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Student Centric Model for Learning Analytics in Smart Campus Ecosystem: A Systematic Literature Review

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ABSTRACT

The development of smart campuses has intensified the use of data-driven technologies to support institutional decision-making in higher education. However, many existing smart campus implementations remain system-oriented, with limited emphasis on learning processes and student needs. This study aims to formulate a student-centric model for learning analytics within digital twin–enabled smart campus ecosystems through a systematic literature review. The review follows the PRISMA 2020 guidelines and analyzes peer-reviewed articles indexed in the Scopus database, focusing on digital twins, smart campuses, learning analytics, and data governance. The findings indicate that digital twins have evolved from static digital representations into integrated platforms that combine real-time data, modeling, and analytics to support proactive decision-making. Nevertheless, the integration of learning analytics that explicitly centers on students is still fragmented. The concept of the student digital twin emerges as a promising approach for modeling learners as dynamic analytical entities, but it also raises critical concerns related to ethics, privacy, transparency, and governance. Based on the synthesis, this study proposes a conceptual student-centric model consisting of data sources, sensing mechanisms, student modeling, learning analytics, feedback and intervention pathways, and governance safeguards. The model provides a structured foundation for designing responsible and sustainable learning analytics in smart campus environments.

1. Introduction

Digital Transformation in higher education does not stop at the automation of administrative services. In the era of technological advancement, universities are moving toward the development of smart campuses, an ecosystem that connects academic services, facilities, and campus activities through data. In the early state of smart campus development, the focus tends to be on operational aspects such as monitoring facilities or conditions around campus, while the use of data to support student learning success remains underdeveloped. As a result, data from academic systems, learning management systems (LMS), attendance records, library services, and other digital interactions have not been consolidated into actionable insights used for learning.

The concept of smart campus refers to an integrated digital ecosystem in which various campus services, infrastructures, and stakeholders are interconnected through data driven technologies. In this environment data generated form academic systems, campus facilities, sensors, and digital platforms are continuously collected and integrated to support intelligent services and informed decision making within universities. Recent studies emphasize that smart campuses increasingly rely on the orchestration of advanced technologies such as the Internet of Things (IoT), cloud and edge computing, artificial intelligence, big data analytics, and digital twin systems to create responsive and sustainable campus services [2]. In addition, the implementation of digital twin technologies within smart campuses demonstrates how digital representations of campus environments, combined with real-time data streams and analytical capabilities, can support monitoring, simulation, and evidence-based campus management decisions [1]. Through this integration, the smart campus ecosystem aims to transform traditional campus operations into a more adaptive, data-driven, and intelligent educational environment.

At this point, the concept of learning analytics becomes relevant, as it is oriented toward leveraging data to understand learning processes and provide timely support. By analyzing patterns derived form students academic interaction and performance, learning analytics enables institution to identify potential learning risk and provide targeted interventions. Studies discussing the student's digital twin emphasize that the use of AI and predictive models in university environments cannot be separated from issues of ethics, privacy, legality, transparency, and data minimization. These aspects are not supplementary but rather design prerequisites [3]. In other words, being “student-centric” is not merely about improving prediction accuracy but also about ensuring data governance and accountability when analytics outcomes are used to make decisions that affect students. Furthermore, the development of immersive digital spaces expands how human engagement is understood within digital twin ecosystems. Concepts that combine digital twins and the metaverse highlight the importance of human-in-the-loop and user participation in data-driven governance [4].

In this context, digital twin technology emerges as a potential approach to bridge the gap between data availability and meaning full services in smart campus environment. Bridging the gap between data and services can be achieved through digital twin technology. Digital Twin offers a continuously updated digital representation that enables universities to understand real conditions, simulate scenarios, and make evidence-based decisions. The implementation of digital twins in smart campuses has been developed as systems integrating campus environment modeling (e.g., 3D models), data streams from monitoring devices, and analytical and predictive capabilities to support campus management decision-making. However, early smart campus research has not yet demonstrated the full potential of digital twins in delivering truly intelligent services, particularly in the aspects of prevention, prediction, and decision-making [1]. Recent smart campus literature emphasizes that modern campuses will increasingly rely on the orchestration of technologies like Internet of Things (IoT), Cloud/Edge Computing, Artificial Intelligence (AI), Big Data, Augmented Reality (AR)/Virtual Reality (VR), blockchain, and digital twins to provide responsive and sustainable services [2]. Nevertheless, the adoption of these technologies does not automatically result in designs that focus on the core needs of learning. A common challenge is that many platforms and architectural design are developed using system centric logic, while students’ needs as the primary users of learning are not always placed at the center of the data and analytics ecosystem design.

From this synthesis of literature, a clear gap emerges. Research on smart campuses and digital twins tent to emphasize technological integration and system infrastructure, while learning analytics research is strong in leveraging learning data. However, the convergence of both into a truly student-centric model remains inconsistent. This gap includes: (1) how students are modeled as dynamic digital twin entities relevant to learning, (2) how academic and non-academic data sources are integrated into an operational smart campus architecture, and (3) how analytical results are transformed into interventions and feedback that are understandable, fair, and accountable.

Therefore, this study conducts a Systematic Literature Review (SLR) to formulate a Student-Centric Model for Learning Analytics in Smart Campus Ecosystems. The focus at this stage is not on building a software prototype, but on developing a conceptual model that explains the key components of the ecosystem: data sources, sensing and updating mechanisms (sense), student modeling (student twin), learning analytics (insight), feedback and intervention pathways (act), and governance and ethical principles as safeguards. Through this approach, the SLR is expected to produce an evidence map and a conceptual that can later be translate into system design in subsequent research.

This direction aligns with the research contributions of Jusia Amanda Ginting, which emphasize the importance of architectural planning and user-centered aspects in digital learning ecosystems. Work on enterprise architecture planning for metaverse development in educational institutions highlights the need for integration frameworks and governance to ensure that campus digital ecosystems evolve in a structured manner [5]. Other studies evaluating user experience in immersive technologies indicate that interaction quality and user acceptance should be treated as design components rather than merely end-stage evaluations [6]. From the perspective of foundational campus digital service infrastructure, research on intranet network service quality underscores the importance of stable network capabilities as a prerequisite for reliable data and analytics services [7]. With this foundation, this SLR aims to develop a conceptual model that is not only comprehensive at the conceptual level but also realistic for adoption within complex smart campus ecosystems. To guide this systematic review, the following research questions are formulated:

RQ1: What are the characteristics and recent research trends regarding the implementation of digital twins in smart campus ecosystems, particularly in the context of data integration and decision-support mechanisms?

RQ2: What technological components and architectural elements are most frequently identified in the literature as the foundation for digital twin–based smart campus development (e.g., data acquisition layers, platform integration, modeling, and intelligent services)?

RQ3: How is the concept of student-centric learning analytics represented in the smart campus and digital twin literature, particularly in relation to modeling students as student digital twins or dynamic analytical entities?

RQ4: What analytical mechanisms and forms of learning support/intervention are proposed in the literature to generate actionable insights for students within smart campus environments?

RQ5: How are issues of data governance, privacy, and ethics discussed in the literature regarding the implementation of student-oriented digital twins and learning analytics in higher education, and which principles are most frequently emphasized to ensure implementation legitimacy?

2. Methodology

2.1 Research Design SLR

This study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure a transparent and replicable process in identifying, screening, and synthesizing relevant studies [1]. This systematic literature review was conducted between November and December 2025 using the Scopus database as the primary academic source due to its comprehensive indexing of scholarly journals in the fields of education and technology.

2.2 Search Strategy

Database Selection

The literature search was conducted using the Scopus Database as the primary academic source. Scopus was selected because it provides comprehensive indexing of peer-reviewed journals across interdisciplinary fields such as information systems, educational technology, and smart infrastructure.

Keywords and Boolean Operators

The search process focused on publication related to the following key concepts such as: “Smart Campus”, “Digital Twin”, “Learning Analytics”, “Student Digital Twin”, “Data Governance”. This keywords were combined using Boolean operators such as AND and OR to retrieve relevant articles discussing the intersection of smart campus ecosystem, digital twin technologies, and learning analytics in higher education environments.

2.3 Inclusion and Exclusion Criteria

To ensure the relevance and quality of the reviewed literature, a set of inclusion and exclusion criteria was applied during the screening process. Inclusion criteria include: article discussing smart campus ecosystems or digital twin technologies in higher education contexts, studies addressing learning analytics or student digital twin concepts, research examining data governance, privacy, or ethical consideration in educational analytics, and peer-reviewed articles indexed in Scopus. Exclusion criteria include: article discussing digital twin exclusively in industrial contexts, studies focusing solely on technical system implementation without relevance to learning, articles lacking sufficient conceptual explanation required to synthesis.

2.4 Article Selection Process

Prisma Flow Diagram

The article selection process follows the PRISMA methodology, consisting of four stages: identification, screening, eligibility, and inclusion. A total of 48 articles were initially retrieved from the scientific database during the identification stage. No duplicate articles were identified during dataset preparation. Subsequently, all articles were screened based on their titles and abstracts, resulting in the exclusion of 16 articles that were not directly related to the research focus. Examples of excluded studies include articles discussing digital twins exclusively in industrial environments or studies focusing only on technical system implementation without connections to smart campus learning environments. Figure 3. Illustrates the overall articles selection process following the PRISMA framework.

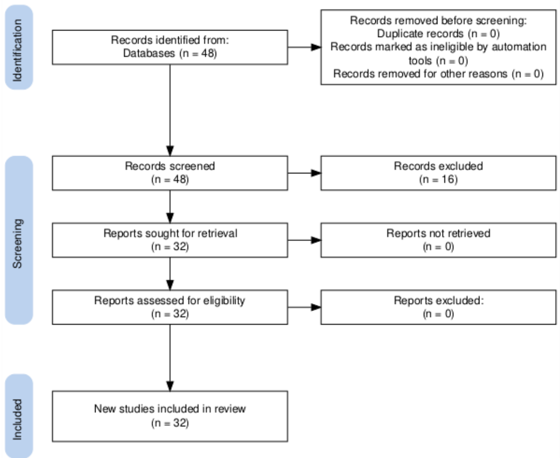

Figure 1. Prisma Methodology

The remaining 32 articles were then evaluated through full-text analysis and were considered eligible for inclusion in the qualitative synthesis of this systematic literature review.

2.5 Data Extraction and Analysis Techniques

Coding Process

Each selected article was examined to identify key elements related to: technological components of smart campus architecture, digital twin implementation approaches, learning analytics mechanisms, student modeling and student digital twin concepts, governance, privacy, and ethical considerations. Relevant information from each study was systematically coded and categorized to support the subsequent analysis stage.

Bibliometric Analysis

bibliometric analysis was conducted in the initial stage of this study to obtain an overview of the development, trends, and structural landscape of research related to smart campuses, digital twins, and their implications for learning analytics and student-centric approaches. This analysis aims to identify publication patterns, dominant scholarly outlets, and the interconnections among key themes emerging in the literature, thereby providing a strong foundation for the subsequent systematic synthesis and formulation of the conceptual model.

The bibliometric data were derived from articles that had previously undergone the selection process and were deemed relevant to the research focus. Not all selected articles were explicitly included in the bibliometric analysis; only those with complete publication metadata and substantive relevance representing the core themes of smart campuses, digital twins, learning analytics, and data governance aspects were utilized.

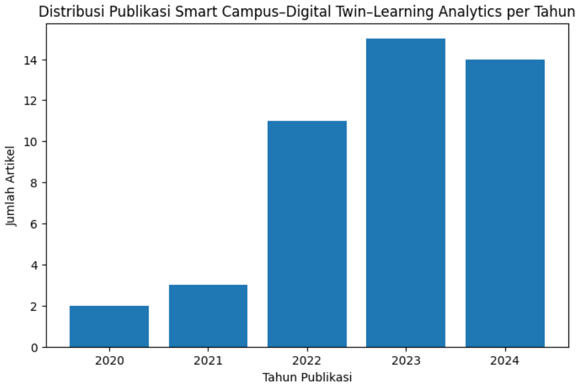

Figure 2. Publications Distributions

The graph of publication distribution by year shows a significant increase in research on smart campuses, digital twins, and learning analytics in recent years. Publications were relatively limited during the early period (2020–2021), reflecting an initial exploratory phase of smart campus and digital twin concepts within higher education. Starting in 2022, there was a sharp rise in the number of publications, indicating growing academic attention to the use of digital twin technology, IoT, and data analytics to support campus services and learning environments. The peak of publications occurred in 2023 and remained high in 2024, suggesting that this field is currently in a phase of research growth and consolidation. This trend reinforces the relevance of conducting a systematic literature review to synthesize research findings and formulate a student-oriented conceptual model within smart campus ecosystems.

Studies on the design and implementation of digital twins in smart campuses demonstrate how educational institutions are beginning to utilize digital representations, monitoring data, and predictive analytics to support more systematic and sustainable campus decision-making [1]. These findings indicate that digital twins are no longer viewed as experimental concepts but as increasingly operational approaches within higher education contexts. Research integrating RFID technologies in smart campuses illustrates how activity and identity data can be leveraged to build responsive and contextual campus systems, which in later stages may become important data sources for learning analytics [8], [9].

As the analytical focus shifts toward students, the literature increasingly emphasizes the importance of student-centric approaches and modeling students as analytical entities. Studies on the student's digital twin highlight that the application of predictive models and machine learning in university environments must be accompanied by clear ethical and governance frameworks [3], [10]. Furthermore, several publications associate digital twins with virtual environments and the metaverse as an extension of digital interaction spaces. Although this perspective is not the primary focus of the bibliometric analysis, the integration of metaverse concepts within urban digital twins provides a conceptual framework for understanding the interconnectedness of physical, digital, and human dimensions [4].

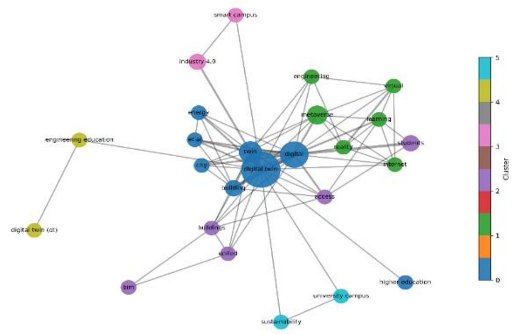

Figure 3. Bibliometric Mapping

The bibliometric mapping in this study visualizes the co-occurrence relationships of terms from the selected articles to reveal the dominant thematic structure within the topics of smart campuses, digital twins, and learning analytics. The map shows that the terms smart campus and digital twin occupy central positions, indicating that much of the reviewed literature positions digital twins as an integrative approach for modeling, monitoring, and decision support within intelligent campus environments. This finding is consistent with studies on smart campus digital twin implementations that combine digital campus representations, monitoring data integration, and analytics for decision-making.

Another strongly connected cluster highlights the role of IoT/RFID as a data acquisition layer, emphasizing that the collection of activity and identity signals is a critical prerequisite for intelligent services and analytics within campuses. In addition, a cluster emerges that points toward the concept of the student digital twin and issues of ethics and privacy, indicating that as analytics increasingly focuses on students, the need for data governance and the legitimacy of predictive model usage becomes a primary concern.

Thematic Analysis

Following the bibliometric overview, a thematic analysis was conducted to synthesize findings from the selected literature based on the research questions formulated in this study. The thematic synthesis focuses on identifying:

a. Technological architectures supporting digital twin–enabled smart campuses
b. Representation of students as analytical entities within learning analytics systems
c. Mechanisms for generating actionable insights and learning interventions
d. Governance and ethical frameworks supporting responsible implementation of student-centered analytics.

The results of this thematic analysis form the basis for the development of the Student-Centric Model for Learning Analytics in Smart Campus Ecosystems proposed in this study.

3. Result and Discussion

RQ1: To address this research question, this systematic literature review analyzes recent studies discussing the implementation of digital twins within smart campus ecosystems. The analysis focuses particularly on how digital twins are used to integrate heterogeneous campus data sources and support decision-making processes through monitoring, simulation, and predictive analytics. The main characteristics and research trends identified in the literature are summarized in Table 1.

Table 1. Characteristics and Research Trends of Digital Twin Implementation in Smart Campus Ecosystems

Dimension	Key Characteristics	Research Trends	Implications	References
Conceptual orientation	Digital twins function as digital counterparts that represent campus environments, including facilities and operational processes	Evolution from visualization-oriented models toward integrated analytical platforms	Supports monitoring and data-driven campus management	[1]
Data integration	Integration of heterogeneous campus data sources such as academic systems, services, and sensor infrastructures	Increasing emphasis on cross-system interoperability and unified data ecosystems	Enables real-time data synchronization across campus systems	[1]. [11]
Technology Stack	Combination of IoT devices, real-time data streams, and analytical platforms within smart campus environments	Growing integration of analytics platforms and data-driven architectures	Strengthens predictive capabilities and operational intelligence	[11]
Data Governance & Security	Management of institutional data generated across campus systems and infrastructures	Increasing attention to responsible data usage and governance within smart campus ecosystems	Requires institutional policies for data governance and accountability	[12], [13]
Decision Support Capabilities	Integration of modeling, real-time data streams, and analytics	Growing use of predictive and analytical capabilities for operational decision-making	Facilitates evidence-based campus management	[11]
Application Domains	Digital twin implementations applied in campus infrastructure monitoring and operational management	Expansion toward broader digital campus services and ecosystem integration	Enables multi-domain smart campus services	[1], [12]
Research Methodology	Existing studies often rely on conceptual models and system architecture proposals	Increasing use of analytical frameworks and system integration approaches	Indicates gradual movement toward more applied smart campus research	[11], [12]
Maturity Level	Current implementations remain largely experimental or prototype-based	Gradual transition toward more integrated smart campus ecosystem	Highlights opportunities for developing scalable and student-centered models	[12], [13]

The synthesis presented in Table 1 highlights the major characteristics and emerging research trends in digital twin–based smart campus development, emphasizing the growing importance of data integration, analytical capabilities, and governance considerations.

RQ2: To address this research question, this study analyzes the technological components and architectural elements frequently discussed in the literature on digital twin–based smart campus systems. The analysis focuses on how different technological layers—including data acquisition, integration platforms, digital modeling, and intelligent services—form the architectural foundation that enables digital twin implementations in smart campus environments. The key architectural characteristics identified in the reviewed literature are summarized in Table 2.

Table 2. Technological Architecture of Digital Twin–Based Smart Campus Systems

Dimension	Key Characteristics	Research Trends	Implications	References

Conceptual orientation	Smart campus architectures are structured as layered ecosystems combining sensing, data integration, modeling, and analytics	Growing shift toward integrated digital twin–based campus platforms	Enables holistic management of campus operations and services	[21], [22]
Data integration	Integration of heterogeneous campus systems including academic platforms, student services, and infrastructure systems	Increasing adoption of interoperable platforms and unified data environments	Supports seamless data exchange and real-time system coordination	[16], [17], [18], [19], [20]
Technology Stack	Use of IoT devices, sensors, RFID systems, and monitoring technologies to collect environmental and activity data	Expansion of sensing technologies for continuous campus data collection	Strengthens real-time monitoring and contextual data acquisition	[4], [14], [15]
Data Governance & Security	Management and coordination of large volumes of campus data across interconnected systems	Increasing awareness of governance requirements for complex campus data ecosystems	Highlights the need for structured data governance frameworks	[16], [18], [20]
Decision Support Capabilities	Integration of analytics and digital twin modeling to support simulation and prediction	Increasing use of predictive analytics to support operational decisions	Enables evidence-based campus decision-making	[21], [22]
Application Domains	Implementation across campus infrastructure monitoring, environmental management, and service coordination	Expansion toward integrated campus-wide digital services	Supports multi-domain smart campus operations	[4], [14], [21]
Research Methodology	Studies commonly adopt system architecture design and technological framework approaches	Increasing use of system integration models and platform architectures	Indicates growing maturity in smart campus architectural research	[16], [21]
Maturity Level	Current implementations remain largely architecture-focused and prototype-oriented	Gradual transition toward integrated smart campus platforms	Indicates opportunities for further large-scale implementation	[21], [22]

Table 2 highlights the technological layers and architectural components frequently discussed in the literature. Future studies may further strengthen this architecture by integrating learning analytics and student-centered data models to support more comprehensive smart campus ecosystems.

RQ3: To address this research question, this study examines how the literature conceptualizes student-centric learning analytics within smart campus environments. The analysis focuses on how students are represented as analytical entities, how learning data are utilized to understand student behavior and performance, and how ethical and governance considerations influence the development of student-centered analytical systems. The key characteristics identified in the reviewed literature are summarized in Table 3.

Table 3. Student Centric Learning Analytics Representation in Smart Campus Ecosystems

Dimension	Key Characteristics	Research Trends	Implications	References
Conceptual orientation	Learning analytics shifts the focus from system management toward supporting students' learning needs	Increasing emphasis on student-centered data analysis in educational systems	Enables deeper understanding of learning behavior and academic progress	[3], [8]
Data integration	Integration of academic interaction data, performance data, and student activity records	Expansion of learning data sources across campus digital platforms	Supports holistic analysis of student learning environments	[3], [8]
Technology Stack	Use of analytics platforms, predictive models, and data-driven monitoring systems	Growing adoption of AI-driven analytical models in education	Enhances the ability to identify learning patterns and risks	[3], [23], [24]
Data Governance & Security	Ethical, privacy, and transparency considerations in handling student data	Increasing attention to responsible data use and ethical learning analytics	Ensures fairness, accountability, and trust in educational analytics	[25], [26]
Decision Support Capabilities	Analytical insights used to support interventions and learning support strategies	Expansion toward predictive learning analytics and early-warning systems	Supports proactive academic guidance and student success initiatives	[3], [23]
Application Domains	Applications in monitoring engagement, performance analysis, and learning risk identification	Increasing integration with broader smart campus data ecosystems	Enables contextualized insights about student learning environments	[3], [8], [23]
Research Methodology	Studies frequently employ conceptual frameworks and analytical modeling approaches	Increasing use of data-driven evaluation methods in educational analytics	Indicates growing maturity in student analytics research	[23], [24]

Maturity Level	Student-centric analytics implementations remain emerging within smart campus ecosystems	Gradual movement toward integrated learning analytics platform	Highlights the need for more comprehensive student-centered models	[25], [26]

Table 3 highlights how student-centric learning analytics is conceptualized in the literature, emphasizing the role of student digital twins, ethical data governance, and the integration of learning data within broader smart campus ecosystems**.**

RQ4: To address this research question, this study analyzes how analytical mechanisms and intervention strategies are discussed in the literature related to digital twin–based smart campus learning analytics. The analysis focuses on how different forms of analytics—such as descriptive, predictive, and prescriptive analytics—are used to generate insights and support interventions for students, lecturers, and academic administrators. The key characteristics of these analytical mechanisms identified in the reviewed literature are summarized in Table 4.

Table 4. Analytical Mechanisms and Intervention Strategies in Smart Campus Learning Analytics

Dimension	Key Characteristics	Research Trends	Implications	References
Conceptual orientation	Learning analytics mechanisms are designed to support monitoring, prediction, and intervention within smart campus ecosystems	Increasing integration of digital twin data with learning analytics processes	Supports data-driven learning environments and proactive academic support	[27], [28]
Data integration	Integration of learning activity data with broader campus contextual data	Expansion toward multi-source data integration across campus platforms	Enables more contextualized and accurate learning insights	[29], [30]
Technology Stack	Use of analytics platforms supporting descriptive, predictive, and prescriptive analytics	Growing adoption of predictive analytics and intelligent recommendation systems	Improves the capability to identify learning risks and opportunities	[27], [28], [31]
Data Governance & Security	Emphasis on transparency, accountability, and responsible use of analytics outcomes	Increasing concern regarding ethical implementation of automated analytics systems	Ensures that analytical decisions remain accountable and transparent	[33], [34]
Decision Support Capabilities	Analytical dashboards, class performance summaries, and decision-support tools	Expansion of analytics tools supporting lecturers and academic administrators	Facilitates data-driven academic management	[32], [33], [34]
Application Domains	Applications include monitoring student engagement, learning performance, and risk detection	Increasing use of analytics for personalized learning support and academic interventions	Enables targeted learning assistance and early-warning mechanisms	[29], [30], [31]
Research Methodology	Studies frequently use analytical modeling and data-driven evaluation approaches	Increasing use of predictive learning analytics frameworks	Demonstrates growing sophistication in educational analytics research	[27], [31]
Maturity Level	Learning analytics systems in smart campuses remain evolving and partially implemented	Gradual movement toward integrated smart campus analytics platforms	Indicates opportunities for improving intervention design and scalabilit	[30], [32]

Table 4 summarizes the analytical mechanisms and intervention strategies discussed in the literature. Future research may further enhance these mechanisms by integrating digital twin data with student-centered learning analytics to support more adaptive and context-aware educational interventions.

RQ5: To address this research question, this study analyzes how the literature discusses data governance, privacy protection, and ethical considerations in the implementation of digital twin–based learning analytics within smart campus ecosystems. The analysis focuses on governance mechanisms, privacy protection strategies, and ethical principles that guide the responsible use of student data in analytics systems. The key characteristics identified in the reviewed literature are summarized in Table 5.

Table 4. Analytical Mechanisms and Intervention Strategies in Smart Campus Learning Analytics

Dimension	Key Characteristics	Research Trends	Implications	References
Conceptual orientation	Governance and ethical principles are essential components of learning analytics systems using student data	Increasing recognition that governance must accompany technological innovation	Ensures responsible implementation of data-driven educational technologies	[2], [7]
Data integration	Integration of student data across multiple campus platforms requires controlled data access and usage boundaries	Expansion of cross-platform data integration within smart campus ecosystems	Requires strong governance structures for data coordination and management	[2], [33]

Technology Stack	Smart campus systems rely on interconnected platforms that process and analyze large volumes of student data	Growing reliance on integrated analytics platforms and intelligent systems	Highlights the need for secure data infrastructures and system protection	[7], [33]
Data Governance & Security	Implementation of privacy protection mechanisms, cybersecurity frameworks, and controlled data usage policies	Increasing concern regarding data privacy and institutional accountability	Supports protection of sensitive student data within integrated campus systems	[2], [7], [33]
Decision Support Capabilities	Analytical models used to support academic decision-making involving student data	Growing awareness of risks related to bias and prediction errors	Emphasizes transparency and fairness in analytics-driven decisions	[4], [28]
Application Domains	Governance frameworks applied across learning analytics and digital twin ecosystems	Expansion of governance discussions toward ethical AI in education	Promotes responsible deployment of intelligent technologies	[4], [35]
Research Methodology	Studies examine governance frameworks, ethical guidelines, and policy implications of learning analytics	Increasing interdisciplinary research on ethics and governance in education technology	Supports the development of responsible analytics frameworks	[28], [35]
Maturity Level	Governance frameworks for smart campus analytics remain evolving	Growing institutional attention to governance, sustainability, and legitimacy	Indicates the need for comprehensive governance models in smart campus ecosystems	[33], [35]

Table 5 highlights that governance, privacy protection, and ethical principles are fundamental components of digital twin–based learning analytics systems. Future research may further explore governance frameworks that integrate technological, ethical, and institutional dimensions to support responsible smart campus ecosystems.

4. Conclusion

This Systematic Literature Review shows that the application of digital twins in smart campus ecosystems has evolved from simple digital representations into integrated systems that support data-driven decision-making in higher education. The literature highlights the growing importance of cross-system integration, well-designed data architectures, and analytical capabilities that enable campuses to move from reactive monitoring toward more predictive and evidence-based management. The review also indicates that learning analytics in smart campus environments is increasingly used to support monitoring, prediction, and learning interventions. The concept of the student digital twin emerges as a promising approach for representing students as dynamic analytical entities that combine learning data with broader campus contextual information. However, the implementation of truly student-centric learning analytics remains inconsistent, particularly in terms of pedagogical relevance, transparency, and responsible data use. In addition, governance, privacy, and ethical considerations are identified as essential components in the implementation of digital twin–based learning analytics. Responsible data management, transparency in analytical processes, and institutional accountability are necessary to ensure that intelligent technologies are applied in a sustainable and trustworthy manner within higher education ecosystems. This study therefore provides a conceptual foundation for developing a Student-Centric Model for Learning Analytics in Smart Campus Ecosystems, emphasizing the integration of technological architectures, analytical mechanisms, and governance principles. Limitations. This review is limited by the use of a single academic database and by the fact that many existing studies focus on conceptual models rather than large-scale empirical implementations of digital twins in higher education. Future studies may focus on empirical validation of student-centric digital twin models and explore how digital twin architectures can be integrated with learning analytics platforms to support personalized learning interventions and responsible data governance in smart campus environments.

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