

Scientiarum: A Multidisciplinary Journal
Vol. 2 No. S1 (2026): Supplement Issue
DOI: 10.54646/SAPARS.2026.53

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AN AI-ENABLED DIGITAL TWIN FRAMEWORK FOR INTEGRATED SMART CAMPUS MANAGEMENT AND INTELLIGENT LEARNING

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Abstract

The increasing prevalence of the use of technology in the field of education leads to a growing necessity to develop centralized, efficient, and intelligent mechanisms to handle campus and academic activities in the most effective way possible. Usually, conventional educational institutes make use of separate mechanisms for admissions, academic management, attendance, assignments, learning activities, placements, and many others, which leads to the dispersion of information and creates additional workload for administrative employees. In order to solve the problem stated above, in the current research, an AI-Enabled Digital Twin Framework for Integrated Smart Campus Management and Intelligent Learning is developed. The described framework is implemented through the application called Edu Verse, which serves as a centralized web-based platform that digitally connects administrators, faculty members, students, and prospective applicants depending on their roles. The application includes such functionalities as admission management, student and faculty management, course and timetable management, face-based attendance management, assignment management, AI-based question generation, learning resources, online live classes, internship and placement management, announcements, notifications, and academic reports. Generative AI is used in order to assist faculty members in the process of assignment questions generation, and face verification ensures the security and efficiency of attendance management process. The Digital

Twin approach allows for providing a digital reflection of significant activities in the process of campus management and academics, thus allowing for a centralized and improved interaction between different users. The implementation of the application is conducted with the use of such technologies as Python, Flask, MySQL, HTML, CSS, JavaScript, Bootstrap, Jinja2, WebRTC, and Flask-Socket IO.
Key Words: Digital Twin, Smart Campus, Artificial Intelligence (AI), Generative AI, Intelligent Learning, Academic Administration, Face Recognition, E-Learning, Campus Administration, Web Application, Flask Web Framework

Introduction

The swift progress of digital technology has greatly transformed the way educational institutions conduct academic activities, perform administrative functions, and organize the process of learning. The constant development of internet connection, cloud services, web applications, Artificial Intelligence (AI), mobile technology, and real-time communication tools has led to the creation of opportunities for turning traditional educational systems into smart and digitally connected environments. Modern educational institutions manage a great number of processes related to admissions, management of students and faculty members, course management, schedule planning, attendance management, assignments, learning resources, online lessons, internships, placements, announcements, notifications, and academic reports. However, despite the growing usage of technology in education, many of those processes are still organized using separate applications, independent systems, spreadsheets, paper documents, or manual methods. As a result, duplicated information, increased amount of work for administrators, delayed communication, difficulties in accessing services, and coordination between students, faculty members, and administrators become significant challenges. The Smart Campus has appeared as one of the most promising strategies for overcoming those issues. Smart Campus is the strategy that uses digital technology, digital services, information, and institutional services in a single connected environment in order to improve efficiency of campus management and quality of educational services through the use of digital systems and data. However, the use of single digital service does not solve all the problems related to campus management fragmentation. Academic and administrative activities performed independently may cause difficulties for institutions in terms of maintenance of consistent information and getting a complete understanding of

campus activities. Students have to use several platforms for assignments, attendance, learning resources, live lessons, internships, and placements, whereas faculty and administrators need to maintain information from different systems. All of that causes additional complexity and lowers efficiency and accessibility of educational services. Digital Twin technology creates opportunities for creation of a connected digital representation of entities, activities, and processes.

Problem Statement

Educational institutions conduct numerous activities associated with admission, students and faculty management, course management, attendance, assignments, learning resources, live classes, internships, placements, announcements, and academic reports. Currently, many institutions conduct those activities separately via different systems, manual processes, or even different digital platforms, which brings challenges regarding information centrality, coordination of activities, and convenience for students and faculty in terms of accessing the necessary services. Firstly, fragmentation of academic and campus services can be considered one of the problems in current education processes. Students will have to deal with various platforms or rely on administration staff for the information related to attendance, assignments, courses, learning resources, internships, and placements. The same way, faculty and administrators might be forced to repeat similar actions using different systems, creating additional workload and inefficiencies. Moreover, another significant problem in current processes is the reliance on manual academic processes in particular in terms of attendance and assignment-related activities. Attendance tracking methods can take time and will not always be able to verify the presence of the student. Also, the creation of assignment questions will require much effort from the faculty member. Finally, the absence of the centralized real-time communication and digital processes will influence the coordination between students, faculty, and administration. Current campus management systems provide individual services; however, those systems rarely represent different activities related to academic and campus processes in the unified digital ecosystem. Also, those solutions do not utilize intelligent technologies to assist in the academic processes. Thus, the integration of academic and administrative services, the minimization of manual processes, improvement in terms of accessibility, and provision of support of intelligent learning activities will be the focus of the proposed platform. The research focuses on solving

the mentioned problem by introducing the concept of AI-Enabled Digital Twin Framework for Integrated Smart Campus Management and Intelligent Learning.

Literature Review

Recent developments in digital twin technology, artificial intelligence (AI), generative AI, and smart campus systems provide possibilities for revolutionizing higher education. In previous research, these technologies were used to develop campus management, learning, academic services, integration of different types of data, and decision making. Nevertheless, most of these studies consider each aspect of smart campuses without developing a unified system that would incorporate academic management, learning, services for students, and intelligent technologies. In recent literature, there was a considerable interest in using digital twins in smart campuses. Digital twins for campus visualization, monitoring, navigation, teaching, resource management, and intelligent decision-making were developed. The results of these studies show that digital twin technology allows improving the organization of campus activities. At the same time, digital twins used in current literature are often more focused on visual representation or specific campus management activities rather than incorporating all academic and student-oriented services in one platform. Artificial intelligence has also become an essential technology for the field of higher education. Literature states that AI could be used for teaching, learning, assessment, academic administration, and decision making. In addition, the development of generative AI extended the capabilities of AI and provided assistance in content creation, assignments, and other activities related to academic studies. Literature emphasizes the importance of responsible implementation of generative AI, human oversight, high accuracy, and safety of data. Moreover, face recognition and face-based verification technologies were explored to automate the process of attendance management. The main idea of these systems is reducing the efforts needed for recording attendance and making attendance information more reliable. Such technologies could be used for the development of automated educational systems. Despite the positive impact that digital twin technology, AI, generative AI, and face-based verification have, they are usually used separately. For the purpose of providing a unified solution for management and learning, it is necessary to integrate academic management, learning services, attendance, student services, internships, and

placements. Therefore, the proposed AI-enabled digital twin framework for integrated smart campus management and intelligent learning, implemented via Edu Verse will unite these services into a single role-based digital ecosystem.

Proposed System Architecture

The suggested system is an AI-Enabled Digital Twin Framework for Integrated Smart Campus Management and Intelligent Learning. It is implemented using a web-based platform called Edu Verse. The system is designed to enable transformation of traditional and disjointed campus activities into the digital ecosystem where students, faculty members, administrators, and prospective applicants will have access to services depending on their roles. In contrast to the traditional approach where campus activities such as academics and student services are managed separately from each other via various platforms or manually, Edu Verse allows bringing major campus activities under one roof. The suggested system is built based on multiple interconnected modules that enable academic management, learning, student services, and administration.

Role-Based User Management

It provides secure and role-based user authentication and access for Administrators, Faculty members, Students, and prospective applicants. Depending on their responsibilities, users will get access to the functionalities provided by the system. As a result, the access to academic and administrative data is controlled and the separation between various user activities is ensured.

Admission and Academic Management

Edu Verse provides digital admission workflow through which prospective applicants will be able to submit their information and administrators will be able to manage the admission activities. Besides, the platform allows managing students and faculty members, courses, and timetables thus enabling maintenance of the academic information in a centralized manner.

Digital Twin Smart Campus Environment

The main idea behind the suggested system is the Digital Twin Smart Campus. Edu Verse provides digital representation of the key campus activities, users, academic workflows, and services in the centralized environment. The use of dashboards and interconnected modules allows managing and accessing different campus activities within the single environment. Thus, the connected representation of the academic

ecosystem is achieved as opposed to treating each activity independently.

AI-Assisted Learning and Assignment Management

The suggested system integrates Generative AI that assists the faculty members in preparing the assignment questions. Faculty members will be able to use the AI-assisted functionality to prepare relevant questions thus reducing the time and efforts needed to prepare the assignment. Further, generated assignments will be managed and published through the academic platform thus enabling students to access and submit them.

Face-Based Attendance Verification

Edu Verse provides the face-based attendance verification that will allow enhancing the efficiency of the attendance management. It verifies the student's face against the registered facial information before recording the attendance. Thus, dependency dependency on traditional manual attendance procedures and provides a more automated approach to maintaining attendance records.

Digital Learning and Live Classes

The platform offers a central hub of learning-related services, which include assignments, learning resources, and live classes that can be accessed by faculty as well as the students. The faculty can manage the live sessions along with all the activities pertaining to academics, and students can take part in learning activities through the platform itself.

Internship and Placement Management

This module integrates internship and placement services into the ecosystem of academia. Students will have access to the information regarding internship and placements through the platform, and administrators will have control over the opportunities and associated information.

Announcements, Notifications, and Reports

The platform allows announcements and notifications for improved communication between the administrators, faculty, and students. There are also provisions for the generation of academic and administrative reports.

Centralized Database and Information Management

All the major academic and administrative information is handled by a centralized MySQL database. The information that can be managed through this database includes information about users, students, faculty members, courses, attendance, assignments, live classes, internships, placements, and others (Figure 1).

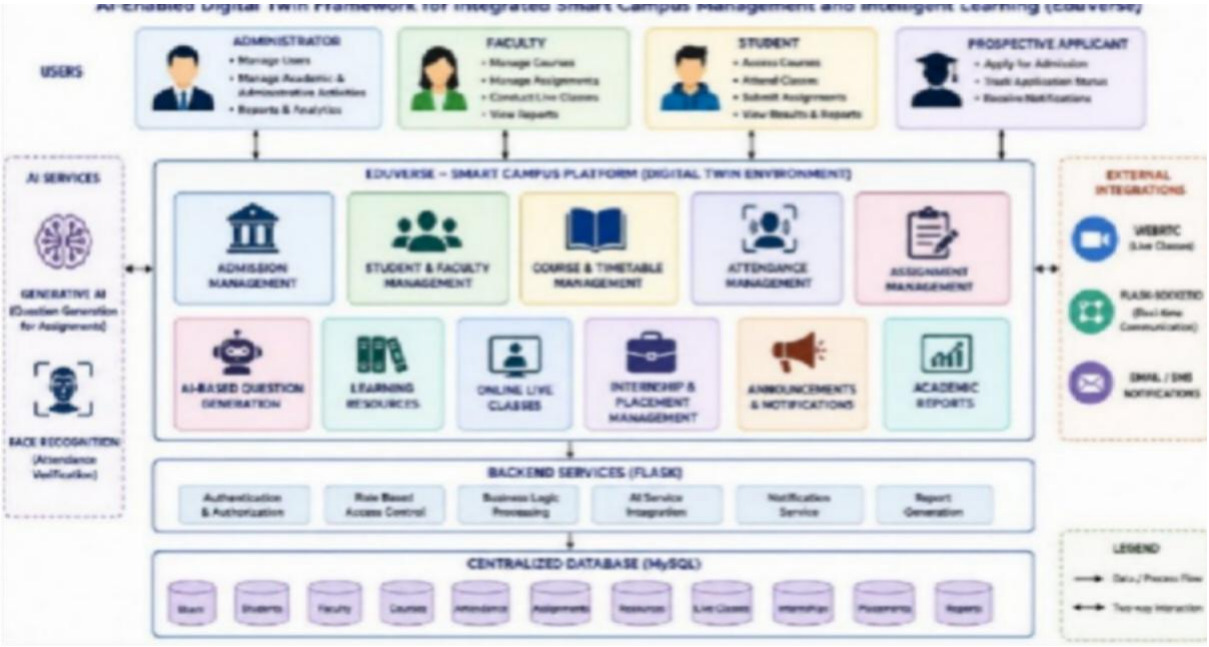


Figure 1: System Architecture for AI-Enabled Digital Twin Framework for Integrated Smart Campus Management and Intelligent Learning

Methodology

The development of the proposed AI-Enabled Digital Twin Framework for Integrated Smart Campus Management and Intelligent Learning involves a methodology aimed at ensuring the effective integration of academic, administrative, and learning services in a centralized digital environment. The methodology includes the following steps:

Requirement Analysis: The identification of functional and non-functional requirements through an analysis of existing campus management processes and the requirements of administrators, faculty members, students, and prospective applicants. The functional requirements include admission management, user management, course and timetable administration, attendance, assignments, learning resources, live classes, internships, placements, notifications, and reports. Non-functional requirements involve security, usability, reliability, scalability, performance, and maintainability.

System Design: Creation of the proposed Digital Twin-oriented framework through system architecture, module design, database design, data-flow models, and role-based interaction models. The system architecture identifies the relationship between campus users, academic and administrative processes, centralized data management, AI-assisted services, and application modules.

Digital Twin Implementation: Representation of important academic and

administrative activities in a connected digital environment. Information from admissions, student and faculty activities, courses, attendance, assignments, live classes, internships, placements, and reports is managed in interconnected modules, offering a centralized representation of the institutional ecosystem.

AI and Intelligent Services: Integration of Generative AI in order to assist faculty members in generating assignment questions based on the requirements of academic processes. The generated content is reviewed by the faculty members before being published. Face-based identity verification is employed to match the live facial input of the students with their registered information before recording attendance.

Implementation: Implementation of the proposed framework using Python and Flask as backend technologies and MySQL as a centralized database management tool. The web interface employs HTML, CSS, JavaScript, Bootstrap, and Jinja2. Live classes and other realtime communication functionalities are enabled by WebRTC and Flask-Socket IO.

Testing: Functional testing of the proposed platform including testing individual modules and integrated workflows. The testing involves authentication, role-based access, admission processing, academic management, assignments, AI-assisted services, attendance verification, live classes, notifications, internships, placements, and reporting.

Evaluation: Evaluation of the effectiveness of the system based on functional correctness, usability, response time, module integration, security measures, and the ability of the proposed framework to avoid fragmentation of academic and administrative services.

Management of Secure Data and Information

The management of secure data and information forms another key element of the AI-enabled Digital Twin Framework for Integrated Smart Campus Management and Intelligent Learning. Given that Edu Verse manages academic, administrative, user, and attendance data, the mechanisms need to be put in place to ensure controlled access, privacy, integrity, and proper management of institutional information.

Controlled Access and Role-Based Authentication: Controlled access to information for various users, including administrators, teachers, students, and applicants is provided by the framework. With this mechanism, users can have access to information, modules, and functions based on their role.

Centralized Data Management: Academic and administrative information, which

includes student and teacher information, courses, timetable, assignments, attendance, live class sessions, internships, placements, notifications, and reports is managed using a centralized MySQL database to minimize information fragmentation and consistent management of information.

Facial Data Protection: Information related to facial recognition used in attendance verification is to be used for identity verification only and should not be accessed by unauthorized persons. Privacy and security of biometric information should be ensured.

Controlled Access to Academic Information: Assignments, submissions, attendance information, learning resources, and any other academic information is to be accessed and viewed based on authorized role. This prevents any unauthorized access or manipulation of information.

Activity Monitoring and Accountability: Some of the actions taken within the framework can be monitored to ensure accountability, troubleshooting, and management of academic and administrative activities (Figure 2).



Figure 2: Methodology of AI-Enabled Digital Twin Framework for Integrated Smart Campus Management and Intelligent Learning

Limitations

Dependency on Network Connectivity: Edu Verse is a web application and thus depends on network connectivity. Users with poor or intermittent Internet connection will face challenges in accessing live classes, assignments, attendance, notifications, and other academic activities. Constraint on Digital Twin Representation: The current implementation represents a digital twin of the key academic and administrative processes. However, a comprehensive Digital Twin of the entire physical campus will involve synchronization of the model with the actual world continuously through IoT devices, data streams, campus infrastructure, and the physical environment.

Constraints Associated with Generative AI: The AI-assisted assignment generator tool is likely to generate inaccurate, repetitive, irrelevant, or academically inappropriate questions at times. Thus, AI generated outputs will need to be verified and approved by faculty members for academic purposes. Human intervention will be necessary in deployment of AI technology in education.

Constraint on Face Verification: Attendance verification using facial recognition could be affected by factors such as light, camera, orientation, occlusion, appearance change, and others.

This means that the accuracy of face verification is dependent on the quality of facial information and verification method.

Constraint Associated with Data Privacy: Edu Verse deals with sensitive data, which include student profiles, academic records, attendance information, authentication data, and potentially biometric data. Appropriate privacy measures, access control, retention policies, and data governance strategies are therefore necessary.

Infrastructure Requirement: For large scale implementation, extra server space, database optimization, backup infrastructure, monitoring infrastructure, security measures, and reliable network resources might be necessary.

Integration with Other Systems: Integration with existing Learning Management Systems, Student Information Systems, examination systems, library systems, and others could be challenging due to different architectures, databases, API and other different data formats.

Requirement for Maintenance: Regular maintenance will be needed to ensure updates of application, database, AI services, security measures, dependencies, and infrastructure.

User Adoption: Faculty members, students, and administrators will require training

and technical support for adoption of the integrated smart campus platform.

Constraints Associated with AI Evaluation: The quality of AI generated academic content will vary based on prompts, models and subject domains. Extensive evaluation is necessary before use of AI generated content in making academic decisions.

Constraint Associated with Scalability: The performance of the application could be affected when there are too many users, academic records, assignments, live classes, database transactions and real-time connections.

Challenges

Building a Comprehensive Digital Twin: One of the key problems is transforming the regular web-based campus management system into a comprehensive Digital Twin which would keep synchronization between real-life campus activities and their digital replica at all times.

Real-Time Data Synchronization: A smart-campus Digital Twin may be required to analyze information provided by various data sources simultaneously. Ensuring the accuracy and timely synchronization of data becomes difficult with the increase in the amount of devices, users and data sources.

Integration with the IoT: There may be a lot of challenges associated with the integration with sensors, smart classrooms, environmental control devices, occupancy sensors, energy counters, and other IoT devices.

Accuracy and Reliability of AI: Generative AI is capable of producing relevant academic content, however, it is also capable of producing irrelevant or wrong information. Hence, it is necessary to develop some kind of validation mechanisms and involve faculty members in making decisions regarding this issue. UNESCO also advocates for the human-centric and responsible approaches to using Generative AI for educational purposes.

Responsible AI Management: AI systems should be tested for reliability, transparency, privacy, security and many other risks over the course of their lifecycle. NIST's AI Risk Management Framework provides some guidelines about managing such risks.

Biometric Information Security: Face recognition attendance tracking will require solving the issues related to the protection of the collected biometric information.

Cybersecurity: A centralized smart-campus platform will represent a valuable target

for cyberattacks and the platform should be able to withstand various cybersecurity challenges including unauthorized access, credential attacks, malware, data breach, injection attacks, denial-of-service attacks, and many others.

Interoperability: Connecting different systems within an institution will involve standardized data formats, APIs, authentication mechanisms, communication protocols and other challenges.

Data Management Challenges: A Digital Twin environment will produce large amounts of academic, operational, IoT and event data. Thus, efficient storage, processing, indexing and analysis will become key challenges.

Scalability Challenges: The smart-campus platform should remain performant despite the growth in the number of students, faculty members, administrators, courses, assignments, live classes, connected devices and many others.

User Trust and Adoption: Users may find it hard to trust AI recommendations and fully automated systems, especially if it concerns academic evaluations or attendance tracking and face-based authentication.

Digital Literacy: Differences in the level of technological literacy between students, faculty members and administrative staff will have an effect on the adoption of the platform and its efficient.

Outcomes

The application of the proposed framework, through the Edu Verse platform, brought about the integration of the various major academic, administrative, and learning activities into a web-based platform. The major outcomes of the proposed solution are as outlined below:

Centralized Smart Campus Management

The Edu Verse platform offers the users a centralized platform through which all activities such as admissions, students, faculty members, courses, timetables, attendance, assignments, learning resources, live classes, internships, placements, announcements, notifications, and academic reports are managed.

Digital Representation of Campus Activities

The platform offers the digital representation of important academic and administrative activities through interlinked modules and dashboards. This forms the basis of Digital Twin-based smart campus management, where different institutional processes can be accessed and managed through a single platform.

Role-Based Access and Management

Through the Edu Verse platform, Administrators, Faculty Members, Students, and Prospective Applicants have different access and functionalities to carry out respective tasks. It thus ensures that users perform their respective roles in the system, and access to academic and administrative information is controlled.

Enhanced Admission Management

This admission module will provide a digital process where future applicants will be able to fill their admission-related information and where the administrators will be able to manage the admission processes through this central portal.

Automatic Facial Attendance

The face-based attendance module will provide an automatic way to verify attendance by comparing the facial information of the student with the registered one prior to marking their attendance. It will make the system less reliant on manual methods for taking attendance.

Question Generation with the Help Of AI

This AI-based solution will provide assistance to the faculties in question generation for assignments which will save them from making efforts for making these questions manually and will allow them to review and approve the contents prepared.

Digital Learning Platform for Learning Activities

The integration of Edu Verse in this process will give a chance to access all assignments, learning resources, and live classes through the same platform. It will help the students and faculties to access and manage the learning activities and sessions on this platform.

Future Scope

Real-Time IoT-Enabled Digital Twin: Future iterations of Edu Verse can be equipped with IoT sensors that can gather real-time data from various classrooms, laboratories, libraries, buildings, and other campuses' facilities. Thus, this iteration will bring the system closer to Digital Twin architecture. The current work on international standards specifically outlines IoT, AI, cloud computing, big data, monitoring, simulation, and predictive analytics as key features of smart-campus Digital Twins.

Integration of Smart Classrooms: Smart classrooms can be integrated into Edu Verse with the help of sensors and intelligent devices that monitor occupancy rates, environmental parameters, class room utilization, and equipment statuses.

Student Attendance Prediction: Machine Learning can analyze attendance, assignment performance, assessment outcomes, and learning activities to pinpoint the students who may need additional academic assistance.

Personalized Learning: AI can offer personalized recommendations about educational materials, assignments, practice questions, and learning activities based on student performance and learning needs.

AI Academic Assistant: An intelligent academic assistant can offer students personalized assistance regarding course selection, assignments, attendance, learning resources, internships, placement, and academic progress.

Advanced Generative AI: Future iterations of Edu Verse can use AI not only for generating questions but also for automatically analysing question difficulty, mapping learning outcomes, creating personalized learning material, quizzes, and helping the faculty.

NLP: NLP can allow students and teachers to interact with the Edu Verse in a natural language manner and query about assignments, attendance, timetable, courses, and academic activities.

AI Attendance Analysis: Historical attendance data can be analyzed for detecting attendance patterns and generating early warnings to students who have been absent or are frequently absent

Predictive Maintenance: IoT sensor data along with Machine Learning can be used for predicting infrastructure, lab equipment, networking equipment, and other facilities' failure before it happens.

Smart Energy Management: Edu Verse can be used for monitoring electricity usage, lighting, cooling systems, and other energy-consumption resources. Analysis by the AI can help institutions to optimize their energy consumption.

Optimization of Campus Resources: Digital Twin simulation can help administrators to analyze classroom utilization, lab utilization, faculty allocation, infrastructure, and other institutional resources before any physical changes are implemented.

Simulation of Campus Changes: Future models of Digital Twins can be used to perform simulation of proposed campus changes such as new buildings, classroom extensions, timetable changes, or changes in resource allocation.

Conclusion

The proposed "An AI-Enabled Digital Twin Framework for Integrated Smart Campus Management and Intelligent Learning" was created in order to solve the problem of the fragmented nature of the academic and administrative procedures in educational institutions that are conducted manually. The implementation of the Edu Verse platform resulted in the integration of several major campus services, such as admission management, student and faculty management, course and timetable management, attendance, assignments, learning resources, live classes, internships, placements, notifications, and academic reports into a unified web-based platform. The incorporation of AI contributed to the intelligence of the system by providing assistance to the faculty in generating questions for the assignments, while the face-based verification technology made attendance management more automated. The role-based access control allowed students, faculty members, administrators, and applicants to work with the system in accordance with their roles. The centralized MySQL database helped keep academic and administrative data organized, while Flask, WebRTC, and Flask-Socket IO were used for implementing the web-based and real-time features of the platform.

The creation of the proposed system showed that the integration of different campus services in one digital ecosystem leads to less fragmentation of processes, reduction of repetitive manual work, better accessibility, and improvement of communication between students, faculty members, and administrators. The Digital Twin-oriented system also set the ground for the digital representation of interrelated academic and administrative activities.

In the future, the proposed Digital Twin framework can be further developed into a more complex real-time Digital Twin by incorporating IoT sensors, smart classrooms, real-time campus monitoring, Machine Learning, predictive analytics, personalized learning, cloud and edge computing, smart energy management, and 3D/AR/VR visualization. AI can also be applied in the processes of student-performance prediction, intelligent academic recommendations, automated analytics, and personalized learning. Privacy-preserving AI, explainable AI, and improved security measures can be used to ensure responsible and secure usage of student and institutional data.

Therefore, the present work serves as the foundation for the transition of traditional campus management into an intelligent and integrated smart-campus ecosystem, and

future research can extend the functionality of Edu Verse from being a centralized platform for academic management to becoming a real-time AI-enabled Digital Twin of the whole educational campus.

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