3D simulation modules. The workflow can be divided into two parallel processing streams: 2D GIS processing and 3D modeling and visualization, which are ultimately merged in the immersive VR environment.

2.2.1. Step 1: UAV flight planning and aerial imagery acquisition

The data collection process began with the design of UAV flight missions over the 152-hectare research area at the ThaiBinh Seed Crop Research Institute. Flight planning was conducted using DJI Pilot 2 software, where the survey boundary, flight altitude, camera parameters, and image overlap were carefully configured. The UAV (DJI Mavic 3 Enterprise) was operated at a ground-referenced altitude of 80 meters above ground level (AGL), resulting in an average ground sampling distance (GSD) of approximately 2 cm/pixel. The onboard 4/3 CMOS sensor ensured high spatial detail and geometric accuracy across the entire area.

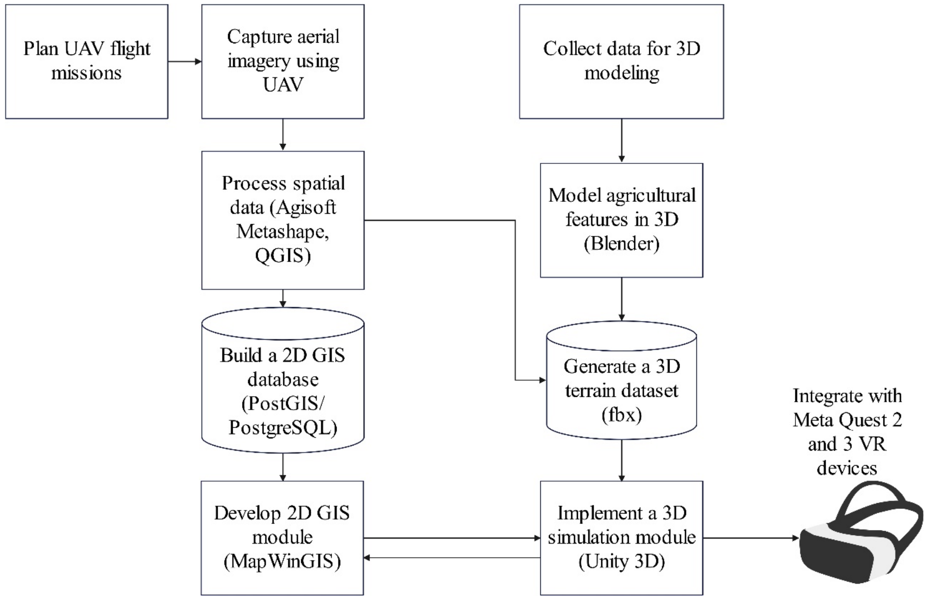


Fig. 4. Technical workflow of the VRGIS system development integrating UAV data acquisition, 2D GIS, 3D modeling, and immersive VR visualization

The flight speed was maintained at 6.5 m/s, with 75% frontlap and 65% sidelap between consecutive images. A total of 205 photographs were captured following a double-grid flight pattern. Prior to the mission, a comprehensive pre-flight inspection was conducted to verify the UAV's operational readiness, including checks of the battery level, GNSS connectivity, and remote controller status. During the mission, the UAV followed an automatically generated waypoint route, and the onboard camera captured nadir images at 0.7-second intervals. The APAS 5.0 obstacle avoidance system remained active throughout the flight to maintain stability and safety under mild wind conditions. Upon completion of the mission, the UAV autonomously returned to the designated home point using the Advanced Return-to-Home (RTH) function. All acquired imagery was subsequently downloaded and securely backed up to a workstation for further photogrammetric processing.

2.2.2. Step 2: Spatial data processing

The UAV imagery was acquired using a DJI Mavic 3 Enterprise and processed in Agisoft Metashape Professional. The UAV's RTK module was connected directly to the Vietnam National CORS network, ensuring high-precision positioning without the need for ground control points (GCPs). Given the relatively small size of the study area, no GCPs were established. All spatial data were referenced to the VN-2000/UTM Zone 48N coordinate system (EPSG: 3405). The georeferenced outputs included an orthophoto mosaic, digital surface model (DSM), and dense point cloud, all exported in GeoTIFF and LAS formats. The onboard RTK correction ensured centimeter-level positional accuracy, providing reliable geometric consistency across the dataset.

2.2.3. Step 3: Building a 2D GIS database

The processed spatial data were organized in a PostgreSQL/PostGIS database for efficient storage and analysis. Vector layers were created for field boundaries, crop types, irrigation systems, greenhouses, pathways, and buildings, each linked with attributes such as crop variety, planting date, and management practices. The database followed a normalized relational structure with primary-foreign key constraints, using the VN-2000/UTM Zone 48N (EPSG:3405) system and GiST spatial indexes to improve query performance. MapWinGIS was chosen for visualization due to its lightweight C#/.NET integration, direct PostGIS connectivity, and offline operation suited to the ThaiBinh Seed Crop Research Institute's local environment.

2.2.4. Step 4: Developing 2D GIS module

Custom 2D GIS module were developed using the MapWinGIS library, an open- source ActiveX component designed for desktop GIS applications. These module enabled users to interactively explore spatial layers, perform attribute queries, and visualize the agricultural landscape in an intuitive 2D environment. Core functionalities included layer control, zooming and panning, feature selection, and information pop-ups, allowing researchers to analyze spatial patterns, monitor crop distribution, and support field-based decision-making processes.

2.2.5. Step 5: 3D modeling of agricultural features

Simultaneously, a collection of 3D assets was developed in Blender to accurately represent key agricultural features, including rice fields, experimental greenhouses, irrigation canals, roads, and farm buildings. The modeling process was guided by both field observations and UAV-derived imagery to ensure spatial and structural accuracy. To enhance visual realism, real-world textures captured from the study area were applied to the 3D surfaces, simulating materials such as soil, water, vegetation, and construction materials. These assets were optimized for polygon count and structured hierarchically for seamless integration into the immersive VR environment.

2.2.6. Step 6: Generation of 3D Terrain Dataset

The processed photogrammetric outputs and 3D models from Blender were integrated into a 3D terrain dataset exported in .fbx format. The dataset included detailed topography, field boundaries, irrigation systems, and buildings, and was optimized for real-time rendering in Unity 3D. To preserve spatial semantics and ensure interoperability with the GIS database, each 3D object was assigned a unique global identifier (GUID) corresponding to its attribute record in PostGIS. These identifiers were stored in Unity using a JSON-based mapping structure, allowing attribute queries and pop-up information retrieval within the VR environment. The geodetic reference (VN-2000/UTM Zone 48N) was maintained through a local origin rebasing strategy, where all coordinates were offset relative to a central reference point to minimize floating-point errors while preserving spatial accuracy. This integration pipeline ensured that geometry, attributes, and semantics remained consistent between the GIS and VR systems, enabling interactive visualization, object selection, and real-time data linkage across both environments.

2.2.7. Step 7: Implementation of 3D Simulation in Unity

The 3D terrain and objects were imported into Unity 3D, where scripts were developed for navigation, interaction, and user interface elements. Scene optimization techniques were applied to ensure smooth real-time performance.

2.2.8. Step 8: Integration with VR Devices

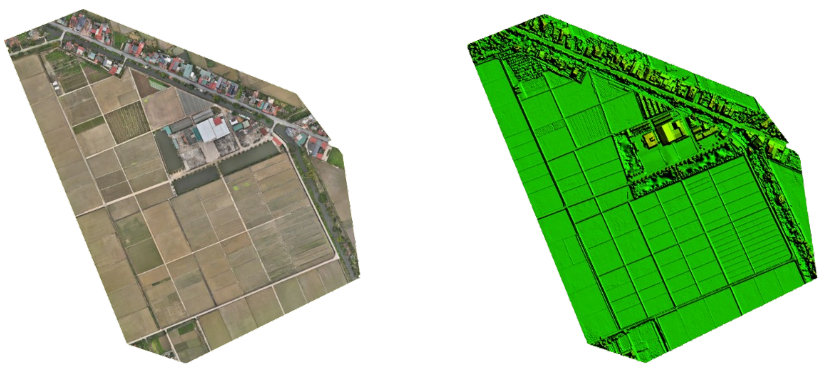
The final simulation was deployed on Meta Quest 2, 3 and other VR headsets. Users could freely explore the virtual landscape, interact with mapped features, and view contextual information, offering an immersive experience of the ThaiBinh Seed Crop Research Institute and its rice production systems.

3. Results and discussion

To visualize and analyze the spatial characteristics of the study area, UAV imagery and derived elevation data were processed. Figure 5a shows the high- resolution aerial imagery captured by the UAV, which provides a detailed visual overview of the crop production landscape. Figure 5b presents the Digital Surface Model (DSM) derived from photogrammetric processing, highlighting the terrain structure, field boundaries across the ThaiBinh Seed Crop Research Institute.

The research team successfully developed a 3D model of the ThaiBinh Seed Crop Research Institute, featuring multiple object categories such as infrastructure components (administrative building, research facilities, storage units, processing areas, livestock zones), greenhouses, parking areas, experimental crop plots, vegetation, and key agricultural products (rice, corn, sweet potatoes, chickens, ducks, etc.).

Covering an area of 13.5 hectares, the team employed the Level of Detail (LOD) technique to optimize rendering performance while modeling the entire institute. In Unity, LOD is a performance optimization method that displays simplified versions of 3D models as their distance from the camera increases. The LOD Group component in Unity enables automatic switching between detail levels, conserving system resources while maintaining high visual quality for objects close to the viewer.

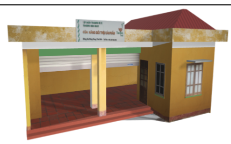
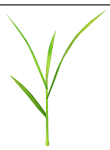
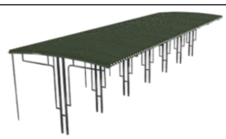


(a) (b)

Fig. 5. UAV-captured imagery (a) and Digital Surface Model (DSM) (b) of the study area

This technique was applied to various elements in the 3D scene, including buildings, vegetation, and agricultural features. In Unity, LOD 0 represents the highest level of detail, containing full polygon count, textures, and geometric precision used when the object is close to the camera. As the camera moves further away, the system automatically transitions to LOD 1, LOD 2, and so on, each with progressively reduced complexity.

Table 2. LOD technique is used for some 3D models

No.	3D models	Category	LOD 0	LOD 1	LOD 2
1		Working facility	32671 Tris	22869Tris	13000Tris
2		Key agricultural product (duck)	4764Tris	1424Tris	
3		King palm tree	51134Tris	25567Tris	15340Tris
4		Product exhibition house	1698Tris	1111Tris	707Tris
5		Key agricultural product (young rice plant)	48461Tris	12256Tris	
6		Parking shed	65712Tris	33782Tris	18576Tris
7		Agro-processing house	321Tris	233Tris	

In addition, the research team has developed a virtual simulation tool for the ThaiBinh Seed Crop Research Institute with various functions, including virtual reality and 3D simulation modes, navigation and interaction within a 3D virtual environment, map-based location visualization, journey recording, day/night cycle simulation, and customizable simulation spaces according to crop seasons (such as young rice, ripe rice, corn, etc.), along with other utilities.

To evaluate the results before and after integrating the LOD technique, the research team conducted experiments on computer systems with the following specifications: Intel(R) Core™ i7-9700F 3.00GHz; RAM: 32 GB; GPU: NVIDIA GeForce RTX 3060 12 GB; Operating System: Windows 10. To ensure the reliability of the performance assessment, all tests were conducted under controlled conditions using the Unity Profiler tool. The rendering resolution was fixed at 1920×1080 pixels, with VSync disabled and the graphics quality preset set to “Medium”. Each scenario was executed five times following a predefined camera path, and the average CPU and GPU frame times (ms ± SD), along with FPS values were recorded. The LOD transition thresholds were configured based on screen-relative height for each asset category to achieve a balance between visual quality and computational efficiency.

Table 3. Evaluation parameters for LOD technique

Parameters	Without LOD	With LOD	Change
FPS	38.8	85.2	+119%
Main Thread Time	25.8 ms	11.7 ms	-54.7%
Render Thread Time	9.5 ms	8.1 ms	-14.7%
GPU Utilization	68 %	42 %	-26%
GPU Temperature	56 °C	52 °C	-4°C
CPU Utilization	41 %	40 %	-1%
Triangles (tris)	25.1 M	6.9 M	-72.5%
Vertices	33.2 M	9.6 M	-71.1%
Batches (draw calls)	9 649	5 055	-47.6%
SetPass Calls	410	384	-6.3%
Shadow Casters	2 988	1 420	-52.5%
VRAM Screen Textures	23.7 MB	23.7 MB	↔ 0%

From the data presented in the Table 3, several key performance improvements can be identified following the implementation of the LOD optimization technique. The system’s frame rate (FPS) more than doubled, exceeding 60 FPS and thereby delivering a significantly smoother and more responsive user experience. The main thread CPU time was reduced by more than half, primarily due to the reduction in geometry processing and the decreased number of draw calls. Concurrently, GPU load decreased by approximately 40%, accompanied by a temperature reduction of around 4 °C, which enhanced operational stability and allowed for longer sustained performance.

Furthermore, the total number of geometric elements, specifically triangles and vertices was reduced by roughly 70% as a result of LOD application, coupled with a 50% decrease in draw call batches. This reduction represents the primary factor contributing to the observed improvements in both CPU and GPU efficiency. Additionally, the number of shadow-casting objects was cut by half, leading to faster and more efficient shadow rendering. After the optimization process, the team performed extensive testing across multiple computer configurations. The results confirmed that the application maintained smooth and stable operation under various system environments, demonstrating the robustness and scalability of the optimized solution.

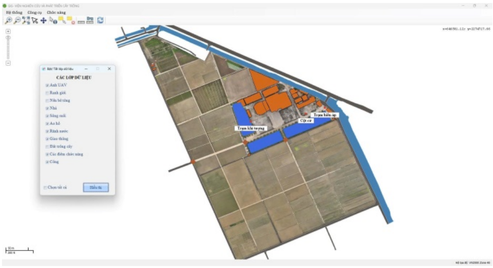
The Unity rendering environment was further optimized using several real- time performance enhancement techniques. GPU instancing and static batching were activated to minimize redundant draw calls for repeated objects, while occlusion culling was employed to prevent rendering of non-visible geometry. Mipmapping and anisotropic filtering (×8) were enabled to improve texture sampling efficiency without compromising visual quality. In addition, baked global illumination (lightmapping) was applied for static lighting to reduce the runtime GPU workload. These combined techniques contributed significantly to the reduction of batches (-47.6%) and SetPass calls (–6.3%), as shown in Table 3, resulting in smoother and more stable real- time performance.

Table 4. Performance evaluation across different hardware configurations after LOD optimization

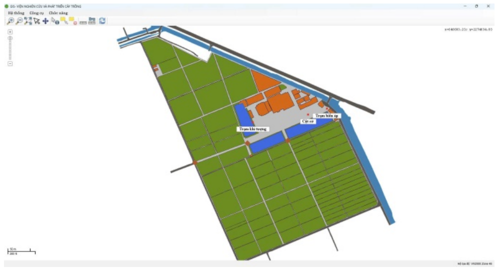
No.	Configuration	Graphics Performance		Geometric Complexity	
1	Intel(R) Core™i7-9700F 3.00GHz RAM: 32 GB NVIDIA GeForce RTX 3060 12 GB OS: Windows 10	GPU	38%	Tris	7.2 M
		CPU	36%	Vertices	9.8 M
		FPS	71.7		
2	Intel(R) Core™i5-14400F 2.5GHz RAM: 32 GB NVIDIA GeForce RTX 3060 12 GB OS: Windows 11	GPU	42%	Tris	7.2M
		CPU	24%	Vertices	9.8 M
		FPS	80.9		
3	Intel(R) Core™i7-14400KF 2.34GHz RAM: 32 GB NVIDIA GeForce RTX 4060 Ti 16 GB OS: Windows 11	GPU	44%	Tris	7.2 M
		CPU	15%	Vertices	9.8 M
		FPS	138		
4	Intel(R) Core™i7-13650HX 2.34GHz RAM: 32 GB NVIDIA GeForce RTX 4060 8 GB OS: Windows 11	GPU	41%	Tris	7.2 M
		CPU	20%	Vertices	9.8 M
		FPS	107		

The simultaneous development of both the 2D GIS module and the 3D virtual simulation module at the ThaiBinh Seed Crop Research Institute has resulted in several tangible outcomes, contributing significantly to digital transformation in high-tech agricultural research, management, and promotion. With the 2D GIS module, the system has completed a comprehensive spatial database of the study area, including parcel maps, functional zoning (research areas, production zones, greenhouses, irrigation systems, etc.), and crop data. The module supports various functions such as visualizing vector data layers, UAV imagery, displaying detailed object information, and updating agricultural data. Its user-friendly interface, developed based on MapWinGIS and PostGIS/PostgreSQL platforms, allows users to efficiently access, query, and perform in-depth data analysis. Figures 6a and 6b respectively illustrate the interface for UAV imagery layers and the spatial data layers of the ThaiBinh Seed Crop Research Institute.

Meanwhile, the 3D virtual simulation module digitally reconstructs the research institute's space in a realistic three-dimensional model. This module is built on platforms including Unity 3D and Blender, and integrated with Meta Quest 2/3 virtual reality headsets. The application was configured with a target frame rate of 120 Hz, employing Single-Pass Instanced rendering and Fixed Foveated Rendering (FFR) to optimize real-time performance and visual quality. Asynchronous Spacewarp (ASW) was enabled to maintain smooth operation during complex scenes, and performance tests over 30-minute continuous sessions confirmed stable frame rates without thermal throttling or frame loss. It offers a range of functionalities, including switching between virtual reality and 3D simulation modes, navigation and interaction within the 3D virtual environment, map-based spatial visualization, journey tracking, day/night cycle simulation, and customizable virtual environments themed around agriculture along with other utilities.



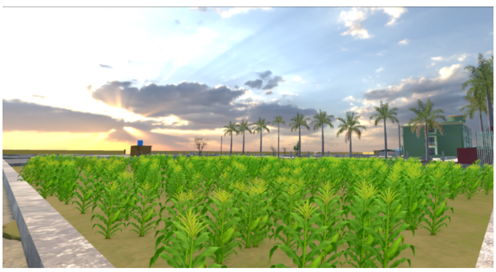
(a) A subfigure



(b) A subfigure

(c) A subfigure

(d) A subfigure



(e) A subfigure

(f) A subfigure

Fig. 6. User experience in a virtual reality environment: interface of the 2D model system (a, b), users operating and observing the model using virtual reality devices (c, d), simulated agricultural landscape in the virtual environment (e, f)

This module not only provides a highly realistic experience but also effectively supports training, technology demonstration, and enhances visual communication. Figures 6c and 6d respectively illustrate the development process of the 3D simulation program for the ThaiBinh Seed Crop Research Institute. Figures 6e and 6f depict interactive 3D simulations of corn and rice fields.

However, this study has certain limitations. The current system is restricted to a single research site, which may limit the generalizability of the findings. Future studies should aim to integrate Internet of Things (IoT) data streams, crop monitoring analytics, and user interaction modules to enhance the system's interactivity and scalability. Expanding the workflow to multiple agricultural regions would also help validate its broader applicability and contribution to digital agriculture.

4. Conclusion

This study proposed a practical workflow for building a VRGIS system to support the promotion of agricultural products, using the ThaiBinh Seed Crop Research Institute as a case study. The method integrated UAV imagery, photogrammetric processing, 3D modeling in Blender, and real-time visualization in Unity. As a result, a detailed 3D model of the 13.5-hectare research area was created, featuring key agricultural elements such as buildings, experimental fields, and major crops. The use of LOD techniques ensured efficient rendering performance in immersive environments. The system provides an effective tool for visualizing agricultural spaces, enhancing product communication, and supporting agricultural education and outreach through immersive technology. This approach demonstrates the potential of integrating open-source platforms to provide reusable and cost- effective solutions for the digital transformation of the agricultural sector. It not only enhances the research and management capacity at the Institute but also opens up the possibility of expanding applications to future smart agriculture models.

Author contributions

Conceptualization: S.T.N., L.H.T., V.T.N.; methodology: S.T.N., L.H.T.; formal analysis and investigation: S.T.N., V.P.L.; writing – original draft preparation: V.P.L.; writing – review and editing: L.H.T.; supervision: L.H.T., V.T.N..

Data availability statement

The datasets used during the current study are available from the corresponding author on reasonable request.

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