Revolutionizing Agriculture Through Digital Twins

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1. INTRODUCTION

The agriculture industry is essential to the functioning of any economy. The U.S. agricultural sector encompasses not only the farming industry but also a variety of related industries. This industry is an important source of food, raw materials, and a vital source of employment opportunities for the total population. In 2021, the agricultural sector employed nearly 10.5 percent of US employment—21.1 million full and part-time workers. The U.S. economy received an annual contribution of approximately $1.264 trillion in 2021 from crops, livestock, seafood, food service, and other agriculture-related industries. That accounted for a 5.4 percent contribution to the U.S. Gross Domestic Product (GDP). America's farms contributed $164.7 billion—about 0.7 percent of U.S. GDP (USDA, 2023). Agriculture's impact on GDP exceeds 0.7 percent, as various industries that depend on agricultural inputs add value to the economy. These industries include food and beverage manufacturing, food and beverage stores, food services and restaurants, textiles, apparel, leather products, forestry, and fishing (USDA, 2023). After the European Union, the United States is the world's second-largest agricultural trader. Agriculture is also a major source of US export earnings, accounting for approximately 25 percent of all US exports. Additionally, the US is one of the world's leading producers of food and agricultural products, which helps ensure a stable and secure food supply for the country's population. Finally, agriculture plays a critical role in ensuring food security in the US (USDA, 2022).

The global population has been steadily increasing over time, and this growth trend is projected to continue in the future. With more people to feed, there is a higher demand for agricultural products. Additionally, consumers today are increasingly concerned about the quality and safety of the food they consume and the environmental impact of food production. This has led to a growing need for sustainable and responsible agricultural practices that can meet these demands. As a result of these challenges, the agricultural sector is under significant economic pressure to increase productivity and efficiency while maintaining profitability. As a result, farmers must produce more with fewer resources and less land,

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which can be daunting. To meet these challenges, they need access to new technologies, techniques, and information to improve their yields and manage their resources more efficiently (FAO, 2017).

Moreover, environmental and climate change issues have become more critical for agriculture. The changing climate can affect the availability and quality of water, soil, and other resources necessary for agriculture, making it challenging to maintain consistent yields. Climate change can also lead to the emergence of new pests and diseases that can threaten crops and livestock, creating additional economic and environmental pressures (The World Bank, 2022).

In summary, food security, sustainability, productivity, and profitability have become more crucial for the agricultural sector, as the world population grows, market demand increases, and climate change and environmental issues become more pressing. The agriculture industry must adapt to these challenges by developing and implementing innovative and sustainable practices to remain productive, profitable, and environmentally responsible.

Amid the above challenges, the agriculture industry has been digitally transforming, but now it's happening at speed and scale (Verdouw et al., 2021). COVID-19 disruption is a significant motivator for many industries, including agriculture, for greater traceability and reduced waste. Technologies like Digital Twins are being developed in many industries, including agriculture, to improve the efficiency of supply chains. DT is an essential technology in agriculture because it enables users to make management decisions about things without being physically present. As a result, the technology allows systems to be managed more effectively– saving time, and costs, improving sustainability and attracting higher premiums for produce (Alves et al., 2019).

DT is attracting the attention of practitioners and scholars alike. Today, the technology is used across many industries to provide accurate virtual representations of objects and simulations of operational processes. Gartner estimates that by 2027, over 40 percent of large companies worldwide will use DT in their projects to increase revenue (Gartner, 2022). Moreover, Global Market Insight estimated that the DT market size estimated in 2022 at $8 billion is expected to grow at around 25 percent Compound Annual Growth Rate (CAGR) from 2023 to 2032 (Global Market Insight, 2022). In addition, according to a 2022 report, nearly 60 percent of executives across a broad spectrum of industry plan to incorporate DT within their operations by 2028 (Researchandmarkets, 2022).

Although the journey towards transforming the agriculture industry using DT technology has already begun, there have been very few reported examples of the business benefits realized by leading-edge farms and agricultural landscapes resulting from the applications of this new technology. Although still at a conceptual stage, DT is slowly penetrating and addressing the unmet needs in agriculture. Research about DT and agriculture is currently limited. As DT applications become more mainstream, examining the challenges, benefits, and drawbacks of using this technology in agriculture is essential. Section 2 provides the main perspectives and definitions of DT in literature. Section 3 reviews four enabling technologies of the DT. Section 4 studies trending DT applications and use cases in the agriculture industry. Section 5 highlights the challenges and opportunities of this technology. Section 6 provides a summary and conclusions. Section 7 suggests future research directions. Finally, section 8 lists references.

2. DT BACKGROUND AND DEFINITION

In 2003, the Digital Twins concept (a digital mirror and digital mapping) was first introduced by Professor Grieves in the Total Product Lifecycle Management course at the University of Michigan. Since then, its definition has evolved, and scholars have provided varied definitions of this technology and