APPLICATION OF IMMERSIVE TECHNOLOGIES IN THE AGRICULTURAL SECTOR

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Immersive technologies can be considered as the integration of virtual content with the physical environment, allowing users to interact naturally with mixed reality, which combines two main types of reality: augmented (AR) and virtual (VR) (Arbogast, M., 2019 [1]). On the other hand, immersive technologies include methods and devices that create the effect of immersion in a virtual world through sensory stimuli, using simulation and mapping. This allows people to experience realistic experiences that are not always available in the real world. such technology is the combination of the real environment with digital tools through interactive actions.

Virtual reality (VR) is a technology that creates three-dimensional virtual worlds in which the user interacts with objects and feels a three-dimensional presence. Augmented reality (AR) is an interactive computer visualization technology that adds virtual objects to the real world, allowing users to see and interact with them in real time using mobile devices, applications, and web browsers. The difference between AR and VR is that augmented reality "extends" the real world, while VR "transports" the user to another location.

A modern innovative educational environment can be called a virtual environment associated with current digital technologies, which is actively implemented in education, is virtual reality (VR). It is characterized as an immersive,

realistic three-dimensional environment that provides visual feedback, responding to body movements [2].

Modern agriculture actively integrates innovative technologies to increase productivity, reduce costs and preserve the environment. Immersive technologies, such as augmented reality (AR), virtual reality (VR) and mixed reality (MR), have great potential in crop production. They open up new opportunities for effective resource management, training farmers and optimizing crop growing processes.

Artificial intelligence (AI) and big data processing are used to analyze information, recognize objects, detect plant and animal diseases, predict yields, optimize planting plans and other tasks that help agricultural producers make informed decisions and increase management efficiency. Automation and robotics help optimize agricultural processes. For example, autonomous tractors, drones, and robots can do the work of planting, weeding, harvesting, or caring for animals, which significantly increases the accuracy of production operations, efficiency, and reduces human resource costs.

The use of cloud computing and data analytics provides the collection, storage, and analysis of large amounts of data from various sources. This allows farmers to identify trends, predict weather conditions, optimize resource use, and make effective management decisions that contribute to increased productivity.

Mobile applications and platforms provide access to useful information, such as weather forecasts, market conditions, recommendations, legislation, etc., which will help farmers plan and manage production more effectively. Mobile applications and platforms play a key role in the modernization of agriculture, giving farmers access to a variety of useful information. Thus, they provide accurate weather forecasts, which allows farmers to better plan planting and harvesting, as well as to anticipate possible risks, such as droughts or heavy rains. In addition, applications provide information on the state of markets, including product prices, demand and trends, which allows farmers to optimally sell their products and receive maximum profits.

Based on this platform, recommendations are provided for growing various crops, caring for them, using fertilizers and plant protection products, which allows maintaining best practices in production. Information on current legislation is also an important component, as it will allow farmers to stay abreast of changes in regulatory penalties, avoid and work in accordance with the requirements.

Some applications do not have analytics functions that can collect data from sensors, drones or other devices, automate accounting and reporting, and model future farm development scenarios. Thanks to this, farmers can plan production processes more effectively, reduce costs, increase yields, and ensure the sustainable development of their business.

Scientists emphasize that “the digital transformation of the agricultural sector opens up new opportunities for its effective development. It increases production efficiency, product quality, and increases the level of profitability of agriculture. The digitalization process consists of the introduction of modern digital technologies that allow improving the efficiency and quality of agricultural production and optimizing the use of resources in these processes, thereby increasing profitability. " [3, p. 2].

Now is the era of immersive technologies in crop production, which opens up new opportunities for effective resource management and increased productivity. The integration of virtual reality (VR) and augmented reality (AR) technologies into the agribusiness sector has gained significant momentum in developed countries. These technologies are revolutionizing agricultural practices, increasing efficiency, and solving critical problems in the industry.

In countries such as the United States, Germany, and Japan, VR systems are being used to train agricultural workers and students. These simulations allow users to practice planting, caring for crops, and harvesting in a controlled virtual environment. This approach reduces the costs associated with on-site training and minimizes risks by preparing workers for real-world scenarios.

AR and VR are used to simulate key agricultural processes such as planting, irrigation, fertilization, and pest control. By visualizing these operations, farmers can determine optimal methods and strategies to maximize productivity. In the Netherlands, for example, VR technology is being used to develop precise planting patterns, reduce resource waste, and increase yields.

Augmented reality applications allow farmers to analyze the health of their crops and soil conditions in real time. Sensors integrated into AR platforms provide data on soil moisture, acidity, and nutrient content. This allows for precise planting and fertilization decisions, as seen in advanced agricultural systems in Israel.

Countries such as Canada and Australia are using VR to model the impact of climate change on agricultural practices. These models help farmers prepare for extreme weather events such as droughts, floods, or sudden freezes, allowing them to develop adaptive strategies and reduce potential losses.

AR applications provide a safe environment for testing different methods of pest and disease control. In India, AR tools are helping farmers identify pests and diseases early, providing instant treatment recommendations, thereby reducing the need for extensive pesticide use.

In regions like Europe and North America, AR and VR are an integral part of precision farming. These technologies combine data from drones, sensors, and GPS systems to create detailed field maps, allowing for precise application of water, fertilizers, and pesticides. This not only reduces waste, but also supports sustainable agriculture by minimizing environmental impact.

Countries like the UK and France are using augmented and virtual reality to explore scenarios for maximizing productivity while maintaining ecological balance. Farmers are using these technologies to identify the most effective practices for their specific conditions, ensuring higher yields and profitability.

The adoption of AR and VR technologies in agriculture abroad is demonstrating their transformative potential.

Examples of different climate change or man-made scenarios affecting agricultural yields using immersive technologies

- **Simulation of a prolonged drought**

Scenario: A VR environment recreates the effects of a prolonged drought on crop growth over multiple cropping cycles.

Objective: To analyze how reduced water availability affects soil health, crop yields, and pest outbreaks.

Outcome: Farmers can test irrigation methods such as drip systems or experiment with drought-tolerant seed varieties in a safe virtual environment.

- **Flood Risk Management**

Scenario: An AR simulation simulates flooding conditions, highlighting areas prone to waterlogging.

Objective: To determine crop resilience in saturated soils and determine optimal drainage solutions.

Outcome: Farmers learn to implement preventative measures such as building dikes or selecting water-tolerant crops.

- **Extreme Temperatures and Heat**

Scenario: A virtual reality application visualizes the effects of sudden temperature changes on photosynthesis and plant productivity.

Objective: To assess which crops perform better under high temperatures and adjust planting schedules accordingly.

Outcome: Farmers develop strategies to mitigate heat stress through shade nets or changing planting dates.

- **Soil Degradation from Chemical Pollution**

Scenario: An immersive VR simulation shows the long-term effects of overuse of fertilizers or pesticides, leading to soil acidity or salinity.

Objective: To experiment with soil restoration methods such as crop rotation, organic amendments, or reducing chemical use.

Outcome: Improved knowledge of sustainable methods to restore soil health.

- **Impact of Pests and Diseases in Climate Change**

Scenario: Augmented reality tools overlay live crop data on visual indicators of potential pest infestations, taking into account climate conditions.

Objective: Predict pest outbreaks under varying temperature and humidity levels.

Outcome: Farmers test biological pest control methods or optimized pesticide applications, minimizing losses.

- **Wildfires and Smoke Pollution**

Scenario: VR model recreates the effects of wildfires, simulating smoke damage to nearby crops and nutrient depletion in the soil.

Objective: Assess recovery periods and effectiveness of transplanting strategies.

Outcome: Farmers gain knowledge about management methods after natural disasters.

- **Man-made spills and accidents**

Scenario: Augmented reality tools simulate scenarios such as oil spills or industrial waste affecting farmland.

Objective: To assess impacts on groundwater and crop security, and to test recovery approaches.

Outcome: To improve preparedness for environmental emergencies.

- **Changing rainfall patterns**

Scenario: VR simulation of erratic rainfall patterns and their impact on the planting, flowering, and harvesting stages.

Objective: To develop adaptive planting schedules and test rainwater harvesting systems.

Outcome: Farmers adjust practices to reduce reliance on unpredictable natural rainfall.

- **Impact of urbanization**

Scenario: VR models demonstrate how urban encroachment reduces arable land, changing microclimates and water availability.

Objective: To explore solutions such as vertical farming or greenhouse technologies in confined environments.

Outcome: To provide insights into maximizing yields in confined spaces.

- **Deteriorating air quality**

Scenario: AR app analyzes plant health under conditions of high levels of atmospheric pollutants, such as increased CO2 or particulate matter.

Objective: Test mitigation measures, such as barriers or air purification plants, and predict the impact on yield.

Outcome: Farmers implement methods to protect crops from air pollution, ensuring sustainable growth.

These technological scenarios enable stakeholders to understand, predict, and adapt to the challenges of climate change and man-made factors, paving the way for sustainable and resilient agricultural practices.

By providing innovative solutions for training, resource management, and sustainability, these tools help farmers overcome traditional challenges and pave the way for a smarter and more efficient agribusiness sector.The use of virtual reality (VR) and augmented reality (AR) technologies allows farmers to receive visualized information about the status of positions, assess the quality of justifications and monitor the moisture level on site in a virtual environment. Immersive platforms allow you to simulate various scenarios of crop development, simulate the impact of climate change or man-made factors on yield, and develop plant protection strategies. At the same time, such technologies facilitate the training of specialists, providing access to interactive training and simulators that help master complex agrotechnical processes.

Immersive technologies also help optimize the use of resources such as water, fertilizers and plant protection products by accurately predicting crop consumption in real time. This reduces costs and negative impacts on the ecosystem, supporting the principles of sustainable development in the agricultural sector.

The mass implementation of immersive technologies in crop production will be the first stage in the transformation of the agricultural industry, ensuring its more innovative, technological and environmentally friendly development.[3]

Immersive technologies are digital tools that create virtual environments or integrate digital elements into the real world, providing users with a new level of interaction.

AR (augmented reality) adds digital information to the real environment through devices such as smartphones or glasses.

VR (virtual reality) creates a completely artificial environment that allows you to simulate different scenarios.

MR (mixed reality) combines elements of AR and VR to interact with real and virtual objects.

Using AR allows farmers to create virtual field maps that contain data on soil characteristics, moisture levels and previous yields. This helps optimize crop placement to maximize yields. Using AR allows farmers to create virtual field maps that integrate data on soil characteristics, moisture levels, yield history and even predicted climate changes. Such maps allow for detailed analysis of the skin area, determining the optimal areas for growing specific crops. This ensures the rational use of fertilizers, use and water resources. Based on the analysis of data from satellites and sensors, farmers can predict problems such as soil erosion or the risk of drought, which further measures are taken to prevent losses.

VR technologies are used to simulate various scenarios in crop production, such as sowing, plant care, or harvesting. This provides safe and effective training without the need for real resources. VR technologies also allow you to simulate the impact of various agronomic factors, such as changing weather conditions, the impact of pests, or a lack of fertilizers. Thanks to this, farmers can analyze the possibilities of risks and work out strategies to overcome them.

In addition, these technologies are used to teach students of agricultural specialties, helping them gain practical experience in a virtual environment. VR systems can create interactive simulations to study the structure of justifications, the features of crop development, or the use of modern agricultural technology.

Thus, VR technologies contribute to increasing the efficiency of agricultural production, reducing costs, and a more environmentally friendly approach to farming. They remain another tool in the development of "smart" farming, which is based on innovation and digital technologies/

Mixed reality can be used to analyze the condition of plants in real time. For example, farmers can use AR glasses to visualize data from sensors installed in the field, such as soil moisture or disease risk.

AR technologies allow the visualization of the process of fertilizer or water application based on data collected from sensors and drones. This contributes to the accurate use of resources, reducing waste and negative impact on the environment.

VR can be used to create simulations of future harvests based on climate data, which helps in sales and logistics planning.

Immersive technologies allow the detection of disease or pest outbreaks through real-time image analysis. AR tools can display affected areas on a map of the field, allowing for rapid response.

Ecological approach to the use of VR technologies

The use of VR technologies in crop production opens up new opportunities for the implementation of environmentally friendly practices. Thanks to modeling and simulations in a virtual environment, farmers can reduce the use of natural

resources, minimize the impact on the ecosystem and implement sustainable farming methods.

Virtual simulations allow for training and testing of agricultural techniques without the use of water, fertilizers and plant protection products. This reduces costs and prevents unnecessary stress on soils and water resources. Instead of real experiments in the field, farmers can optimize their approaches in a VR environment without harming the environment.

VR technologies are actively implemented in crop production, providing innovative solutions for agrotechnical process management, training and modeling. They contribute to increasing efficiency, reducing costs and improving the environmental component of agricultural products.

VR technologies allow modeling the impact of different doses of chemicals on crop development and assessing possible environmental consequences. This allows for optimal strategies to be selected that minimize the use of pesticides and fertilizers, reducing their impact on the ecosystem.

Examples of practical applications of VR in crop production:

- Farmer and student training: Interactive programs with simulation of sowing operations, plant care and analysis of justifications.
- Crop monitoring: Modeling of data on the condition of crops for yield prediction.
- Experimental research: Testing new plant varieties in a virtual environment without real resource consumption.
- Ecological optimization: Analysis of the impact of different management methods on the ecosystem.

Advantages of VR technologies in crop production:

- Reduced resource consumption: the ability to conduct training and experiments without the use of water, fertilizers or pesticides.
- Safe environment: Testing risky agrotechnical solutions without harming real fields and crops.
- Environmental friendliness: Reducing the negative impact on nature through the implementation of precision agriculture.
- Innovation: Increasing the competitiveness of the farm through the integration of new technologies.

VR technologies in crop production are a tool for increasing the efficiency of agriculture, conserving natural resources and ensuring sustainable development. application allows you to adapt to modern challenges, such as climate change, and ensure their stable food security.

Table 1. *The main areas of use of VR in crop production*

Area	**Description**
Personnel training	VR systems do not allow a farmer or student to study the processes of sowing, caring for plants and harvesting in a virtual environment.
Modeling of agricultural processes	Creating simulations to optimize sowing technologies, fertilizer application or pest protection.
Analysis of justifications and crops	Simulating the impact of various conditions (moisture, acidity, structure) on crop productivity.
Study of climatic factors	Modeling of climate change, drought, floods and their impact on yield.
Plant protection	Testing methods for pest or disease control in a safe virtual environment.
Optimization of resource use	Calculation of the required water, fertilizer or pesticides to ensure sustainable crop development.
Increasing yield	Scenario analysis to determine optimal growing conditions and maximum harvest.
Precision farming	Using VR to integrate data from drones, sensors and field maps for precise resource management.

Virtual reality (VR) also opens up new opportunities for optimizing processes in livestock farming, increasing production efficiency, improving animal housing conditions and training personnel. Numerous scientific and technical cooperation projects are being implemented in the EU, the largest of which are Copernicus [6] and FaST [7]. These initiatives provide technical support and contribute to the development of the agricultural sector, helping farmers, state agencies of the Member States that finance these programs, consultants and developers of digital solutions to improve their skills and capabilities in various areas. Copernicus projects, in particular, use satellite data to monitor the state of the environment, predict yields, manage natural resources and prevent emergencies. This allows farmers to receive accurate information to make informed decisions that increase production efficiency and reduce the impact on the ecosystem.

The FaST initiative aims to support innovation and digitalization in agriculture by implementing advanced technologies to automate processes, monitor yields, manage resources, and increase overall productivity. Through these projects, farmers and agribusinesses are provided with access to modern tools and methods that contribute to sustainable development, biodiversity conservation, and climate change mitigation. These initiatives promote the integration of digital solutions into the common practices of agriculture, increasing its resilience and competitiveness at the international level.

Analysis of scientific sources shows that "in the context of globalization of the world economy and the era of information and communication technologies, agricultural producers are forced to introduce network technologies into all areas of activity in order to get closer to consumers and ensure sales and minimize the use of resources and costs. The most promising for agricultural business is the use of network technologies and resources implemented on their basis to solve the tasks of

information search, organization of electronic document flow, project management, optimization of activities and forecasting, marketing and sales, communication with fiscal services, banking, communications, personnel training, and production process management" [8].

***Table 2**. Advantages of using VR in livestock farming*

Direction	**Description**
Education and training of personnel	Creation of interactive simulations for practicing skills in animal care, vaccination or equipment operation.
Monitoring of housing conditions	Simulation of different scenarios to analyze animal housing conditions, their impact on productivity and welfare.
Optimization of feeding programs	Studying the impact of different types of feed on animal health and productivity in a virtual environment.
Improving animal health	VR allows you to simulate the spread of disease and develop strategies to combat them, reducing risks.
Veterinary procedure support	Training veterinarians in simulations of complex procedures, which reduces stress and risk for animals.
Simulation of production processes	Creation of virtual scenarios for herd management, optimization of reproduction or control of milk and meat quality.
Ecology	Changing the impact on the environment through process simulation without real use of resources.

Real-world examples of VR applications:

- Farmer training: Interactive programs to train staff without contact with real animals, avoiding stress for the latter.
- Research: Behavioral training of animal behavioral responses to various factors, such as temperature changes or lighting conditions.
- Livestock monitoring: Analysis of virtual farm models to assess its efficiency and animal comfort.
- Risk reduction: Simulation of emergency situations, such as epidemics, to better train staff.
- VR technologies in livestock farming are a powerful tool to increase production efficiency.

VR systems are becoming an effective tool for teaching ecological approaches in crop and livestock production. Students and farmers can learn methods of organic farming, integrated plant protection and sustainable resource use in a safe virtual environment.

Table 3. *Features of VR systems as an effective tool for teaching ecological approaches in the agricultural sector*

Features of the VR system	**Explanation**
Interactivity	VR allows users to actively interact with the learning environment, simulating a real landscape.
Visualization of complex processes	The ability to display difficult-to-access or invisible processes, such as the development of the root system.
Simulation of real conditions	Creation of virtual fields with external climatic, substantiated and ecological conditions.
Safe experimentation	Training without risk to real crops, justifications or the environment.
Scalability	The ability to adapt training programs to different levels of knowledge and needs of the audience.
Engagement and motivation	The interactive approach interests participants and promotes more effective assimilation of information
Access to updated knowledge	The VR system can be regularly updated with new data on technologies and ecological approaches.
Ability to analyze and evaluate	Integration of tools for tracking learning outcomes and user progress.
Global reach	The use of VR allows you to train people from different regions regardless of their location.

The use of VR reduces the need for frequent field trips for monitoring and training, which contributes to reducing greenhouse gas emissions. This makes the agricultural sector more "green" and environmentally responsible.

Immersive technologies such as virtual reality (VR) and augmented reality (AR) are increasingly integrated into livestock farming, helping to optimize processes, improve animal welfare and increase the efficiency of farm management.

VR simulations allow farm workers and agricultural students to work out animal care techniques, veterinary procedures, and rules for safe handling of animals without the need to interact in a real environment. Reduces risks to people and animals and ensures effective learning of skills.

With the help of AR technologies, farmers can store real-time data on the condition of animals, including body temperature, activity level or changes in behavior. This contributes to early detection of disease and timely measures.

Immersive technologies help to simulate and optimize animal housing conditions, including ventilation, temperature and lighting. For example, VR systems have lost the ability to check how changes in the design of premises affect the comfort and performance of animals.

Table 4. *Advantages of immersive technologies in the agricultural sector*

Benefit	**Description**
Effective learning	Provide hands-on training for students and farmers in a safe virtual environment.
Reduced resource costs	Enable simulations without the use of water, fertilizers, or other materials.
Increased productivity	Optimize processes such as planting, crop monitoring, and harvesting.
Extreme situation modeling	Simulate the impact of climate change, natural disasters, or pests to predict risks.
Environmental friendliness	Reduce chemical use and negative impact on the ecosystem.
Reduced carbon footprint	Accelerate field trips and equipment use, reducing CO_2 emissions.
Access to modern technology	Enables the use of innovative methods for data analysis and decision-making.

The use of VR and AR can help in the analysis of genetic data, modeling of breeding processes and selection of the best individuals to obtain high-quality offspring.

VR allows you to create simulations of different climatic or environmental conditions that interact, how they can affect the quality of animals and how to adapt farm productivity to these changes. VR can be used to create a stimulating environment for animals, especially in confined spaces. This reduces and increases their well-being, which has a positive effect on productivity.

Virtual simulations allow veterinarians to practice complex surgical operations or diagnostic procedures, performing treatment with accuracy and safety.

Table 5. *Examples of the use of immersive technologies in animal husbandry*

Application	**Description**
Virtual employee training	VR simulations for dog training
Animal health monitoring	AR glasses provide temperature information,
Modeling housing conditions	VR systems model optimally
Ration and feeding analysis	AR applications scan feed, analyze its nutritional properties and provide diet recommendations in real time.
Climate change modeling	VR technologies can simulate the impact of climate change, such as drought or temperature increases, on animal performance and develop adaptation strategies.
Creating a stimulating environment	VR technologies create "virtual walks" for animals, reducing their stress levels and improving welfare.
Animal behavior control and adaptation	AR systems analyze animal behavior, identifying stress factors or diseases based on changes in the environment
Large farm management	AR glasses or tablets can view animal health data, maps of their location, and herd performance parameters.

The use of AR applications allows you to analyze animal diets and adapt them to maximize productivity and reduce costs. For example, visualization of the nutrient content of feed in real time allows you to quickly make adjustments.

Advantages of using immersive technologies in animal husbandry:

- Cost reduction: due to accurate forecasting of needs and cost reduction.
- Productivity improvement: optimization of housing, feeding and breeding processes.
- Environmental sustainability: modeling of resource use and reduction of environmental burden.
- Commercial benefit: improving product quality and farm competitiveness.

Implementation challenges:

- High cost of equipment and software.
- The need to train personnel to work with new technologies.
- Dependence on stable Internet connection and infrastructure.

Conclusions

Immersive technologies are becoming an integral part of modern crop production. Their implementation allows farmers to increase production efficiency, reduce costs and increase environmental friendliness. Immersive technologies are also a key tool for modernizing livestock farming, contributing to its development in the face of modern challenges and requirements. Immersive technologies provide the opportunity to make livestock management more precise, efficient, and environmentally sustainable, which contributes to increased productivity and animal welfare. Despite certain challenges, these technologies have the potential to significantly improve the management of agricultural processes, ensuring sustainable development of the industry.

An ecological approach to the use of VR technologies in crop production allows not only to increase production efficiency, but also contributes to the sustainable development of agriculture. These innovations help preserve natural resources, protect ecosystems and ensure food security for future generations.

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