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Spatial environment design in agricultural information systems with Unity XR

Diseño de entorno espacial en los sistemas de información en la agricultura con Unity XR

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ABSTRACT: Virtual Reality (VR) technologies aim to develop immersive or mixed spatial environments to adapt tasks ranging from video games to scientific research applications, in the topic of digital agriculture the importance of the metaverse in the processes of agronomy has put this sector in the spotlight, glimpsing future results that could revolutionize agriculture 5.0. The requirements of the application are explained based on an "APK" compatible with the Meta Horizon operating system for Meta Quest viewers, which was developed on the Unity VR CORE platform and the XR Interaction Toolkit Plug-ins, showing the architecture of the spatial environment and the interconnection layers, a class diagram is used to explain the composition of the programming structure used. The implementation strategy of the conceptual models is discussed through the formats of sequence diagram, usage and the logical scheme of the database, which were used to trace the layout of the project and thus the three-dimensional construction of the spatial environment in Unity, giving as evidence real-time images with the Oculus Meta Quest 2 interface in the interactivity modes with Touch controls and the Hand Tracking mode. The importance of spatial ecosystems in the metaverse oriented to information systems in digital agriculture is addressed and the work to follow that awaits us in terms of improving the Agroverse.
Keywords: Virtual-Reality, Interface-VR, Immersive, Agronomy, Meta-Horizon.

RESUMEN: Las tecnologías de Realidad Virtual (VR) tienen el objetivo de desarrollar entornos espaciales inmersivos o mixtos para adecuar tareas que van desde los videojuegos hasta aplicaciones científicas de investigación, en el tópico de la agricultura digital la importancia del metaverso en los procesos de la agronomía ha puesto en la mira a este sector, vislumbrando futuros resultados que podrían revolucionar a la agricultura 5.0. Se explica los requerimientos de la aplicación basado en una “APK” compatible con el sistema operativo de Meta Horizon para los visores de Meta Quest, el cual se desarrolló en la plataforma de Unity VR CORE y los Plug-in de XR Interaction Toolkit, mostrando la arquitectura del entorno espacial y las capas de interconexión, se emplea un diagrama de clase para explicar la composición de la estructura de programación empleada. Se discute la estrategia de implementación de los modelos conceptuales a través de los formatos de diagrama de secuencia, de uso y el esquema lógico de la base de datos, los cuales sirvieron para el trazado del maquetado del proyecto y así la construcción tridimensional del entorno espacial en Unity, dando como evidencia imágenes en tiempo real con la interfaz Oculus Meta Quest 2 en los modos de interactividad con los controles Touch y el modo de Hand Tracking. Se aborda la importancia de los ecosistemas espaciales en el metaverso orientados a los sistemas de información en la agricultura digital y los trabajos a seguir que nos depara en materia perfeccionamiento del Agroverso.
Palabras clave: Realidad-Virtual, Interfáz-VR, Inmersivo, Agronomía, Meta-Horizont.

INTRODUCCIÓN

In the current era, the faster development of computational technologies has opened the doors to revolutionary ideas, as the same as the artificial intelligence, the oblique computation, the big Data, the high reality experience, the quantum computation, etc. These technologies are fundamental to dealing with the high demands of modern society, each time it is more notorious the integrity in our current days.

In concern to the Agricola sector, the technology es necessary to keep competitive. In USA, China, Japan and the Netherlands are leaderships in the implementation of 5.0 agriculture Vargas-Canales (2022), approaching the robotics and AI as a key tool. In contrast to them, developing countries are still closing the technological brochure, although the efforts of capacitation and technological transfer are starting to give good results. in lack of infrastructure inversion to goals to the challenge Global of Tecno-Agro.

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The virtual reality (VR) creates interfaces that immerse the users in virtual realities, enhancing the interaction with computational technologies. The metaverse, emerge as a future virtual reality, offering users the ability to operate avatars through human-computer interfaces, such as PCs, smartphones, or VR devices like Oculus Meta Quest or the new Apple Vision Pro Apple Corporation (2024), these innovations are undoubtedly laying the foundation for advancements in cybernetics and human bionics.

The integration of virtual reality (VR) and the metaverse in agriculture represents an emerging frontier with the potential to radically transform the way agricultural processes are managed and optimized. The adoption of these technologies promises to enhance productivity, sustainability, and data-driven decision-making, addressing key challenges such as food security, climate change, and efficient resource management (Anacona *et al.*, 2019). This study is justified by the urgent need to explore and develop innovative solutions that can contribute to a more resilient and sustainable agricultural future.

Virtual reality, by overlaying digital information onto the physical world, offers unprecedented opportunities for agricultural data visualization, environmental change simulation, and training field workers in advanced techniques without the risks or high costs associated (Zagalo, 2020).Therefore, the metaverse, as a shared collective virtual space, has the potential to revolutionize collaboration, knowledge exchange, and the management of remote agricultural operations, promoting connected and technologically enabled agriculture (Page *et al.*, 2021).

The practical implementation of these technologies in agriculture is still in its early stages, with significant barriers in terms of technological access, required skills, and acceptance by the agricultural community (Koutsabasis *et al.*, 2021). Therefore, this study aims not only to demonstrate the technical feasibility and benefits of an agricultural ecosystem in the metaverse but also to provide a framework for its effective and scalable implementation.

The research line on metaverse technologies aimed at digital agriculture (Agroverso) is part of the field of digital agriculture, which is defined as:

> “It is a holistic approach aimed at optimizing production, improving efficiency, and reducing environmental impact by leveraging technological resources that enable farmers to monitor and control various aspects of the agricultural process remotely and in real time through different technological solutions” (Flores, 2024).

The synergy of digital agriculture and human-computer interfaces can create virtual spaces for the design of information systems in agriculture, which serves as a cyber repository to ubiquitously interconnect with cloud computing, computer networks, and massive information systems (Big Data), for the creation of virtual ecosystems that allow the transaction of information in agriculture in a user-friendly, intuitive, dynamic, and highly cybernetic way, this mode, the project has been named AgroVerse, a 3D architecture based on the Metaverse for real-time interaction between the Avatar (User) and digital agriculture systems (Serrano et al., 2024)."

MATERIALS AND METHODS

Application Requirements

Technical objective: Design a virtual reality environment in Unity XR for the metaverse that enables the connection of data system sources to create a haptic, kinesthetic, and immersive experience for the user, applied to digital agriculture systems.

Technical Characteristics:

- Installable APK
- Unity VR CORE development platform and XR Interaction Toolkit plug-in
- Compatible with versions of Meta Horizon OS operating system
- Compatible with Oculus Meta Quest 2 headsets and preferably Oculus Meta Quest 3
- Navigation and control via Touch controls and Hand Tracking
- Internet navigation support
- Audiovisual support

Software requirements

Software use case specifications: Table 1

Technology selection

Other alternatives for the project design include the new Apple Vision headsets, which are the most scalable competitors in VR technology Apple Corporation (2024), these are goggles with a 4K virtual reality display that provide an immersive experience by integrating both physical and virtual environments, thereby enhancing user capabilities; no obstante, in 2024, Meta is launching the Oculus Meta Quest 3, which offer capabilities similar to the Apple Vision, although they are still headsets with camera systems for detecting the physical environment, rather than goggles with a peripheral display, as proposed by Apple.

On the other hand, Oculus is based on the Android operating system, allowing for greater versatility in development and access to platforms like Unity for spatial content creation, In contrast, Apple Vision is a spatial computer based on the visionOS operating system, requiring Mac infrastructure for content design (although it has great potential). As seen in the world of computers and smartphones, Apple’s product compatibility is exclusively limited to their own products.

VR Environment Architecture

Data Flow Diagrams (DFD) are a way to map the circulation of data within information systems. These diagrams are structured in levels that that analyze the behavior of their components IBM (2025), Below, Diagram 1 illustrates the system behavior in a Level 0 DFD.

TABLE 1. General desktop application use case descriptio

Use case	Specifications
User role	User Avatar
Description	A spatial virtual reality environment in the Metaverse focused on information systems in agriculture, designed to enable haptic and kinesthetic activities in different activities that allow users to navigate immersively within a virtual ecosystem, enhancing the consultation and learning of the most important topics in digital agriculture.
Preconditions	APK compatible with Meta Horizon OS for Oculus Meta Quest headset, with navigation interfaces using Touch controllers and Hand Tracking. The user must have a Wi-Fi connection point with internet access.
Activities	• APK installation on the headset • Navigation in the agro-verse using a Touch controller • Internet connectivity and access to digital information system points in agriculture through Hand Tracking interaction • Spatial navigation in the following rooms: ◦ Main Room ◦ ICT Room in Agriculture ◦ Agriculture Database Room ◦ Multimedia room ◦ Download Room ◦ Agronomic Practice Room ◦ Agronomic Library Room

* Own authorship

The following diagram shows the system deployment represented in a Level 1 1 DFD:

In Diagram 3, the architecture layers of the working system can be seen, composed of 5 sub-layers, it begins on the left with the Unity design, followed by the compilation and construction of the APK file, Then, the process for linking the constructed environment to the Oculus Meta Quest, which enables the loading of the virtual environment and access to the Meta Horizon OS platform for real-time execution and Finally, the infoproducts represent the launch of the VR spatial environment simulation between the user and the HMI.

Class diagram

RESULTS AND DISCUSSION

Below, Figures 1 - 4, show the context of the main room and the architecture with which it is designed:

Sequence diagram

In software engineering, sequence diagrams are a modality of the UML standard that allows for visualizing the simultaneity of interaction between objects and processes Vidal-Silva *et al.* (2019), this enables the analysis of the lifelines between the user and the interaction of the lifecycle of the instances that make it up. In Diagram 5, the process of the prototype is described in its sequence diagram, where the lifelines can be observed and how the user can interact with the processes that comprise it.

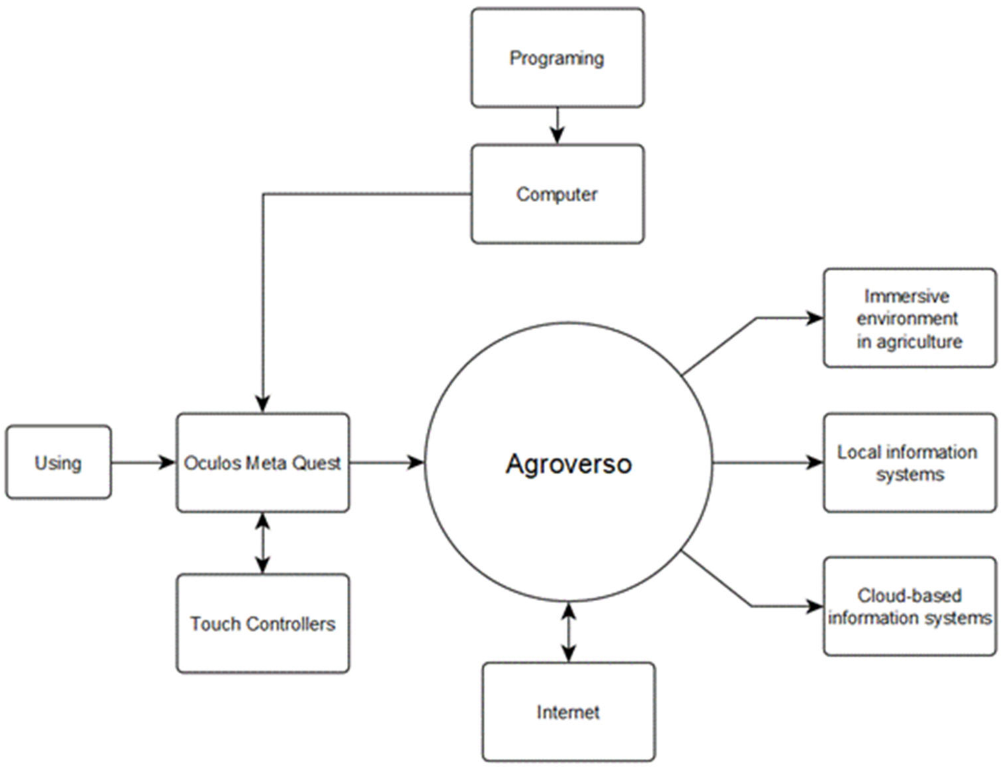

DIAGRAM 1. Level 0 DFD of the Virtual Environment (Own Authorship).

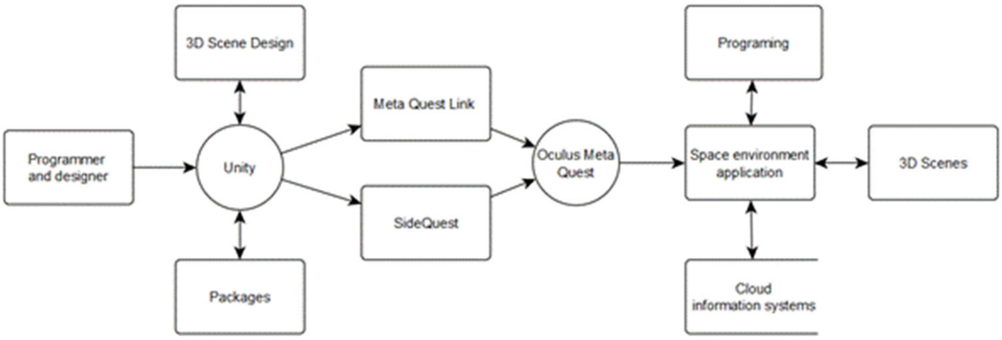

DIAGRAM 2. Level 1 DFD of the Virtual Environment (Own Authorship).

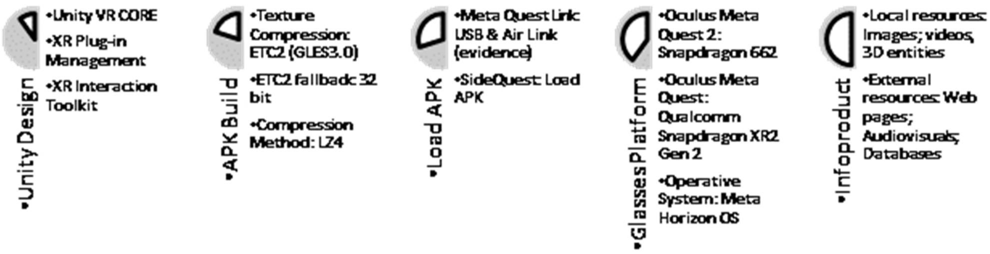

DIAGRAM 3. General Workflow Architecture of the VR System (Own Authorship).

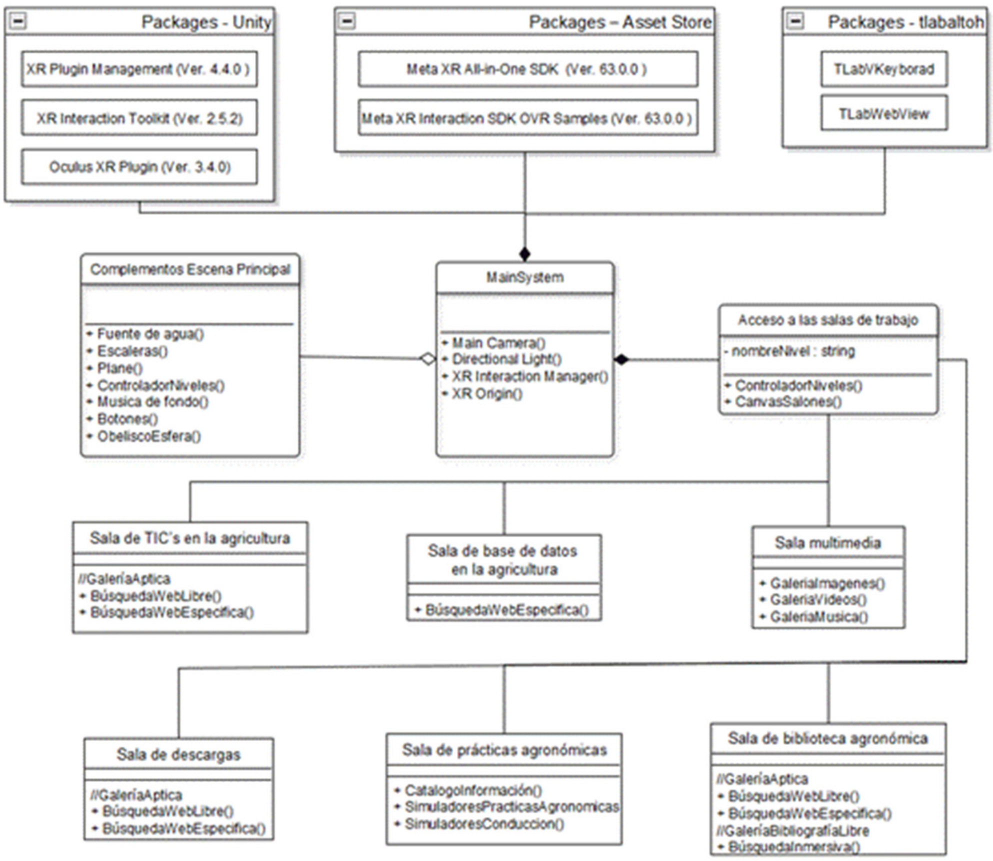

DIAGRAM 4. Class diagram of the general scheme of the agroverse project.

TABLE 2. Operational description of the main sections of the virtual environment

Section	Description
Packages - Unity	Importing the plugins and package kits that enable the basic configurations of the Oculus Meta Quest environment in the Unity VR Core works template
Packages - Asset Store	Composed of two packages imported directly through Unity support, which allow operation and debugging of programming and communication in the virtual environment within the XR SDK architecture for programming the controllers Touch.
Packages - tlablatoh	It is an open-source package called TLabWebViewMRTK for implementing the WebView tool and mixed reality applications using the Mixed Reality Toolkit (MRTK) for Hand Tracking control (TLabAltoh, 2025).
Main System	Contains 3 fundamental GameObjects: Main Camera(), XR Interaction Manager(), XR Origin(), which allow basic and advanced creation and navigation of the Avatar in the virtual environment.
Complements - Main Scene	Contains the GameObjects that make up the main scene and allow for the architectural construction of the spatial environment, as shown in Figure 4.1 and Figure 4.2, this can be seen in the hierarchy of the GameObjects that make up the main scene.
Accesos a las salas de trabajo	Includes a GameObject called ControladorNiveles(), which manages access to the 6 work sub-rooms. This interaction is achieved through a GameObject CanvasSalones(), which contains the labels and buttons for user access through Touch controllers

*Own Authorship

FIGURE 1. Hierarchy of the GameObject components that structure the main room project (Own authorship).

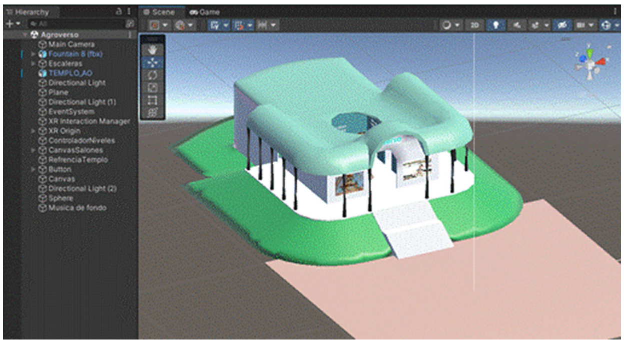

FIGURE 2. Isometric view of Unity of the main room (Own authorship).

FIGURE 3. Main Unity view of the main room of the Agroverse (Own authorship)

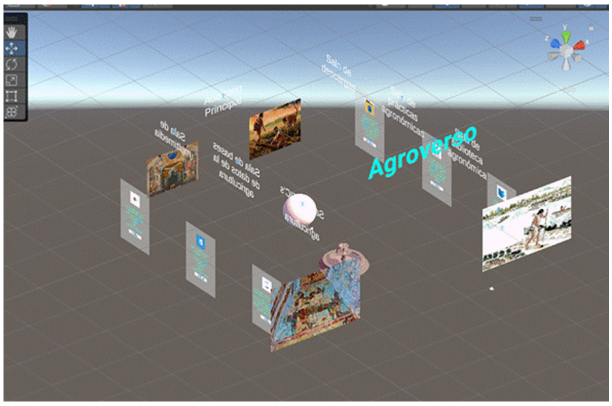

FIGURE 4. General infrastructure of the Agroverse rooms (Own authorship).

Use Case Diagram

Use case diagrams are a tool in the schematic processes of software projects that allow for observing the behavior of the system's operation Marín y Tolmo (2020), in diagram 6, the use case of the spatial environment prototype was outlined, clearly showing how the user interacts with the various rooms of the Agroverse, each allowing access to different haptic and kinesthetic work modalities.

Project Layout

The layout in the design of information systems in agriculture is a topic that is just beginning to formalize, with the transformation of digital agriculture, software for managing the various activities carried out in the vast world of agronomy is being used more regularly.

An example of this application can be the article "Desarrollo de un sistema web móvil para la gestión

DIAGRAM 5. Sequence of the Agroverse virtual reality prototype (Own authorship).

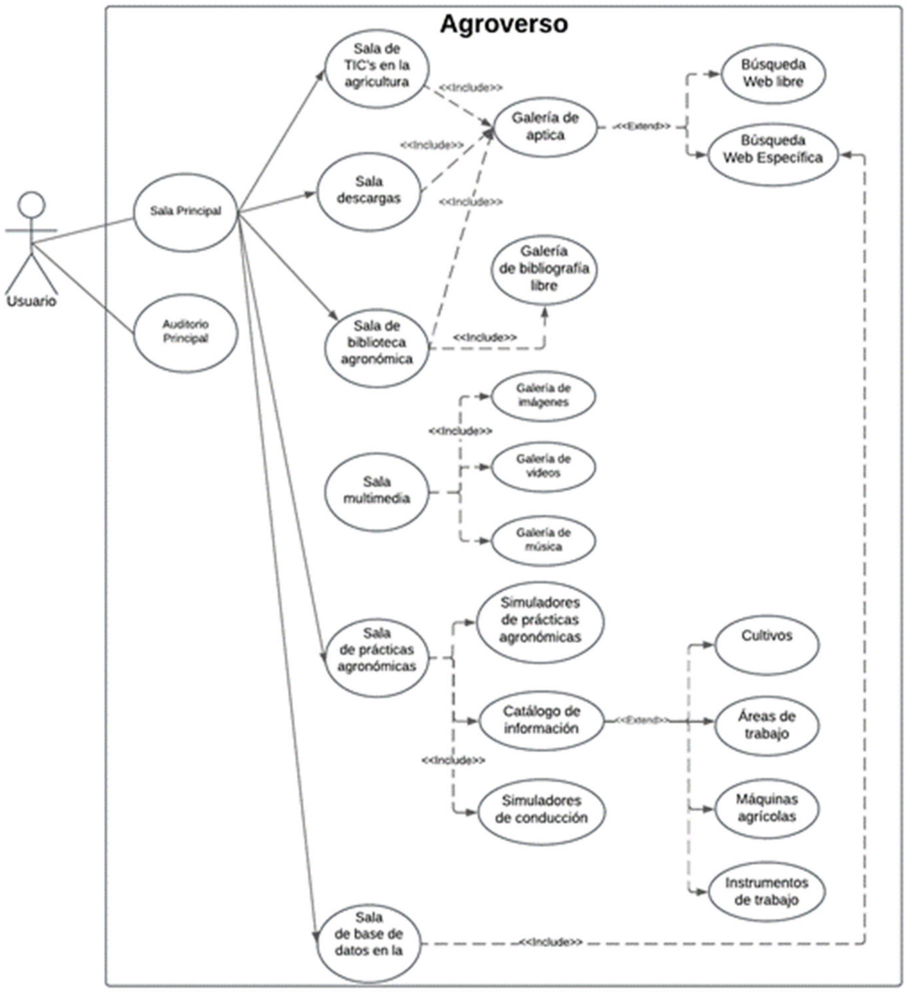

DIAGRAM 6. Use case diagram of the Agroverse virtual reality environment prototype (Own authorship).

de cultivos agrícolas", where the use of tools for drawing UML diagrams and views of the Mobile App prototype can be observed Martínez-Villalobos *et al.* (2018), they also have been used for the design of web systems to commercialize cape gooseberry, potato, and onion in the municipality of Pasca Cundinamarca Triana-Rincon (2023), as in the design of intelligent information systems for tree tomato cultivation Reyes-Roldán & Hernández-Ortiz (2021), another case is in the use of information systems for the commercialization of Hass avocado Bolaños-Camacho & Amaya-Santana (2019), they have also been used in the design of web geographic information systems for thematic maps of irrigation areas Fiallos (2020) and in web geospatial systems focused on lemon fields Sotomayor & Chávez (2024), although this is a brief literature review, there are other cases, demonstrating that digital agriculture has been taking shape in recent years advancing toward the digitalization of information systems processes to place the primary objectives of production in the field at the forefront (Alvarado-Torres *et al.*, 2019).

With a view to the future, prototyping in information system design must gain formality to develop computer systems oriented toward agriculture. This will enable engineers to outline the correct methodological paths in software architecture design for the construction of technical work reports.

Figures 5-8 provide a detailed schematic of the spatial project prototyping.

Database Schema

Below is the descriptive model of the entity-relationship database from the perspective of logical infrastructure:

Navigation results

The 3D spacial environment was designed through a synergy of Solidworks and Blender, also Open Source FBX models were used to complement animation of 3D geometries of the virtual ecosystem, thus, structuring the main room of the Agroverso and work sub-rooms, with the Unity VR CORE development engine the architectural organization of 3D models was carried out and its corresponding programming with the tools from XR Interaction plug-in of XR Interaction Toolkit plug-in package, as described above.

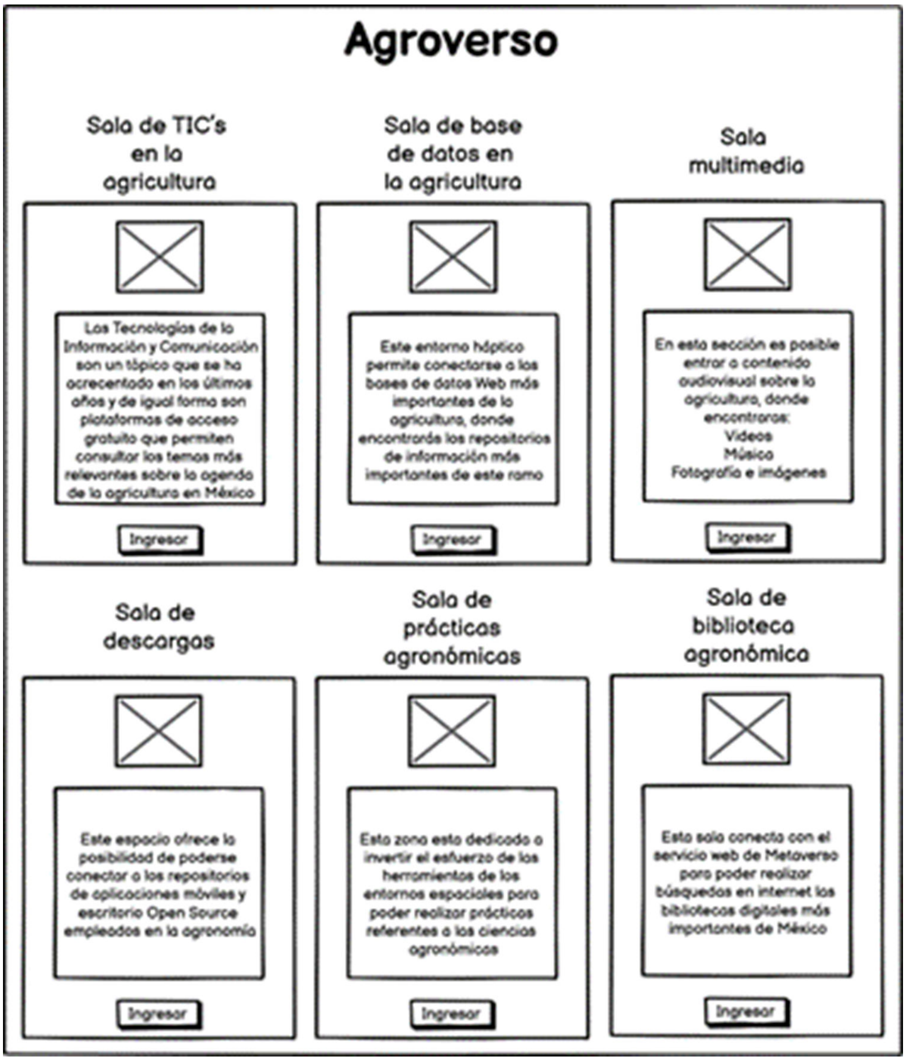

FIGURE 5. Prototype model of the main room of the Agroverse.

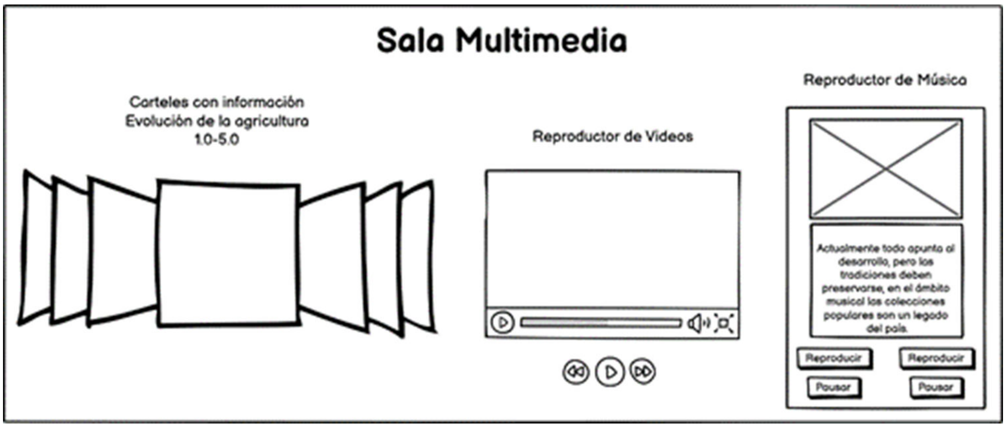

FIGURE 6. Prototype model of the multimedia room.

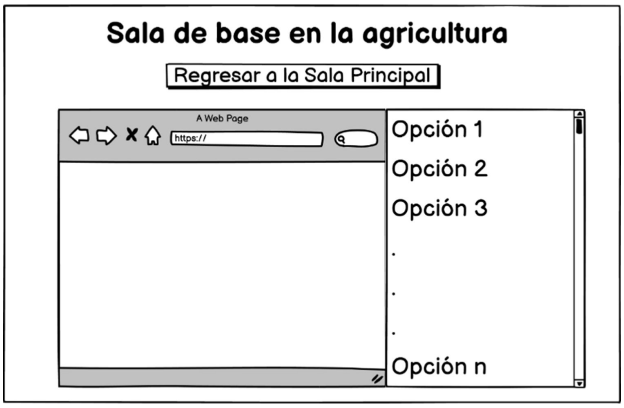

FIGURE 7. Prototype model of the agriculture database.

FIGURE 8. Prototype model of the ICT room in agriculture.

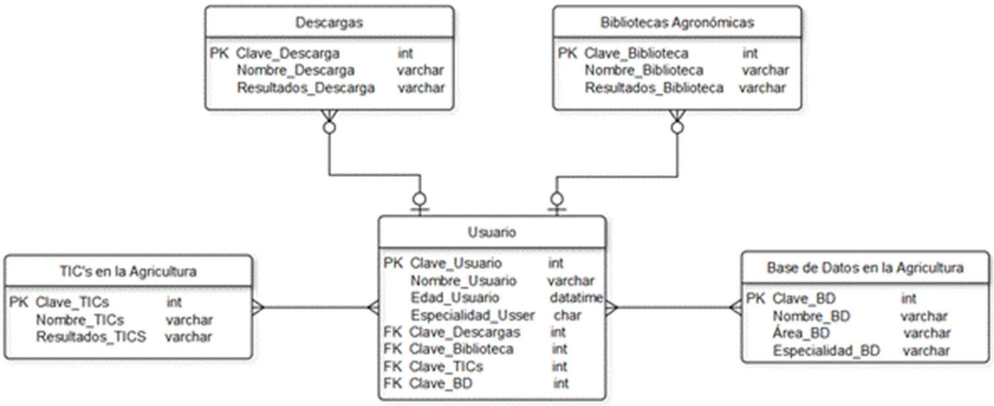

DIAGRAM 7. Entity-relationship logical database schema.

The following group of images shows the navigation of the spatial environment using Oculus Meta Quets 2 with the option of using Touch controls or Hand Tracking (depending on the mode of operation of each room).

CONCLUSIONS

- Information systems in agriculture, or more precisely digital agriculture, are a highly relevant topic in the technological development of this sector, the virtual reality is still an emerging and evolving technology, and it will take a few more years before these systems expand into other sectors, leading to the obtain of new software and hardware products that enhance their functionalities.
- In the context of VR technologies applied to agriculture, there are online notes about interest, opportunities, findings, ideas, and other expectations where spatial environments in the metaverse will have a great impact on the Agro sector, without a doubt, virtualization is a phenomenon that has spread globally, pushing contemporary society further into digitalization.

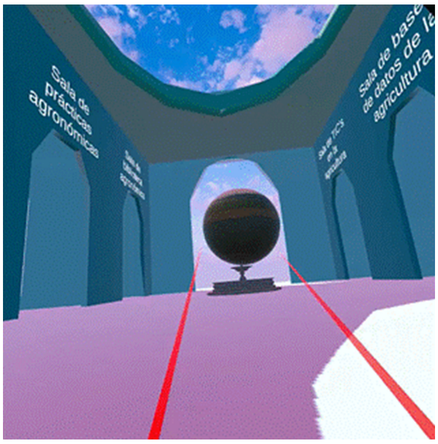

FIGURE 9. Main room of the Agroverse for access to the work sub-rooms (Own authorship).

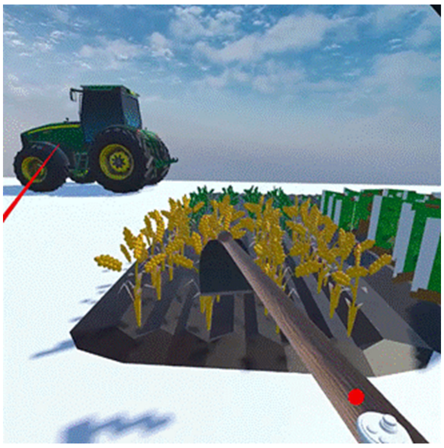

FIGURE 10. Touch control action demonstration for object interaction, agronomic practice room (Own authorship).

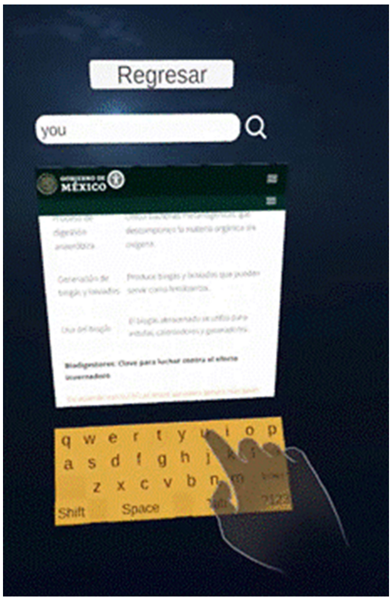

FIGURE 11. Hand Tracking mode for web navigation of information systems in agriculture (Own authorship).

- A working framework focused on agricultural information systems has been documented. However, this is not the only opportunity available for the Agro sector, considerations can be made regarding national and international trade, agro-industrial process simulation, training for mechanical and mechatronic machinery, advanced kinesthetic laboratory simulations, and many other potential applications.
- In the framework of the development of computer programs, software engineering is a tool that allows designers to outline both the methodological and logistical strategies of the software production process, in the realm of VR project production in the metaverse and digital agriculture, this resource is a key element to guide the planning efforts and the creation of technical, key, and critical paths that can be observed throughout the entire planning process.
- As future work, the formation of a multidisciplinary work team with a broad spectrum to involve designers, programmers, documentalists, researchers, experts in the topics of agronomy, etc., who can contribute from the inter, multi, and transdisciplinary perspectives to enrich the Agroverse and one day consolidate it as a spatial environment in the metaverse composed of world's, allowing avatars to navigate through different spatial areas to maximize the potential of a future Multidisciplinary Agroverse.

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