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SMART DIGITAL TWIN: AN INTERACTIVE AI CAMPUS PLATFORM

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***Abstract*—With the expansion of smart campus technologies, there is now an increasing demand for intelligent and interactive platforms that can make navigating and managing college campuses easier, faster, and more intuitive. In this paper, we present Smart Digital Twin: An Interactive AI Campus Platform, which is an online, digital representation of a campus that incorporates interactive 3D visualization, artificial intelligence, smart navigation, and campus services, The system allows users to explore college buildings and facilities within a virtual environment, receive assistance from an AI assistant through text and voice interaction, and find their way to classrooms, laboratories, and other services thanks to smart indoor and outdoor navigation, The architecture of the platform consists of a React frontend, a Node.js and Express backend, AI services provided via the OpenAI GPT API, MongoDB Atlas for storing data, and mapping services like Mapbox or Leaflet. It uses JSON Web Tokens (JWT) for authentization and offers cloud storage and media services for deploying the platform. This system provides a comprehensive solution by bringing together campus visualization, AI assistant services, navigation and information, aiming to minimize fragmented information access, manual inquiries, facilitate wayfinding, and enhance the overall campus experience. Moreover, its modularity allows for the future integration of IoT data, live occupancy information, smart classrooms, multilingual features, predictive analytics, and emergency workflows.**

***Keywords*— Digital Twin, Smart Campus, Artificial Intelligence, 3D Visualization, AI Assistant, Smart Navigation, React, Three.js, Node.js, MongoDB.**

I. INTRODUCTION

Development of digital technologies in the field of higher education has made the demand for interactive and easily accessible campus services higher than ever before. Traditional campus information is usually scattered across different portals, noticeboards, departmental pages, and different navigations. Such a scattered approach may hinder newcomers from finding information about the campus facilities, locating rooms, getting acquainted with campus services, and answering their queries.

Smart Digital Twin attempts to solve this problem by developing a visual map of the college campus together with the integration of the AI technologies and digital campus services. The platform offers its users a three-dimensional view of all campus buildings, walkways, and indoor areas that can be inspected, explored, and navigated to.

Along with the visual elements, Smart Digital Twin uses an AI virtual assistant that is able to answer natural language questions, offer recommendations and assist the user by voice. This way, Smart Digital Twin not only creates the visual representation but also serves as the access point for the campus information and services.

This system is supposed to help students, faculty members and other visitors of the college campus. The main goals of this system are centralization of the campus information, ease

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of use in finding the necessary information and locations, reduction of manual queries, improved accessibility and development of the scalable infrastructure for the future smart-campus developments.

II. RELATED WORK

The rapid development of smart campus technologies has created opportunities for universities to improve the way students, faculty, and visitors interact with campus environments. Existing approaches increasingly utilize digital twins, three-dimensional visualization, artificial intelligence, cloud services, and smart navigation to provide digital access to physical campus facilities. Digital Twin technology enables the representation of buildings, pathways, and indoor spaces in a virtual environment, while AI-based assistants can provide natural-language interaction and information support. Similarly, smart navigation technologies assist users in locating classrooms, laboratories, libraries, and other campus facilities. However, campus information may still be distributed across multiple portals, noticeboards, and services, making information access and wayfinding difficult. The proposed Smart Digital Twin addresses this gap by integrating interactive 3D visualization, AI-powered assistance, smart navigation, and centralized campus services into a unified digital platform.

A. Digital Twin-Based Campus Representation

Digital Twin technology creates a virtual representation of a physical environment.In a campus environment, it can represent buildings, classrooms, laboratories, pathways, and other facilities.Interactive 3D models allow students, faculty, and visitors to explore campus facilities virtually.The proposed Smart Digital Twin extends this concept by combining the 3D campus model with AI assistance and navigation services.

B. Smart Campus Management Systems

Smart campus systems integrate digital technologies to improve campus services and resource management.Existing approaches generally focus on individual services such as campus information, transportation, classrooms, or resource management. A major challenge is the distribution of information across multiple independent platforms.The proposed system provides a centralized platform for departments, timetables, events, announcements, bookings, and campus facilities.

C. 3D Visualization and Virtual Campus Environments

Three-dimensional visualization provides an intuitive way of understanding complex campus layouts.Virtual campus environments can help users identify buildings and facilities before physically reaching them. Interactive building models can display contextual information when users select a particular location.The proposed platform uses Three.js and React Three Fiber to create an interactive 3D campus environment.

D. Artificial Intelligence-Based Campus Assistants

AI-based virtual assistants can provide users with natural-language access to information.Chat-based systems can answer frequently asked questions and provide contextual recommendations.Voice interaction can further improve accessibility and convenience for users.The proposed system integrates an OpenAI GPT-based assistant to answer campus-related queries and assist users with navigation.

E. Smart Indoor and Outdoor Navigation

Conventional campus maps may not provide sufficient guidance for new students and visitors.Smart navigation systems can combine maps, landmarks, routes, and estimated travel time.Indoor and outdoor navigation can help users locate classrooms, laboratories, libraries, and other facilities. The proposed system includes accessibility-aware routing and step-by-step navigation using mapping services such as Mapbox or Leaflet.

F. AI, Cloud, and Database Integration

Intelligent campus platforms require integration between frontend applications, backend services, databases, AI services, and cloud infrastructure.A centralized database can maintain information related to users, buildings, facilities, events, and campus services.Cloud infrastructure enables scalable access to campus information and media resources.The proposed architecture combines React.js, Node.js, Express, MongoDB Atlas, OpenAI GPT API, JWT authentication, and cloud services.

G. IoT-Enabled and Future Smart Campus Systems

Future smart campus platforms can integrate IoT sensors to obtain real-time information from physical campus environments.Live occupancy information can help users identify available classrooms, laboratories, and other facilities. Predictive analytics can support campus operational decision-making.The proposed Smart Digital Twin is designed as a modular platform that can be extended with IoT sensor feeds, live occupancy data, smart classrooms, multilingual support, predictive analytics, and emergency workflows.

III. PROPOSED METHODOLOGY

The proposed Smart Digital Twin platform follows a modular development approach that integrates 3D campus visualization, AI assistance, smart navigation, centralized information management, and secure authentication. The methodology begins with requirement analysis and UI/UX design, followed by the development of an interactive 3D campus using Three.js and React Three Fiber. The AI assistant is integrated using the OpenAI GPT API, while Node.js and Express manage backend services and MongoDB Atlas stores campus data. Mapbox or Leaflet is used for indoor and outdoor navigation, including routes, landmarks, accessibility options, and estimated travel time. JWT provides role-based authentication for students, faculty, and guests.

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Finally, the system undergoes functional, accessibility, and load testing before cloud deployment. The modular architecture also supports future integration of IoT data, live occupancy, smart classrooms, multilingual services, predictive analytics, and emergency workflows.

A. Requirement Analysis

The first stage focuses on identifying the requirements of the major campus stakeholders, including students, faculty members, and visitors. The system requirements are derived from common campus activities such as locating classrooms and laboratories, accessing announcements and events, exploring campus facilities, and obtaining information about departments and services. Accessibility and privacy constraints are also considered during the requirement-definition stage. The identified requirements form the basis for the subsequent design and development of the platform.

B. UI/UX Design

The user interface is designed as a responsive web-based environment that provides simple access to the major campus services. Wireframes are developed for the dashboard, digital campus, AI assistant, navigation interface, and other functional components. Three-dimensional interaction patterns are incorporated into the interface to allow users to explore campus buildings and access contextual information. The design process also considers usability and accessibility to provide an intuitive experience across different user groups.

C. Digital Twin Development

The digital twin component provides an interactive virtual representation of the physical campus. Campus buildings, pathways, facilities, and selected indoor spaces are represented within a three-dimensional environment. Three.js and React Three Fiber are used to develop the interactive 3D visualization. Buildings can be selected to display contextual information about their corresponding facilities. Georeferencing and level-of-detail optimization are considered to improve the representation and interaction of the digital campus

D. AI Assistant and Backend Integration

An AI-powered virtual assistant is integrated into the platform to provide natural-language interaction. The OpenAI GPT API is used to support question answering, campus-related guidance, and contextual recommendations. The backend is developed using Node.js and Express, which manages application routes, authentication, and communication between the frontend, database, AI services, and other components. MongoDB Atlas is used to store the structured campus and application data. JWT-based authentication provides secure access to role-aware user profiles

E. Smart Navigation

The navigation module provides indoor and outdoor guidance for users navigating the campus. Mapping services such as Mapbox or Leaflet are integrated to support route visualization. The system is designed to provide landmarks, step-by-step directions, accessibility-aware paths, and estimated walking time. This functionality allows students and visitors to identify suitable routes to classrooms, laboratories, departments, and other campus facilities.

F. Centralized Campus Information

The proposed platform centralizes important campus information within a single digital environment. Information related to departments, timetables, events, announcements, and resource bookings can be accessed through the dashboard and supporting services. This centralized approach reduces the dependency on multiple information sources and enables users to obtain relevant campus information through a common interface.

G. Testing and Deployment

The final stage involves functional, accessibility, and load testing of the developed system. Individual modules such as authentication, 3D visualization, AI assistance, navigation, and information management are tested to verify their intended functionality. After validation, the platform can be deployed using cloud infrastructure with appropriate monitoring and media storage services. The modular architecture also allows future integration of IoT sensor feeds, live occupancy information, smart classroom systems, multilingual support, predictive analytics, and emergency workflows.

This version is much more suitable for the actual project paper because it uses formal academic paragraphs and IEEE-style subsection organization instead of presentation bullets.

H. System Architecture

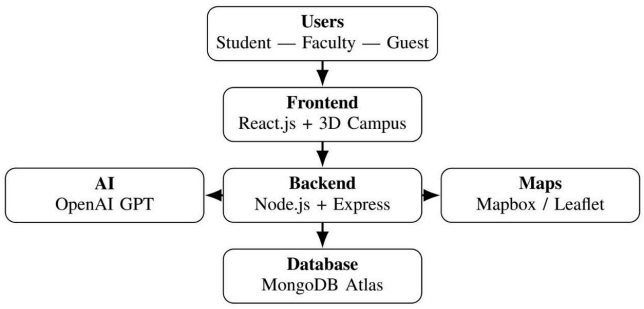


Fig. 1. System architecture of the Smart Digital Twin platform.

Figure 1 illustrates the overall system architecture of the proposed Smart Digital Twin platform. The system enables students, faculty, and guests to access the platform through a React.js-based frontend. The frontend provides key functionalities such as 3D campus visualization, smart navigation, and AI-assisted campus services, creating a unified interface for interacting with campus information.

The frontend communicates with the Node.js and Express.js backend, which manages authentication, APIs, and the core application logic. The backend connects with the OpenAI GPT

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API to provide AI-based assistance and with Mapbox/Leaflet to support campus mapping and navigation services.

The backend also communicates with MongoDB Atlas, which stores user and campus-related information. As shown in Figure 1, the integration of these components provides a centralized architecture that connects users, campus visualization, AI services, navigation, and data storage within a single Smart Digital Twin platform.

I. Algorithm

The proposed Smart Digital Twin platform follows a sequential algorithm to provide users with integrated campus services. Initially, the system loads the interactive 3D campus model and relevant campus database. The user is authenticated through the login system before accessing the platform. After successful authentication, the dashboard provides access to the 3D campus visualization, AI assistant, and navigation services.

TABLE I
MAJOR COMPONENTS OF THE SMART DIGITAL TWIN PLATFORM

Component	Function
React.js	User interface and dashboard
Three.js / R3F	Interactive 3D campus model
Node.js + Express	Backend services and APIs
OpenAI GPT	AI-based campus assistance
MongoDB Atlas	User and campus data storage
Mapbox / Leaflet	Campus mapping and navigation
JWT	Secure authentication and access control
Cloud Deployment	Web hosting and scalability

Table I: presents the major components used in the proposed Smart Digital Twin platform and their respective functions. The React.js frontend provides the main interface through which students, faculty, and guests interact with the system, while Three.js or React Three Fiber is used to create the interactive 3D representation of the campus. The Node.js and Express.js backend manages application logic, APIs, and authentication. The OpenAI GPT API provides AI-based assistance, while MongoDB Atlas stores user and campus-related information. Mapbox or Leaflet supports mapping and navigation services, and JWT authentication provides secure access control. Together, these components form an integrated platform that combines 3D visualization, artificial intelligence, navigation, and centralized campus information.

IV. RESULT AND DISCUSSIONS

The proposed Smart Digital Twin platform provides a unified digital environment for accessing and managing campus-related information. The integration of the interactive 3D campus model enables students, faculty, and guests to explore campus buildings, facilities, and services through a single interface. The system combines visualization, centralized information, and navigation features, reducing the need to depend on multiple information sources or manual enquiries. The AI-assisted campus service improves the way users interact with campus information by allowing natural-language queries.communication between the frontend, AI service, and database. The navigation module further supports users by providing route information between campus locations through Mapbox or Leaflet. These integrated features demonstrate how artificial intelligence and digital twin technologies can be combined to improve accessibility and interaction within a campus environment.

TABLE II
FUNCTIONAL RESULTS OF THE PROPOSED SMART DIGITAL TWIN PLATFORM

Functionality	Observed Outcome
3D Campus Visualization	Enables interactive exploration of campus buildings and facilities.
AI Campus Assistant	Provides natural-language assistance for campus-related queries.
Smart Navigation	Supports route identification and navigation between campus locations.
Centralized Information	Provides campus services and information through a unified platform.
Authentication	Provides secure access for different categories of users.
Data Management	Stores and manages user and campus information using MongoDB Atlas.
Integrated Architecture	Connects frontend, backend, AI, database, and mapping services.
Future Scalability	Supports potential integration of IoT, occupancy monitoring, and predictive analytics.

Table II summarizes the major functional outcomes of the proposed system. The platform successfully integrates 3D visualization, AI assistance, smart navigation, centralized information management, and secure authentication into a single web-based system. The modular architecture allows individual components to be maintained and extended independently. Future improvements can include real-time IoT data, live occupancy monitoring, multilingual assistance, predictive analytics, smart classroom integration, and emergency support, further expanding the capabilities of the proposed Smart Digital Twin platform. Fig. 2 illustrates the evaluation trend of the proposed

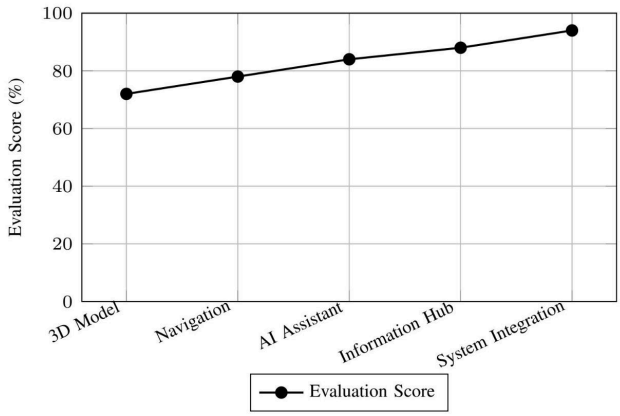


Fig. 2. Illustrative evaluation trend of the Smart Digital Twin platform.

Smart Digital Twin platform across its major functional stages. The illustrative results show a progressive improvement from the initial 3D campus model through navigation, AI assistance, centralized information, and complete system integration. This

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demonstrates the potential of integrating the individual modules into a unified intelligent campus platform.

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