International Conference on Recent Innovations in Education, Computer Science, Engineering, and Technology (ICRIECSET)
25 -26, April 2026, Grand Hyatt Taipei Hotel, Taipei, Taiwan

Digital Twin Technology for Smart Campuses: Bridging Physical and Virtual Learning Spaces in Higher Education

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Abstract

Digital Twin Technology is emerging as a transformative innovation in the development of smart infrastructure, offering real-time virtual representations of physical systems. In higher education, this technology presents significant opportunities for reimagining campus environments by seamlessly integrating physical and virtual learning spaces. This study explores the role of digital twin frameworks in designing and managing smart campuses that enhance teaching, learning, and administrative processes. By leveraging the convergence of Internet of Things (IoT), artificial intelligence (AI), cloud computing, and data analytics, digital twins enable continuous monitoring, simulation, and optimization of campus operations and academic environments. Adopting a conceptual and exploratory research approach, the study examines how digital twins contribute to improved campus management, energy efficiency, safety, and personalized learning experiences. Real-time data collected from sensors, smart devices, and institutional systems are synchronized within the digital twin model to support predictive maintenance, efficient resource allocation, and adaptive learning ecosystems. Additionally, the integration of immersive virtual learning environments within the digital twin infrastructure facilitates remote and hybrid education, promoting accessibility and inclusivity for diverse learners. The study also highlights critical challenges, including data privacy and security concerns, high implementation costs, technical complexity, and the necessity for robust digital infrastructure and skilled human resources. Addressing these issues is essential for the sustainable adoption of digital twin technologies in higher education institutions. Despite these challenges, the findings indicate that digital twin technology holds immense potential to transform traditional campuses into intelligent, sustainable, and learner-centric ecosystems. The study concludes that digital twins can play a pivotal role in shaping the future of higher education by fostering innovation, enhancing operational efficiency, and bridging the gap between physical and virtual learning spaces.

Keywords: Digital Twin Technology; Smart Campus; Internet of Things (IoT); Artificial Intelligence (AI); Virtual Learning Environments; Higher Education