EduTwin: A Unified Digital Twin Architecture for Agricultural Knowledge Preservation

D.Bala Tharani
M.E. – Applied Electronics,
Nexzon Enterprises Ramanathapuram, Tamil Nadu, India
baladharani18ece@gmail.com

***Abstract*—** Digital Twin technology in agriculture primarily focuses on crop monitoring, irrigation, and resource optimization, while agricultural knowledge preservation and transfer remain less explored. This paper proposes EduTwin, a unified Digital Twin architecture that treats agricultural knowledge as a core digital asset alongside farm data. The proposed methodology integrates knowledge capture, digital representation, simulation, and multi-level learning for school students, college learners, engineering students, and experienced farmers. Traditional farming expertise and modern agricultural practices are represented within a common environment, enabling comparative learning and what-if decision simulation. Conceptual analysis indicates that EduTwin unifies agricultural knowledge preservation, tacit knowledge capture, multi-audience learning, and cross-institutional knowledge sharing through a shared simulation architecture. The framework thus proposes a knowledge-centric Digital Twin model that extends conventional farm monitoring toward sustainable agricultural education and long-term preservation of farming expertise.

Keywords— Digital Twin, Agricultural Knowledge Preservation, Tacit Knowledge, Smart Agriculture, Agricultural Education, Knowledge Transfer, Simulation-Based Learning.

I. Introduction

Digital technologies continue to revolutionize agriculture; one way in which this has happened is the invention of the Digital Twin (DT) technology. Digital Twin refers to a virtual simulation of a physical object that helps individuals to analyze situations in relation to a particular object without necessarily interacting with it physically. Some of the uses of DT technology in agriculture include soil and crop monitoring, irrigation scheduling, and yield prediction. The Internet of Things (IoT) platform through which the DT operates consists of four layers: sensing, networking, cloud, and application.

Despite the improvements in the practicality of these concepts, there is one thing in common: implicit acceptance that the only application of the concept of the digital twin is in optimizing the processes in actual farms. This is a perspective that does not take into account the concurrent and equally important problem of losing the knowledge of how to farm in particular places as farmers retire. Experienced farmers leave their jobs without the process of transferring the knowledge they have. Institutions of learning are independent; every institution creates its own tools rather than using common infrastructure. With the development of agriculture, such gaps will keep widening, especially where the land tenure is not permanent and the labor force keeps changing.

This paper proposes that the DT technology, which is quite useful for modeling complex dynamic systems, can also be applied to modeling the transfer and storage of agricultural knowledge. Using this proposition, this study proposes EduTwin, a multi-tier DT architecture where a single underlying digital twin serves different learners: schoolchildren learning the basics of farming, students of colleges taking agriculture and engineering courses, senior students conducting capstone projects, and farmers whose knowledge will be lost due to their retirement. With such an approach, knowledge can be treated as a resource that can be sensed, simulated, and stored alongside farm data. Thus, the digital twin moves from being a monitoring instrument to a knowledge infrastructure of education and organisations.

Such problems of knowledge continuity can become increasingly serious where there are transitions of agricultural land use, farm operators, or cultivation practices occurring relatively frequently, and where educational institutions providing agricultural education have no access to information from active farms. Developing the system that would allow simultaneous monitoring, multi-level education, and knowledge continuity becomes, therefore a timely research direction.

Complicating matters further are ongoing changes in agriculture. As younger generations move into different fields, and as farm holdings get split up or sold off, there become fewer and less people who can be expected to pass on the knowledge of a retiring farmer, assuming that knowledge has any agricultural value at all. Neither informal apprenticeship, which requires a suitable heir, nor traditional record-keeping, which typically ignores any knowledge acquired through experience, are very well suited to addressing the problem on their own. A digital infrastructure which can document such knowledge without the aid of an in-person apprentice represents another alternative.

The key contributions made by this paper are: (1) a knowledge-oriented Digital Twin architecture which treats the preservation of agricultural knowledge as a goal, equal to monitoring operations; (2) a simulation engine used in common by many learners and stakeholders, via a common underlying state of the twin; (3) a Knowledge Capture module designed to document the tacit, experience-based knowledge of farmers before it is lost; (4) a Comparative Learning module to combine traditional and sensor-based farming techniques in the same simulation environment; and (5) a Cross-Institutional Sharing system for agricultural educational materials.

The rest of this paper is organized as follows. Section II presents background literature and identifies the gap. Section III describes the EduTwin methodology and architecture, and

gives an example deployment scenario. Section IV contains results and discussion in the form of conceptual comparative analysis. Section V concludes the paper and presents future directions.

II. Related Work

A. Digital Twins in Agriculture

There have been many studies conducted in recent times about the use of digital twin technologies at the farm level. From the systematic review articles, one can get an idea about the evolution of the agricultural digital twin from the concept stage of its development up to more sophisticated designs that include IoT sensor technology, simulation, and prediction in the cloud-based models for crops and resource management [1], [2], [3]. In these systematic reviews, it has been noted that the layers of sensing, network, cloud, and application are generally considered to be the common representation of the architecture of the implementation models reviewed. The sensors used here measure the following factors.

More modern studies have taken this design further to hybrid edge-cloud architectures with an aim of improving the response time and to reduce the computational burden on the cloud [4] and toward the application domains of livestock twins and aquaponics systems [5]. Even in literature reviews conducted in early 2026, there has been a focus on the presence of challenges in the form of heterogeneity of sensor systems, communication privacy in field-to-cloud communication, and difficulty of integrating data from multiple sources into one simulation model [6], [7], [8]. Some of these literature reviews point out some research directions for the future in the direction of developing the platform for training and capacity building but do not seem to propose any architecture for doing this, thus leaving the question open in the literature. In these studies, agricultural digital twins have been treated as an instrument of operation and education only secondary to this or as a footnote at the end of their discussions.

B. Simulation and Digital Tools in Agricultural Education

Another aspect to consider in the discussion about the utilization of the mentioned technologies for educational purposes is their usage in the field of agricultural education. The review of studies about the use of simulation techniques in the agriculture sector demonstrates that there are two common types of simulations - virtual reality and augmented reality and most studies focus on the undergraduate students [9], [10]. Agricultural education in schools examines the possibilities of utilizing VR in order to provide field-based simulations which are impossible otherwise [10]. Indian researchers state empirically that virtual learning systems can stimulate the interest of people in agricultural education even through gaming involving irrigation planning processes [11].

In addition to the above research, there has been done research related to simulation-based learning in the context of agricultural food production and education in general. It includes examination of simulation as a learning process in higher food engineering education, training of logistics procedures and as a way of transferring digital skills to agriculture due to the technological nature of the latter industry nowadays [12]. Various learning theories such as Kolb's Experiential Learning Cycle are used to illustrate the relationships between classroom learning, agricultural experience and leadership development in agricultural education [13]. At the same time, there have been studies about agricultural extension and its farmer field school approach, which efficacy has been proven before and it is based on comparative analysis of practices conducted on demonstration plots – that foreshadows the importance of comparative simulation in EduTwin (Section III) [14].

C. Research Gap

However, there is no obvious relation between those two branches of research in terms of the literature used for this investigation. First, the reviewed agricultural digital twin literature focuses on the farm as a subject of analysis. Second, the agricultural simulation literature focuses on simulation as an instrument for education directed at a particular learner population without any practical connections to implementation of the concept of digital twin. Finally, the loss of tacit knowledge, which refers to the knowledge possessed by a farmer about the particular piece of land he works on and which he might lose if the land or occupation changed – does not seem to be an issue discussed in the studies reviewed here. Although the origins of the SECI model and the associated knowledge-management literature are in organizational and industrial environment [15]–[17], the possibility of its application to tacit agricultural knowledge, which results from long-term interaction of a particular farmer with the piece of land – seems to be hardly explored in the reviewed literature.

III. Proposed Methodology

A. Design Philosophy

The EduTwin assumes knowledge is separate from the actual state of the farm, which serves as the data to be collected, simulated, and protected by the twin. The twin utilizes the same sensors and simulations as a traditional DT to collect data necessary for its educational purposes. There are three fundamental design elements that are crucial for understanding.

B. System Architecture

In contrast to DTs, which traditionally are based on IoT technology, EduTwin keeps the four-layer architecture of IoT. It receives live data from the field in the same way as a traditional IoT-based digital twin. In addition to the conventional IoT operational stack, EduTwin adds the Educational and Knowledge Layer, which is the novelty of this paper. The Educational and Knowledge Layer is constructed on top of the previously described IoT operational stack and comprises of a simulation engine and six modules that collect the same twin state but show it in a different way to the learner population. Fig. 1 illustrates the layered architecture of EduTwin.

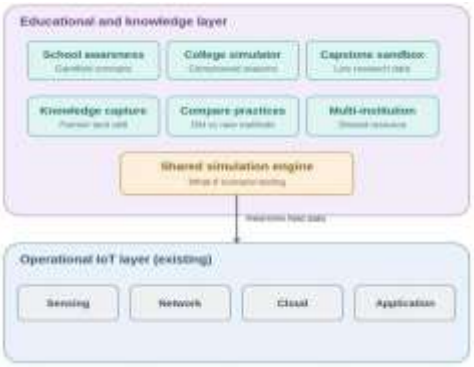


Fig. 1. EduTwin architecture: the operational IoT layer feeds a shared simulation engine, which powers six educational modules.

C. Functional Layers

The School Awareness Module gives the students an easy-to-understand game scenario that revolves around decision-making and seeing its consequences by means of actual pattern of sensors in real-life from the corresponding region. The College Curriculum Simulator enables multi-season farming simulation in shorter intervals, thus, giving teachers an opportunity to create comparison tasks. The Capstone Sandbox helps open the operations of the twin project in order to create realistic conditions for the final year projects of the students in the field of IoT and data analytics.

The Knowledge Capture Module relies on guided interviewing, decision logs, and observations for the purpose of capturing the implicit decision-making process of the experienced farmer before his/her retirement or transfer of land, which would then be saved in structured data form related to the field-level twin and therefore would remain associated with the land. The Comparative Learning Module makes the captured knowledge simulation-ready for the purpose of enabling the learners to compare scenarios of traditional versus modern methods of farming. Figure 2 illustrates the journey of the knowledge capture process mentioned above from the tacit field knowledge of the farmer to the digital twin, simulation, and finally to the student, with the digital twin being updated periodically so that subsequent groups of students and future farmers have additional knowledge stored in the digital twin. Table I describes the main target audience, input and output of each of the modules.



Fig. 2. Knowledge flow: a farmer's tacit knowledge is structured into the digital twin, exercised through the simulation engine, and delivered to students, with the twin updated for future cohorts.

TABLE I. Summary of EduTwin Functional Modules

Module	Audience	Input	Output
School Awareness	School students	Regional sensor patterns	Visual, gamified feedback
College Curriculum Simulator	UG/PG students	Multi-season field data	Compressed scenario runs
Capstone Sandbox	Final-year students	Live operational feed	Project-ready dataset
Knowledge Capture	Retiring farmers	Guided interviews	Structured decision log
Comparative Learning	Students, farmers	Captured + modern data	Side-by-side outcomes
Cross-Institutional Sharing	Partner colleges	Anonymized twin data	Shared curricula, research

D. Shared Simulation Engine

All the six modules have a common "what if" simulator, which will simulate the outcome based on input of initial conditions and decision. Formally speaking, each module could be described as a function S: (state, decision) → outcome, where state is the condition of the twin at hand, decision is a user-specified scenario/input, and outcome is the simulated condition. All six modules have the same simulator mapping but the specific target audience input/output/interface. Figure 3 below depicts the audience structure used for EduTwin, where five types of learners/stakeholders – school students, college students, capstone researchers, farmers, and partners revolve around the EduTwin core.



Fig. 3. Multi-level user ecosystem: five learner and stakeholder tiers draw on and contribute back to the same EduTwin core.

E. Illustrative Deployment Scenario

For example, let us say there is a demonstration farm attached to a college which currently employs sensors for monitoring the soil moisture, temperature, and the NPK levels. In the context of the proposed EduTwin approach, the same data will be utilized for a number of educational purposes at once – for instance, for a condensed one-semester exercise of irrigation planning in the course for first year students; for an actual capstone project for IoT students, for collecting fault detection data; and it can work concurrently with the structured interview of an extension officer with a retiring farmer. The latter will include interviewing a retired farmer with 30 years of experience of managing the adjoining land. He may share, for example, his decision to delay planting of crops in the low-lying

part of the land annually due to some reasons. Then, the qualitative information gathered from the farmer will be used to input to the same simulation system and will enable students of the next semester to make a comparison between the traditional practice of the farmer and the algorithm of the digital twin. In general, EduTwin will reuse this operational sensing equipment, while the Knowledge Capture module is going to need its own light interfaces for collecting information, for example, an audio record device or a structured interview template or an annotation tool. In this case, the role of EduTwin will be in reusing the existing operational data and simulation tools for the above purposes rather than in implementing any additional hardware. In time, as more interviews get accumulated through the Knowledge Capture module, the system is supposed to collect information about the experience of multiple retiring farmers of the adjoining fields, thus creating a localized archive of practical knowledge which would not be possible within a separate course and traditional organizational framework.

F. Implementation Considerations

While this paper presents a rough overview, the goal is to give enough detail to build a foundation that might be useful in building a prototype. In particular, the foundation is intended to integrate existing parts of the agrifood digital twins architecture to minimize the need for developing new technologies for a pilot. The operational layer is intended to work with existing, out-of-the-box, low-power microcontrollers and protocols using short-range wireless communications from existing research on agrifood Internet of Things [2], [18]. This would allow gathering data on the soil conditions, temperature and NPK and sending data to a traditional cloud or on-premises database. The shared simulation engine is specified at the input/output contract level of starting state, input decision, and outputting outcome, instead of specifying a particular approach to simulation or machine learning to give the team the flexibility to build a variety of possible solutions, ranging from a lookup table driven simulator for the first iteration to more complex simulators as data starts to accumulate. Module specific interfaces (Section III-C) are designed to be thin presentation layers for this shared core, instead of six different and fully integrated modules, to reduce the cost of adding one more module.

G. Privacy and Governance Considerations

Since the Knowledge Capture module tracks each individual farmer's decisions and reasoning, and since the Cross-Institutional Sharing layer moves data across institution boundaries, EduTwin architecture design expects that there will be an explicit consent and governance process over data collection, instead of treating data collection as an afterthought. Farmers or their heirs will have to give their consent to record their decisions and use them for educational purposes with a possibility to limit data to a single institution as opposed to the entire multi-institutional system. Anonymization at the point of cross-institutional sharing, i.e. removing any identifiers but keeping the agricultural content of the decision record is required for the sixth module, instead of being optional.

IV. Results and Discussion

A. Conceptual Comparison

Table II compares EduTwin against four representative system categories from Section II across four dimensions drawn from the identified gap: multi-audience reach, tacit knowledge capture, live-data-to-teaching linkage, and cross-institutional design.

TABLE II. Comparison of EduTwin Against Existing System Categories

Dimension	Farm DT	VR/AR edu	FFS	Open dataset	EduTwin
Multi-audience reach	No	No (1 tier)	Partial	No	Yes (6 tiers)
Captures tacit knowledge	No	No	Partial	No	Yes
Live data + teaching link	No	No	No	Partial	Yes
Cross-institutional design	No	Rare	No	Partial	Yes

Among all the system categories listed above, no method was found to incorporate all three elements - live operation, tiered education, and knowledge capture - in one design, making EduTwin a conceptual combination of the different approaches rather than just an improvement over one of them. The classification presented in Table II is based on features described in the literature reviewed in section II, and not on systematic research. Therefore, the comparison performed below is of a conceptual, but not an experimental nature.

B. Discussion

Within the proposed EduTwin framework, assessment of agricultural digital twins outcomes will be expected to go beyond the scope of optimization metrics such as water saved and yield increase. Within the EduTwin framework, the outcomes will be measured in terms of the preservation of tacit knowledge through generational transfer and the use of shared resources between multiple institutions, showing a more holistic intention of situating the agricultural AI within the institutional and human context.

Final year students taking modules in embedded systems, IoT, and computer science programs do not have access to the realistic live data sets for their projects. The pilot program within one department focused on Capstone Sandbox could solve this problem while providing a technological basis on which the remaining five modules could be developed later on.

There are several methodological challenges in the process of data collection and knowledge capture as well as in comparative learning. The first one out of these two is the design of the interview itself and potentially the collaboration with agricultural extension specialists for capturing the tacit knowledge. The second one out of the two challenges is the simulation of the traditional versus modern practices and the

oversimplification of the trade-offs due to the specific soil, climate, and socioeconomic conditions of the area. Thus, these two modules present the biggest challenge to Agricultural Science Faculty when piloting them. Finally, Cross-Institutional Sharing layer requires inter-institutional data governance which is still at an early stage in most regional higher education ecosystems, thus, a gradual development within one institution would be the most pragmatic approach.

EduTwin framework can be aligned with a number of country-wide initiatives within the higher education sector in India. This includes the emphasis on experiential and multidisciplinary learning in the National Education Policy 2020 [19] as well as other digital infrastructure initiatives that encourage higher education institutions to treat data as shared and reusable research infrastructure, rather than siloed departmental one.

C. Limitations

Since this paper is purely hypothetical and untested, all statements on the efficacy of EduTwin and the knowledge capture module must be considered as such – nothing more than speculation rather than values. Additionally, this framework relies on the premise that the infrastructure required for operation by means of the Internet of Things (IoT) exists in the host institution and/or farm. The hypothetical case study provided in Section III is not a validated one, but rather a hypothetical case study at a single site. The purpose of this is to clearly establish that the goal of this paper is an architectural proposal compared against other literature.

D. Alignment with Conference Themes

EduTwin corresponds to several conference themes, notably. First, the emphasis on the learner and the retiring expert rather than the sensor network as the system user distinguishes EduTwin within Human-Centered AI. The Capstone Sandbox module correlates with Student Innovation and Challenge. This is due to the fact that the module provides a way, a common real-time dataset, which will enable student innovation in the realm of embedded systems and IoT, not just encourage it. The framework corresponds to the theme of Sustainable Computing as well. This is due to the fact that the common twin framework, which enables six operations, is meant to reduce duplications of sensor deployments and tools that would occur in case each institution and use case developed their own framework.

E. Future Work

Immediate future steps would entail a pilot implementation, beginning with the College Curriculum Simulator and Capstone Sandbox modules, which are not anticipated to have any additional requirements for data collection outside of the operational layer. The educational worth could be measured by engagement and project quality prior to any attempts at implementing the more complicated Knowledge Capture module. An AI-enabled extraction approach used on interviews with farmers [20] could also assist with implementing the Knowledge Capture module, lowering the amount of work needed for capturing knowledge in a structured manner and thus making this module scalable to many farmers and not only case studies. Language and voice interfaces in the local language would enhance the accessibility of the School Awareness and farmer-facing modules in regions where lack of technical writing in written form hinders adoption regardless of the validity of the system conceptually. Finally, the Cross-Institutional Sharing layer would require standardized protocols for sharing and interoperability and agreements on governance in such a collaboration from multiple organizations, building on the calls from the literature for better interoperability standards across agricultural digital twins [4].

V. Conclusion

The application of digital twin technology in agriculture has largely been limited to optimizing agricultural operations, while its use in the preservation and transmission of knowledge has received relatively little attention. This paper has proposed EduTwin, a framework where a digital twin, using the same IoT data as any other agricultural DT system, will in addition serve six purposes related to learning and knowledge retention through a shared simulator. In light of the literature surveyed in this paper, EduTwin could be considered a conceptual framework that attempts to solve the problems of multi-audience learning, tacit knowledge, live data to teaching, and cross-institutional design.

While most of the framework elements need empirical testing in order to assess their value, and while certain elements pose governance and methodology problems that have been highlighted rather than solved in this paper, EduTwin suggests a viewpoint that does not seem to have gained sufficient traction in contemporary research on digital twins in agriculture, namely treating the DT not only as an operational monitor but as a tool for preserving and transmitting knowledge from farmer to farmer. Moving towards such a view through pilot work, as outlined in Section IV, may be considered the next step in this research line.

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