RESEARCH ARTICLE

Use of Virtual Reality Simulation Practices for Farmers Training

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ABSTRACT

Virtual reality (VR) improves farming training by mirroring real-life farm scenarios. VR employs immersive technology, e.g., digital twin systems, to mimic the development of crops, handle livestock rearing, and enhance supply chain management. Training based on VR improves experiential competencies, allows informed decision-making, and delivers low-cost, eco-friendly agriculture solutions while addressing misinformation on climate change. The simulation of virtual reality (VR) revolutionizes agricultural education by crafting engaging environments that reflect authentic farming experiences. The research highlights the components of the VR system and examines its uses in areas like virtual crop simulation, precision farming, digital twin-based management of livestock, and optimizing supply chains. Additionally, VR can combat misinformation about climate change, boosting practical competencies and strategic decision-making for sustainable agricultural methods.

Keywords: *Virtual Reality; Simulation; Digital Twin Technology; Industry 4.0; Predictive Analytics; Precision Farming; Supply Chain Management.*

INTRODUCTION

Nowadays, computer graphics are incorporated into various aspects of our lives. As we approached the end of the 20th century, it became hard to envision an architect, engineer, or interior designer working without a graphics workstation. In recent years, rapid advancements in microprocessor technology have led to the release of faster computers. These devices come with improved and quicker graphics cards, and their costs decrease swiftly. It is now feasible for even the average user to enter the realm of computer graphics. This excitement for a new reality often begins with video games and endures over time. It enables us to view our surroundings from a different perspective and engage in experiences unattainable in real life or have yet to be created. Furthermore, the domain of three-dimensional graphics knows no limits or restrictions and can be formed and adjusted by our own choices – we can even augment it with a fourth dimension: the realm of our imagination. Yet, that's not enough; people continuously seek more. They desire to immerse themselves in this realm and interact with it, rather than simply observing a display on the screen. This technology, which has gained immense popularity and trendiness in the current decade, is called Virtual Reality (VR).

VR is a computer-generated technique in a simulated environment that brings auditory and visual experience to people (Zhou and Calvo, 2018). It is a simulation system and 3D dynamic scene fused multi-source information (Zou *et al.,* 2004). Using three-dimensional graphics, interactive tools, and high-resolution screens, it is possible to create a virtual

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environment where users can manipulate imaginary objects as if they exist in the real world. As a result, key aspects of experiencing virtual reality include the virtual environment, immersion, tactile feedback (responses to user actions), and interaction. The benefits and importance of rapid product development and cost efficiency have been acknowledged in recent years. Consequently, countries around the globe are exploring virtual reality and its uses, with numerous researchers focusing on various techniques, shifting their priorities from purely technical aspects to practical applications of VR and its potential benefits for individuals. Virtual reality, as a practical technology, is well-established and is currently being explored for its applications across various industries, including computer graphics, CAD, CAM, CIM, robotics, healthcare, architectural design, entertainment, education, multimedia, gaming, and more (Hu *et al.,* 2009). Numerous companies have released commercial products designed to assist in advancing VR application systems. However, its use in virtual experiments for agricultural machinery is still limited. This research aims to present VR technology and create a virtual experimental framework for agricultural equipment utilizing VR.

FEATURES OF VIRTUAL REALITY

The initial idea of virtual reality was proposed by Ivan Sutherland in 1965: "make that (virtual) world in the window look real, sound real, feel real and respond realistically to the viewer's actions" (Feng *et al.*, 2010).

According to the definitions, one could assert that features, which influence the quality of a VR system. Basic features of the VR system can be illustrated through the 3'I' concept (Burdea & Philippe, 2003; Shen & Zeng, 2009). The 3'I' stands for Immersion, Interaction, and Imagination.

- *Immersion*, often called presence, is the experience of engaging with or belonging to the digitally created environment. This occurs due to the system's activation of human senses (sight, sound, touch, smell, etc.).
- *Interaction* serves as a way to communicate with the system; however, in contrast to conventional Human-Computer Interaction that employs one or two-dimensional (1D, 2D) methods such as a mouse, keyboard, or keypad, interaction in virtual reality (VR) typically involves three-dimensional (3D) techniques like a space ball and a head-mounted display (HMD). Key interaction characteristics in VR systems include efficiency, immediate response, and human involvement.
- *Imagination* can be viewed as the designer's vision for achieving a specific objective. Given the versatility of VR system components in tackling complex problems across various domains, it is undeniable that VR serves as a more efficient and effective way to convey ideas compared to traditional 2D drawings or written descriptions.

The Structure of VR Technology: Virtual Reality (VR) involves computer-generated simulations of environments, allowing users to interact with them through various specialized equipment. This technology enables users to engage with virtual objects mimics natural interaction, providing an intuitive experience through visual, auditory, tactile, and other sensory feedback in real-time. The composition of virtual reality consists of three essential components: the environment, which is computer-generated and offers sensory experiences that may replicate the real world or create entirely imaginative scenarios; the machine, which includes computer systems and interactive hardware such as helmets for three-dimensional experiences, data gloves and 3D mice; and the individual, who participates in this simulated environment with their actions processed by the computer to create an immersive experience.

A standard virtual reality system comprises six components: systems for computer-generated virtual reality and processes, software application systems, theories and technologies related to virtual reality, input and output human-machine interface devices, users, and databases. The architecture of a VR system is illustrated in Figure 1.

In the virtual reality system, the computer is responsible for generating the virtual world and realizing human-computer interaction. As the virtual world is a highly complex environment, deep exploration of the virtual world requires a large amount of computing; therefore, virtual reality has higher requirements for the computer system configuration. This shows that the computer is the heart of VR systems. To realize the virtual world and natural interaction, it is necessary to adopt special input and output devices to identify various forms of user input and generate real-time feedback to achieve a dialogue between man and computer. The underlying theories and

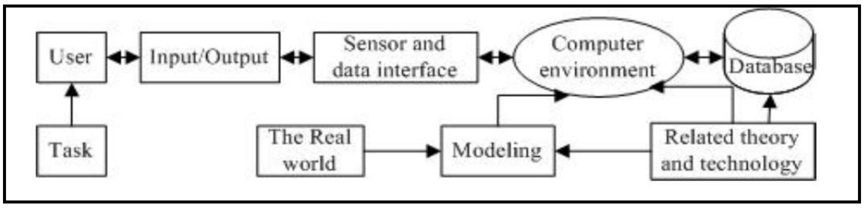

Figure 1: Structure of VR system (Feng et al., 2009)

technologies needed to build a virtual environment deliver essential theoretical and technical support. Key functions include modeling geometric objects in the virtual world, physical modeling, behavior modeling, generating three-dimensional virtual stereo images, managing models, and implementing real-time display technologies while also setting up and managing a virtual world database that stores comprehensive information about the objects within the virtual setting. Ultimately, virtual reality systems are made available for user applications. The essential technologies associated with Virtual Reality include techniques for modeling large-scale three-dimensional scenes, dynamic real-time generation of visual and auditory elements, three-dimensional positioning systems, interactive software, and system integration technologies.

Components of VR Systems

A virtual reality (VR) system consists of two main components: hardware and software. The hardware includes the computer, VR engine, and input and output devices. At the same time, the software is divided into database and application software, as illustrated in the following section.

Virtual Reality System Hardware: The key hardware components include the computer system or VR engine and input and output devices, as illustrated in Figure 3 below.

Input Devices: Input devices are the tools that enable the user to engage with the virtual environment. They transmit signals regarding the user's actions to the system, allowing for timely responses through the output devices. These devices can be categorized into tracking, pointer, bio-controllers, and voice input devices. Tracking devices, also known as position sensors, are utilized to monitor the user's location (Dani & Rajit, 1998) and they encompass electromagnetic, ultrasonic, optical, mechanical and gyroscopic sensors, as well as data gloves, neural and bio or muscular controllers (Craig, William & Jeffrey, 2009). Examples of point-input devices are the 6DOF mouse and force or space ball. These devices utilize technology that builds upon the standard mouse, offering improved functions and features specifically designed for 3D applications. Communication through voice is a prevalent form of interaction among people, making it a logical choice to integrate it into a VR system. Voice recognition or processing software can facilitate this.

VR Engine: In virtual reality systems, selecting the appropriate VR engine or computer system is crucial based on the application's specific needs.

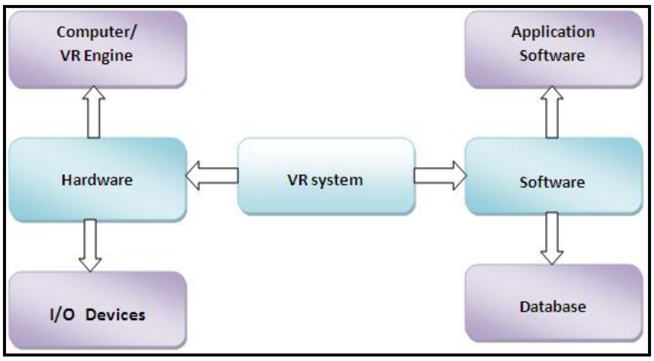

Figure 2: A high-level VR system architecture showing the flow between hardware, I/O devices, computer/VR engine, software components, and databases (Bamodu & Ye, 2013)

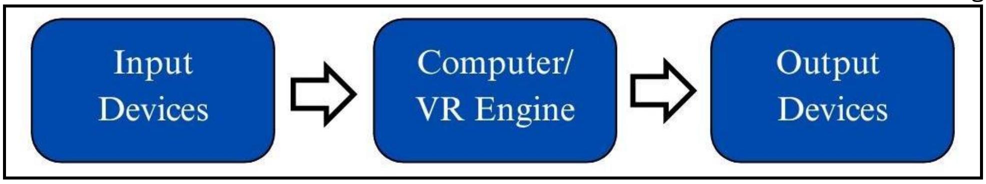

Figure 3: Basic data flow in a VR system from input devices through the VR engine to output devices

Generating graphics and displaying images are among a VR system's most critical and labor-intensive tasks. The application area determines the selection of the virtual environment engine, user preferences, input/output devices, desired level of immersion and required graphic quality, as it is tasked with computing and producing graphical models, rendering objects, providing lighting, performing mapping, applying texturing and displaying simulations in real-time. Additionally, the computer manages user interactions and acts as a bridge with the input/output devices.

A crucial factor to consider when selecting a VR engine is the computer's processing power. This processing power determines how many sensory elements (such as graphics, sound, haptics, etc.) can be rendered within a given period, as highlighted. The VR engine must update the virtual environment roughly every 33 milliseconds and maintain a real-time simulation of at least 24 fps (Burdea & Philippe, 2003). Additionally, the accompanying graphics engine should be able to generate stereoscopic images. The VR engine could consist of a standard PC with enhanced processing capabilities and a high-performance graphics card, or it could be a network of distributed computer systems connected via high-speed communication.

Output Devices: Output devices receive feedback from the VR engine and relay it to users via the appropriate devices to engage the senses. The various types of output devices can be classified based on the senses: graphics (visual), audio (aural), haptic (touch or force), as well as smell and taste. Among these, the first three are commonly utilized in VR systems, while the latter are not yet widely adopted. Two prevalent options for graphics include the stereo display monitor and the head-mounted display (HMD), which offers greater immersion. Within the HMD, the brain interprets the two distinct views generated, creating a 3D representation of the virtual environment. Sound plays a vital role in VR, second only to visuals in importance. 3D audio can enhance realism by emitting sounds from various locations within the VR application. Haptic technology enables users to experience sensations of virtual objects, which can be realized through electronic signals or mechanical devices.

Virtual Reality System Software and Tools: Software for virtual reality systems consists of various tools and applications used for creating, developing, and managing virtual environments, as well as the databases that store the associated information. These tools can be categorized into modeling tools and development tools.

VR Modeling Tools: There are many modeling tools available for VR designing; the most common are 3ds Max, Maya and Creator. Engineering-specific applications may utilize software like CATIA, Pro/E, Solidworks, UG, etc.

VR Development Tools: VR is a multifaceted and integrated technology that draws from various other technologies, including real-time 3D graphics, tracking systems, audio processing, and haptic feedback, which necessitate flexibility in software development and real-time interaction. Beginning the development of a VR system from foundational code in languages like C/C++, Java, OpenGL, etc., demands considerable effort, and the reliability of such systems is typically low; hence, VR development tools are utilized.

Careful thought is required in selecting VR development tools because of the variation in flexibility offered by various software packages concerning model input available, interface compatibility, file format, ease of animation, collision detection, supported I/O devices and support community accessible to the users.

The equipment for developing VR content includes virtual world authoring tools, VR toolkits/

software development kits (SDKs), and application programming interfaces (APIs). It is also not unusual to encounter APIs that function as toolkits, such as the OpenGL optimizer and the Java 3D API (Dani & Rajit, 1998).

Utilizing VR Simulation for Agricultural Training

Development of Virtual Crops: Virtual reality can give users a powerful feeling of reality and authentic experience and occupy a new concept-immersed interactive environment. Using this technology, years of crop growth data can be simulated in just a few minutes. This allows for quick operation, observation, testing, and collection of crop data (Su *et al.,* 2005).

Virtual crops technology uses virtual reality to replicate crops' structure, growth processes and environment in a three-dimensional space. It uses a data collecting system to monitor environmental factors changes and crop growth trends, and to study regular patterns of crops and the environment. The virtual crops system is highly valuable for investigating optimal crop models, enhancing growth strategies, shaping crops, designing gardens, and providing educational opportunities (Sun, 2000; Song *et al.,* 2000; Holt & Sonka, 2003).

Precision Agriculture: Simulation systems have become indispensable tools in modern research and virtual laboratory experiments, providing an advanced platform for in-depth analysis and replication of intricate processes. A prime example of innovation in the agri-food sector is the SIMAGRI platform, a high-fidelity driving simulator designed explicitly for tractors and agricultural machinery. Developed to support precision agriculture (PA) research, SIMAGRI employs advanced algorithms and real-time data processing to mimic the dynamic conditions of modern farming practices (Cutini *et al.*, 2023). Beyond enabling rigorous scientific exploration of innovative PA techniques, this cutting-edge system is a critical training resource for professional farm operators. By allowing drivers to refine their skills in a controlled, risk-free virtual environment, SIMAGRI bridges the gap between theoretical knowledge and practical implementation, ultimately fostering the advancement of sustainable and efficient agricultural practices. Through its virtual environment, researchers can evaluate PA operational strategies' effects and adjustments by replicating real-world scenarios or designing new ones in diverse contexts and configurations. The simulator currently includes an agricultural tractor capable of towing or transporting various farming equipment, such as sprayers, seeders, and fertilizer spreaders. It is integrated with embedded sensors and human-machine interfaces, including joysticks, consoles, or touchscreens, all connected to four virtual environment displays.

Livestock Management: Climate change effects on farm productivity are more severe now, leading to increased food insecurity. It is essential to adopt more sophisticated practices like smart farming instead of conventional methods for increasing production. As a result, livestock farming is quickly

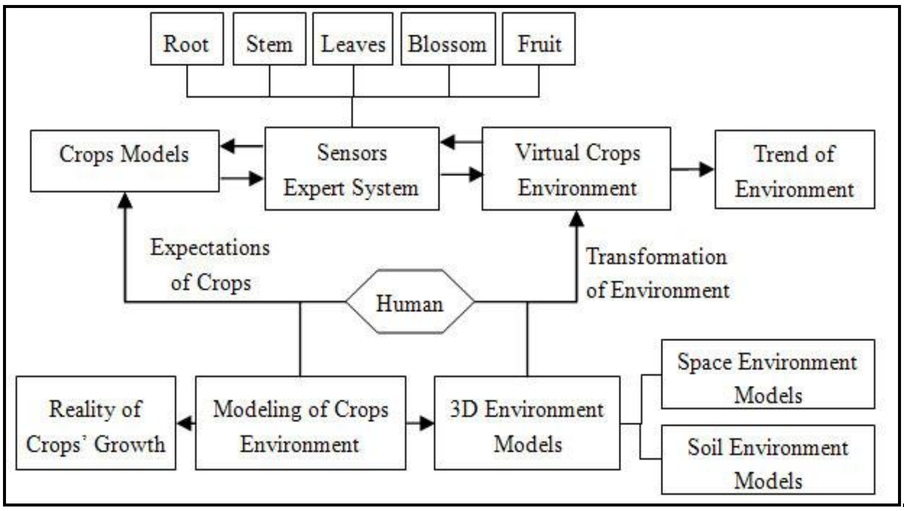

Figure 4: General Architecture of a Virtual Crop System (Li, 2008)

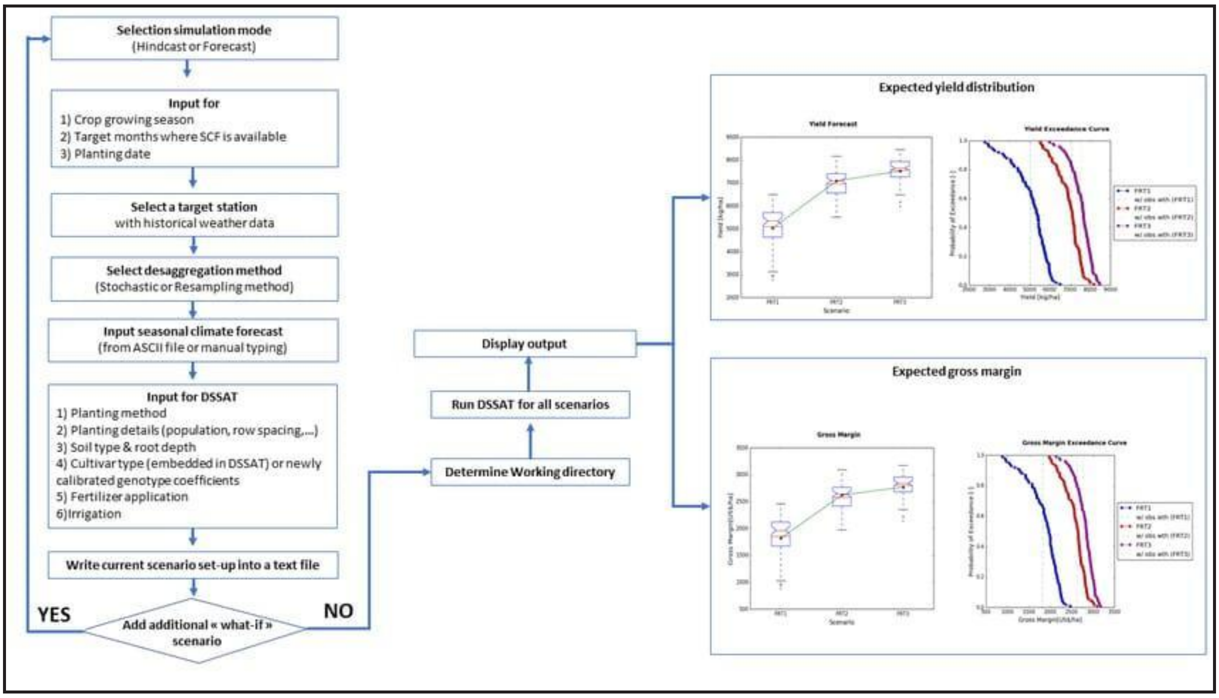

Figure 5: SIMAGRI workflow (version 2 linked with SCF) (Sosa et al., 2017)

transitioning to innovative farming systems, driven by rapid technological advancements such as cloud computing, the Internet of Things, big data, machine learning, augmented reality and robotics. A Digital Twin (DT), an element of state-of-the-art digital agricultural technology, serves as a virtual representation or model of any physical entity (physical twin) connected through real-time data sharing. A digital twin (DT) continuously mirrors the state of its physical counterpart in real time and can also influence it in return. The application of DTs in the livestock sector is currently nascent, reflecting a knowledge gap in their holistic application within livestock systems. The application of DTs in livestock has vast potential to promote animal health, welfare, and productivity (Arulmozhi *et al.,* 2024). The digital transformation landscape in the livestock sector includes monitoring animals, managing the environment, implementing precision agriculture techniques, and optimizing the supply chain. It emphasizes the significance of collecting quality data, maintaining robust data privacy measures, and having

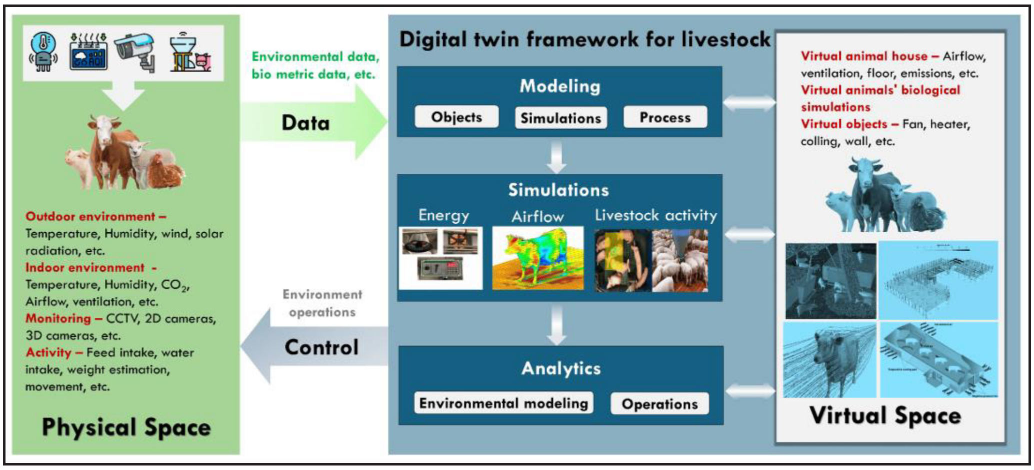

Figure 6: Potential application of digital twins in overall livestock management (Arulmozhi et al., 2024)

seamless data source integration to ensure effective and accurate implementation.

Rationale for Adopting Digital Twins in the Livestock Industry: Despite a recent breakthrough in DT technology, its use in the livestock industry is in the nascent phase of development. However, some industries like aero manufacturing (Ibrion *et al.,* 2019), oil field services (Mayani *et al.,* 2018), software (Brenner & Hummel, 2017), fast-moving consumer goods (Erol, Mendi, & Doğan, 2020), and tire manufacturing (Erol, Mendi, & Doğan, 2020) are already utilizing the benefits of DTs. From the authors' viewpoint, the analysis of prior studies and reviews suggests that DTs offer numerous benefits for improving livestock production. This includes the following:

- *Precision Livestock Farming*: Health and nutrition are enhanced by technology that utilizes real-time data and monitoring for each animal, optimizing productivity on a case-by-case basis. Such growth not only increases animal welfare but also optimizes profitability for livestock farms. This allows farmers the chance to select alternative breeding based on parameters that give optimal productivity, which may include superior growth rates, fertility, or resistance to diseases. Another strategy involves enhancing genetic progress within herds. Digital twins (DTs) can detect early changes in disease-related physiological indicators, behavior, and environmental factors. Predictive models provide farmers with early alerts to help minimize mortality and treatment expenses for emerging health problems. By continuously monitoring the animals' physical condition and their immediate environment, it becomes easier to identify signs of discomfort or stress. This approach enhances overall animal welfare, resulting in healthier and more productive livestock.
- *Sustainability and Environmental Impact*: DTs can greatly minimize waste and lessen environmental impact by enhancing the efficiency of feed and water consumption, along with other resources. This results in more sustainable farming practices that align with the increasing global demand for eco-friendly livestock production methods.
- *Labour Efficiency:* Using DTs in automation minimizes the requirement for additional human oversight. With a virtual system for monitoring and management, farmers can strategically organize multiple schedules for the feeding and care of their animals, thereby enhancing efficiency and reducing the likelihood of human mistakes.
- *Compliance with Regulations*: Digital twins (DTs) offer comprehensive records of animal health, farm management practices, and environmental impacts, while ensuring adherence to both local and international standards for animal welfare and sustainability. This improves traceability across the supply chain.
- *Remote Management:* Digital twin technology enables farmers to manage livestock operations remotely using cloud-based systems. This capability is essential for multi-site farms or large-scale operations, allowing for improved management without physical presence.
- *Operational Cost Efficiency:* While costlier to establish overall, in the long run, the DTs improve resource efficiency, minimize waste feed, and save on healthcare expenditures through early treatment of animal diseases.
- *Training and Education:* The simulated replicas of the livestock system can train employees in innovative management techniques without affecting the real animals, thereby improving the skills and knowledge of farm workers.

Combating Misinformation on Climate Change: Misinformation, whether accidental or deliberate, pertains to incorrect or deceptive information (Lewandowsky, Ecker, & Cook, 2020) and can have serious adverse effects on individuals and society. Misinformation about climate change, especially the denial of its human-induced aspects, can lead to confusion and doubt, undermining efforts to tackle the problem (van der Linden, 2023). It reduces public backing for mitigation strategies, impeding investments in renewable energy, sustainable development, and practices that enhance climate resilience (Winter *et al.,* 2022). Additionally, political divisions and social tensions may emerge from climate change misinformation, creating a split between those who accept the scientific consensus and those who reject or question it (Hart *et al.,* 2015). Combating misinformation, advancing accurate scientific knowledge, and encouraging informed public discussions about climate change are essential for fostering a sustainable future.

To comprehensively grasp the psychology and context behind misinformation, it is crucial to explore the impact of contemporary technology (Ecker *et al*., 2022). Studies suggest that tackling the complexities of the post-truth era demands technological solutions informed by psychological principles (Lewandowsky *et al*., 2017). Virtual reality (VR) has emerged as a promising tool, offering immersive environments that allow users to engage deeply with simulated experiences, thereby providing a unique platform for developing and implementing effective corrective measures (Slater & Sanchez-Vives, 2016). By immersing users in realistic, interactive scenarios, VR can challenge and correct false beliefs and assumptions, making it a powerful tool against misinformation (Slater *et al*., 2020). Additionally, VR can create engaging and memorable experiences that foster critical thinking, learning, and fact-checking (Queiroz *et al*., 2023). This technology can boost media literacy and deepen understanding of intricate issues by allowing users to witness the consequences of misinformation in a controlled setting (Jones *et al*., 2022). Moreover, VR can be combined with data visualization and interactive storytelling to present factual information captivating and impactfully (Krokos *et al*., 2019; Slater & Sanchez-Vives, 2016).

The advantages that make VR effective for delivering persuasive messages can also render it a powerful means of spreading misinformation (Ahn, 2021; Brown *et al.,* 2023). Although creating high-quality VR content is challenging and there are currently low levels of familiarity with VR devices, the significant investment in this technology suggests that VR platforms will likely gain popularity in the future (Trauthig & Woolley, 2023). Therefore, it is increasingly essential to comprehend how VR can be used in harmful ways, such as for disinformation campaigns and to develop strategies for countering these activities within the VR environment.

Supply Chain Management: Supply chains are becoming increasingly important, with competition shifting from individual companies to entire supply chains (Farahani *et al.,* 2014). The swift development of supply chain management (SCM) as an essential area within operations management is propelled by technological advancements such as digital twin (DT) technology, which is a part of Industry 4.0 progress. Digital twin (DT) technology, initiallycreated by NASA in the 1960s, generates a virtual representation of physical assets and processes, continuously updated through sensor information and analytics. Supported by IoT, cloud computing, AI, robotics, and 3D printing (Verboven *et al*., 2020), digital supply chains derive actionable insights from real-time data, improving efficiency, adaptability, and value generation. Initial findings indicate that DT technology enhances performance throughout operations and supply chains.

Contemporary supply chain management (SCM) software encompasses a variety of solutions, including advanced planning and scheduling (APS) systems, warehouse management systems (WMS), and transportation management systems (TMS). Over the last decade, these technologies have streamlined many supply chain operations, significantly improving collaboration and communication between suppliers, buyers, and logistics providers.

Digital twins can complement existing SCM solutions by acting as an innovative layer that enhances the technology stack. In this way, digital twins can refine data inputs for SCM tools, producing predictive analytics to tackle and respond to numerous situations. For example, a multinational OEM created a digital twin to optimize the strategies integrated into its transportation management system (TMS) for managing outbound logistics. Consequently, the OEM achieved an 8 percent reduction in freight and damage costs.

Digital twins enhance supply chain management (SCM) tools in several ways: Digital twins enable comprehensive integration across supply chain management (SCM) software, providing a unified view of performance and the broader impact of decisions across upstream and downstream operations, thereby eliminating fragmented, isolated systems and fostering collaboration—for instance, a retailer used digital twins to connect planning, inventory, and transportation systems. In volatile markets, especially post-COVID-19, supply chain leaders must adapt to shifting demand and disruptions like port delays or material shortages; digital twins paired with SCM tools offer real-time insights, predictive analytics, and actionable recommendations to mitigate risks, as demonstrated

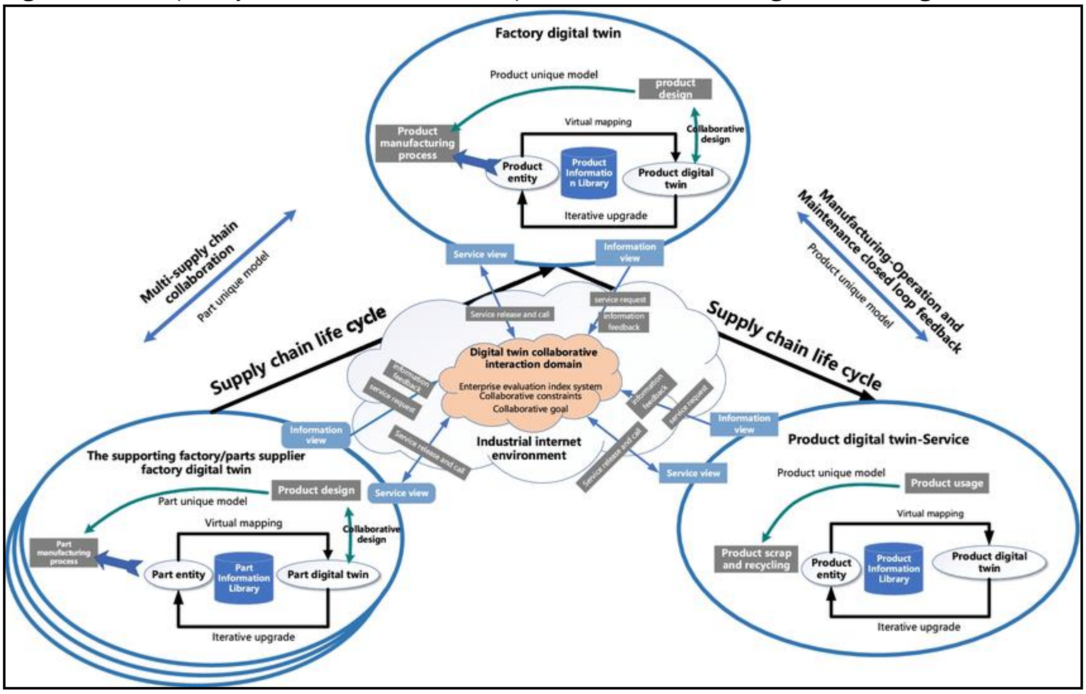

Figure 7: Supply chain digital twin system based on a unique product model (Xia et al., 2022)

by an OEM that reduced last-mile delivery costs by 5% through monitoring carrier performance and surcharges. Additionally, digital twins help balance competing priorities and complex constraints, enabling rapid responses to market changes, such as an automotive manufacturer dynamically aligning demand with supply and operational challenges to optimize sales and production goals. Furthermore, SCM systems enhanced with digital twins can simulate diverse scenarios by analyzing variables like lead times, demand patterns, and supplier reliability, predicting outcomes to strengthen resilience—for example, a consumer goods company reduced distribution costs by 15% by evaluating fluctuating demand and labor levels in its distribution network.

Conclusion: Virtual reality (VR) simulation is a massive milestone in agricultural education that surpasses conventional methods by combining immersive technology with actual farming practice. This technology provides a precisely controlled, interactive environment where farmers can address complex scenarios ranging from accurate crop management and animal care to optimizing supply chain operations without the risks associated with hands-on testing. Consequently, VR simulation facilitates the growth of essential technical skills and promotes higher-order decision-making, strategic problem-solving and adaptive learning in environments characterized by uncertainty and complexity. Combining VR with emerging digital technologies such as digital twin technology, the Internet of Things (IoT), cloud computing and artificial intelligence (AI) further propels its revolutionary potential. Digital twins are constantly updated virtual representations of physical assets and processes, allowing for the incorporation of real-time sensor data with predictive analytics, which gives stakeholders valuable insights into operations. This collaborative interaction between advanced technologies creates a holistic framework for sustainable, efficient, and resilient agriculture, enhancing resource management and environmental care in a more competitive global environment. Further, VR simulation provides advantages beyond technical training, solving systemic problems like dissemination and refutation of climate misinformation. Its capacity to produce engaging, multisensory simulations makes VR a powerful medium for increasing media literacy and promoting an enhanced understanding of complex environmental issues. Therefore, VR not only fosters a more educated and adaptable farming labour force but also helps develop supply chain management strategies, eventually supporting the strategic improvement of farming activities. In summary, including VR simulation in farming education marks the beginning of an era of new education innovation and operational competency. It serves as a productive link between theoretical understanding and functional application, developing a worker base that is technically proficient and strategically resilient in the face of rapid technological and environmental changes. Continued research and further innovation in this field will play the key role in unleashing VR's entire transformative potential, ensuring that agriculture remains on the cutting edge of innovation and sustainable development.

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