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A Systematic Review of Digital Transformation and Smart Campus Adoption in Developing Countries

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Abstract: Higher education institutions (HEIs) are increasingly shaped by digital transformation. Innovative technologies are improving teaching, learning, and campus management, yet their adoption is uneven across contexts. In many developing countries, smart campus projects hold real promise for narrowing both educational and technological divides. At the same time, they encounter barriers that are deeply rooted in social and technical realities. To explore these challenges, the PRISMA method was applied to analyze 87 studies collected from Scopus, Web of Science, and IEEE databases. The review points to recurring obstacles, including weak stakeholder involvement, poor coordination in technology integration, and the lack of frameworks tailored to local needs. The study also found that much of the existing work overlooks important cultural factors, infrastructure limitations, and gaps in digital skills, all of which shape implementation outcomes. By bringing these issues together, the study provides practical direction for policymakers, university leaders, and campus planners. It argues for strategies that are sensitive to local conditions if smart campus adoption in developing regions is to be both effective and sustainable.

Keywords: Digital Transformation, Higher Education Institutions, socio-Technical Challenges, Developing Countries, Smart Campus.

INTRODUCTION

The digital transformation (DT) is now a key point for how higher education institutions (HEIs) adapt and grow. Universities are using DT strategies to enrich the learning experience, reduce administrative complexity, and connect more closely with global knowledge networks [1-4]. DT brings together multiple technologies through IR 4.0. In IR 4.0, Artificial Intelligence (AI) is a single change. The Internet of Things (IoT), big data analytics, virtual reality (VR), and cloud computing are among the most widely used technologies in HEIs. The combination of these technologies is reshaping teaching practices as well as the services that support the learning and teaching digital environment [5-7]. These advancements underpin the idea of the smart campus, an environment. It is connected, flexible, and intelligent. For HEIs, this means going beyond the digitalization of infrastructure. It also involves responding to the shifting expectations of students, faculty, and administrators [8-11].

However, the developed countries have rapidly adopted smart campus technologies to build knowledge-based educational systems [12, 13]. HEIs in developing countries continue to face multiple barriers [14]. These include a lack of digital infrastructure, limited financial resources, and insufficient institutional readiness [15]. Furthermore, there is a gap in digital competencies among educators and students [16-18]. Moreover, despite the promise of smart campuses to bridge educational inequities [19]. The existing research remains fragmented, with limited comprehensive studies examining the socio-technical challenges of smart campus adoption within developing country contexts [9, 20]. These challenges would be addressed because it is crucial to leverage digital transformation for sustainable higher education development in these regions.

The process of digital transformation in higher education must be guided by a coherent strategic vision. It is embedded within an operational framework. The purpose of strategic vision clearly defines institutional goals, technological pathways, and relevant educational use cases [21]. Correani, De Massis [22] highlighted that in 2020, many institutions struggled to realize the full potential of digital transformation due to a misalignment between strategy formulation and its effective execution. Although universities have been early adopters of digital technologies and have invested significantly in digital infrastructures. The transition from isolated digital initiatives to integrated. The institution all over the world remains a challenge, particularly in developing countries, where contextual barriers persist [2, 17, 23-25].

Digital transformation involves more than the implementation of technological tools in HEIs. It encompasses deep organizational change affecting institutional processes, pedagogical methods, and service delivery models [26]. Recent research highlights that this transformation is driving the creation of sustainable, digitally enriched curricula, advancing innovation, and enhancing student engagement for academic performance [27-29]. However, these outcomes do not depend solely on IR 4.0 but also on institutional readiness, staff competencies, and strategic governance factors that remain underdeveloped in many HEIs across the Global South [30]. Although numerous studies have investigated the domain of digital transformation in higher education institutions (HEIs), but it may overlook capturing the critical technology trends driving this transformation, or the important challenges experienced by key stakeholders, including lecturers, students, and administrators [7, 31-37].

These studies often adopt a generalized view of smart campus development. The lack of attention to the localized socio-technical dynamics that influence adoption and implementation. In developing countries, particularly in regions like Oman and Pakistan, the digital transformation journey is shaped by contextual barriers, including limited infrastructure, policy gaps, institutional readiness, and cultural perceptions of technology [1-3]. For example, the Higher Education Commission in Pakistan has recently taken steps toward digital transformation (DT) in universities. However, a shortage of trained development and administrative staff has limited their ability to make effective use of these initiatives. Even in the 21st century, much administrative work remains paper-based rather than computer-based. This not only compromises transparency but also leads to biased decisions, such as in faculty promotions. That is only one side of the issue. On the other hand, the failure to adopt DT reduces productivity and makes routine tasks more time-consuming [37-40].

Smart campuses are promoted as models for digital learning and operations [41]. Yet, without a context-sensitive approach, technology-driven solutions risk ignoring human, organizational, and systemic constraints [42]. Grounded base strategies to analyze the local realities are essential for creating scalable frameworks that work across diverse economic and technological settings [43, 44]. Otherwise, the smart campus remains an abstract ideal and disconnected from the practical challenges of HEIs in the Global South. Cultivating digitally competent graduates requires addressing these gaps through inclusive strategies that consider the interplay between infrastructure, governance, and stakeholder engagement [6, 7, 17, 45-47].

Moreover, there is a gap in comprehensive research examining these challenges across geographical locations. Such as Oman, where contextual factors play a significant role. A contextualization model is essential for providing an operational framework for implementing a smart campus across diverse settings, including both developing and developed countries. Without such contextualization, a smart campus defined solely by the integration of technologies remains incomplete [48]. To prepare graduates who can generate knowledge, apply new technologies, and contribute to smart campus development [38]. Higher education must add Industrial Revolution (IR) technologies and pursue digital transformation (DT) [49]. Skills in these areas are increasingly vital for industry, making it essential to understand what students and future employees can offer [50]. At the same time, integrating IR technologies in universities supports sustainable development goals and addresses critical social challenges. This integration also strengthens the competitiveness of higher education institutions and positions them as leaders of change [51, 52].

The latest waves of industrial revolutions (IR 4.0 and IR 5.0) have brought technologies such as artificial intelligence, blockchain, robotics, cloud computing, data science, virtual reality, the Internet of Things (IoT), 3D printing, chatbots based on generative and agentic AI, smart sensors, digital twins, the Internet of Everything (IoE), A IoT, edge and fog computing, cognitive computing, and even 6G and beyond [53]. These advances are increasingly in demand, as industries seek graduates with the skills to deploy and manage them [54-56]. For universities, applying these tools to teaching, learning, and administration is essential to move toward the concept of the smart campus [41]. The idea of “smartness” now extends across many domains, such as smart devices, smart factories, smart schools, and smart campuses [56]. Closely tied to this is the rise of smart cities, which set new standards for urbanization and sustainable living. In such environments, people benefit from seamless access to services, improved connectivity, and resource efficiency. Smart cities enhance key sectors like healthcare, energy, transport, and education, offering lessons for the development of smart campuses [57]. Practical applications include smart classrooms, digital payment systems, connected stadiums, and intelligent parking solutions [54]. Education systems worldwide are increasingly revising policies and strategies to prepare students for an uncertain future, one shaped by emerging job roles and transformative technologies yet to be imagined [58].

In this context, the Sultanate of Oman has taken proactive steps to advance its education system by continuously updating the science curriculum [59]. The goal is to equip students with the skills and competencies needed to address future challenges and adapt to ongoing digital transformation.

To achieve this, Omani educational policy adopts a structured four-stage approach: awareness, training, deployment, and innovation [14, 60].

Motivation and Contribution

Research on digital transformation in higher education often overlooks the realities of developing countries. Most studies focus on advanced settings, leaving little attention to challenges such as limited infrastructure, low digital literacy, and cultural resistance, especially in contexts like Oman [2, 7, 17, 61]. Reviews also tend to narrow in on specific technologies or policies, without addressing the barriers faced by students, lecturers, and administrators [5, 11, 32]. This creates a gap in understanding how smart campuses can be implemented where institutional readiness differs. To address this, this systematic literature review (SLR) makes three contributions. It maps socio-technical challenges across technology, organization, and people. It identifies contextual factors such as policies, infrastructure, and culture, and builds a knowledge base with strategies to support smart campus adoption. The findings offer practical insights for policymakers, university leaders, and planners working toward inclusive and sustainable digital transformation. The structure of this paper is as follows: Section 2 presents the related work; Section 3 details the research methodology; Section 4 discusses the findings, challenges, and future directions; and Section 5 concludes the study.

LITERATURE REVIEW

Historically, many HEIs in developing countries have struggled to address the socio-technical challenges of digital trans formation [61]. Due to limited experience with large-scale digital learning environments. As these IR and other digital technologies were used to modernize operations and implement smart campus initiatives [9]. They encountered unforeseen issues involving human technology interaction, digital resource development, and organizational coordination. These difficulties affected lecturers, students, and administrators alike, highlighting the complexity of building digitally integrated educational ecosystems. As Bygstad, Øvrelid [15] notes, such challenges emphasize the need for robust socio-technical strategies that align with institutional goals and stakeholder needs. A key barrier has been the lack of consolidated digital resources and inadequate infrastructure to support smart campus initiatives [41]. This problem is particularly acute in developing countries, where limited technological readiness and fragmented support systems hinder progress [9, 62]. By contrast, institutions in developed regions benefiting from early investments and structured guidance from government agencies have been better positioned to manage these socio-technical demands [15].

The study of Truong and Diep [34] conducted a systematic review of emerging tools such as AI, SMAC (Social, Mobile, Analytics, Cloud), IoT, blockchain, VR/AR, RPA, and additive manufacturing, highlighting their transformative potential for teaching, learning, and administration in higher education. However, their focus remained largely technological and with limited attention to the socio-technical. Furthermore, contextual challenges shape successful implementation. This creates a gap in understanding how factors such as infrastructure readiness, cultural resistance, and digital literacy, particularly in developing countries. It affects the transition toward smart campuses. The present study addresses this gap by systematically examining these broader socio-technical dimensions, offering a more holistic perspective on digital transformation in HEIs. The other of Truong and Diep [34] provides a broad overview of new digital technologies in higher education. However, the study does not fully address the socio-technical challenges that institutions face when adopting these tools. It also gives little attention to developing countries, where limited infrastructure and cultural barriers strongly affect digital transformation. In a related review, Sneesl, Jusoh [54] examined the lack of a standardized model for IoT-based smart campuses. They grouped adoption factors into four categories: technological, organizational, environmental, and end-user. Important variables include perceived usefulness, trust, security, privacy, cost, scalability, and replicability. Based on these, they proposed a conceptual model using the VAM framework to guide future research and policy.

Despite these contributions, the study did not consider key socio-technical issues. These include stakeholder involvement, organizational culture, and institutional readiness. Moreover, it lacks contextual analysis of developing countries. In such settings, weak infrastructure and socio-cultural constraints often shape the outcomes of digital trans formation projects.

Alotaibi [33] carried out a systematic literature review on the role of digital learning in supporting sustainable development in Saudi Arabian higher education institutions (HEIs). The review showed a positive link between digital transformation capacity and institutional readiness. It also highlighted challenges such as weak infrastructure, digital skill gaps, and faculty resistance. While the study offers useful insights, it does not fully explore socio-technical challenges. These include organizational culture, stakeholder engagement, and management change. The findings are also limited to the Saudi context and do not compare issues faced by other developing nations.

In another study, Alotaibi and Alshehri [63] reviewed the integration of artificial intelligence (AI) and learning management systems (LMS) in higher education. Their work examined the impact on teaching quality, student outcomes, and institutional performance. They also identified major concerns, including data privacy, algorithmic bias, and digital inequality. To address these issues, the study proposed strategies for responsible implementation. However, it largely overlooks socio-technical factors, especially stakeholder roles, resistance to change, and organizational readiness. The review also lacks focus on developing countries, where infrastructure gaps and socio-cultural barriers strongly shape the adoption of AI-based technologies.

Table 1: Contribution Factors Across Different Studies

No	Contribution Factors	[33]	[53]	[32]	[60]	[61]	[55]	[64]	Current Study
1	Emerging digital technologies (AI, IoT, VR, etc.)	✓	✗	✗	✓		✓	✓	✓
2	Adoption models (TAM, UTAUT, VAM)	✗	✓	✗	✗	✗	✗	✗	✓
3	Contextual focus on developing countries	✗		✓	✓	✗	✗	✗	✓
4	Socio-technical challenges (e.g., stakeholder engagement, culture)	✗	✗	✗	✗	✗	✗	✗	✓
5	Institutional readiness and infrastructure gaps	✓	✓	✓	✓	✓	✗	✗	✓
6	Ethical issues (privacy, bias, digital inequality)	✓	✗	✗	✓	✗	✗	✗	✓
7	Smart campus operational design	✗	✓	✗	✗	✗	✓		✓
8	Evaluation of IS success factors (e.g., LMS/Admin systems)	✗	✗	✗	✗	✓	✗	✗	✓
9	Governance, leadership, and change resistance	✗	✗	✗	✗	✗	✗	✓	✓
10	Comparative analysis across reviewed SLRs	✗	✗	✗	✗	✗	✗		✓

Similarly, Mijač, Jadrić [65] conducted a systematic review on how information systems (IS) success is evaluated in HEIs. Their study covered both academic and administrative digital services. It addressed three main questions: which ISs are most common, which models are used to measure their success, and what indicators are applied across different dimensions. Findings revealed that LMS platforms are widely researched, but administrative systems receive far less attention. The review also highlighted gaps in defining standardized indicators and in integrating user-centered perspectives into IS evaluation. Given that HEIs are undergoing rapid digital transformation, the study emphasized the need for future research that considers institutional, social, and infrastructural influences on IS success.

Zhang, Yip [56] carried out a systematic review on emerging technologies for smart campuses. Their findings show that IoT and AI dominate the literature, while environmental issues receive little attention. The review also points out limited research on smart environments and mobile applications in secondary education. Although it presents a useful taxonomy of smart campus technologies, the study overlooks socio-technical challenges such as organizational culture, resistance to change, and stakeholder engagement.

Similarly, Sneesl, Jusoh [54] reviewed adoption models in higher education and found that TAM, UTAUT, and VAM were the most common frameworks. They grouped 52 adoption factors into four categories: technology, organization, environment, and end-users. The proposed VAM-based model included variables like perceived usefulness, trust, privacy, cost, and scalability. However, the review focuses mainly on technological and behavioral constructs. It does not address socio-technical issues such as governance, culture, and resistance within HEIs. Nor does it consider challenges in developing countries, where weak infrastructure and fragmented policies affect adoption. The model remains theoretical and lacks empirical validation.

Plekhanov, Franke [66] conducted a review of digital transformation in firms using a three-layered framework that covers the organizational core, periphery, and external environment. The study explains how digital technologies reshape business models, internal processes, and ecosystems. It also highlights shifting power dynamics and changes in governance. While insightful, the review is firm-centric and offers little relevance for HEIs. It overlooks issues like faculty readiness, governance bottlenecks, and cultural barriers, particularly in developing regions.

Overall, the related work underscores the growing role of digital transformation in HEIs but also highlights clear gaps. Most studies focus on technologies and adoption models while neglecting socio-technical dynamics such as stakeholder engagement and change management. They also lack attention to developing countries, where infrastructural and institutional constraints strongly shape digital transformation outcomes.

RESEARCH METHODOLOGY

This study employs a systematic literature review (SLR) to investigate socio-technical challenges in digital transformation (DT) and in the adoption of smart campuses in higher education institutions (HEIs), with a focus on developing countries. The review adheres to the PRISMA 2020 guidelines, ensuring a structured, transparent, and reproducible approach to identifying, selecting, evaluating, and synthesizing relevant literature PRISMA2020. The

SLR aims to classify existing contributions, identify research trends, and highlight gaps in the literature, following the protocol outlined by Kitchenham, Brereton [67], Aldahmashi and Abdulsamad [68], Aldahmashi and Abdulsamad [69]. A systematic search was conducted across Scopus, Web of Science, and IEEE Xplore, selected for their comprehensive indexing of peer-reviewed educational technology and socio-technical studies.

Research Process

The SLR follows the PRISMA 2020 framework, executed in four phases, as shown in Figure 1:

1. **Identification:** Search strings, derived from research questions (e.g., "digital transformation and higher education"), were applied across Scopus, Web of Science, and IEEE Xplore, yielding 35,520 records. After removing 1,5403 duplicates, 1,5403 records without DOIs, and 2,524 non-English or incomplete records, 17,593 articles remained.
2. **Screening:** Articles were screened by title and abstract, excluding 9,709 non-academic records (e.g., lecture notes, book chapters), 546 in-press or unpublished records, and 9,710 irrelevant records, leaving 1,382 articles for full-text review. Records were managed using Mendeley.
3. **Eligibility:** Full-text assessment of 1,475 articles used predefined criteria: 156 were excluded for non-CORE-ranked conferences, 559 for Q2–Q4 journals or unranked sources, 87 for failing quality criteria, and 113 for focusing on developed countries, ensuring relevance to developing nations.
4. **Inclusion:** 87 high-quality studies were selected for synthesis, focusing on DT and smart campus adoption in developing-country HEIs, meeting rigorous methodological and thematic criteria.

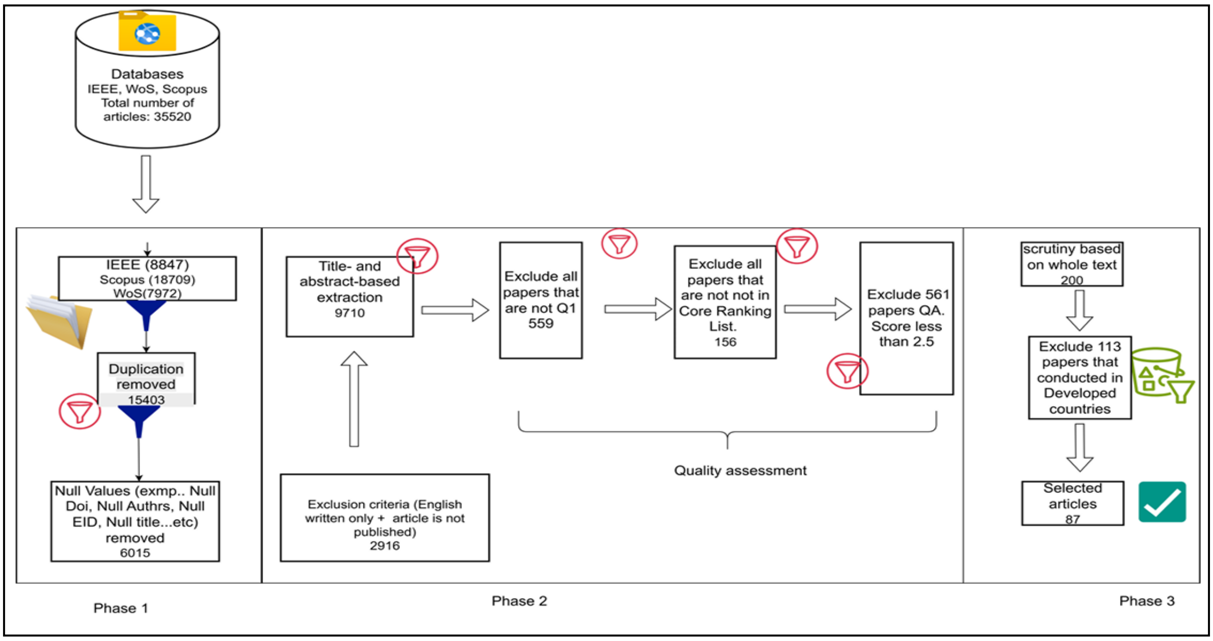

Fig. 1: Selection criteria of articles based on PRISMA methodology from 2021 to 2025 in this study.

Research Questions

The SLR is guided by five research questions that address socio-technical complexities in smart campus adoption, particularly in developing countries (Table 2). These questions were formulated to bridge knowledge gaps and guide the review's scope.

Table 2: Research Questions and Motivation for SLR

No.	Research Question	Motivation
Q1	What perspectives on integrating IR technologies for DT in higher education (the somatization process) are conceptualized in the study?	To synthesize frameworks for sustainable DT, leveraging IR technologies in education.
Q2	What are the essential factors for designing a smart campus in higher education?	To identify technological, stakeholder, and sustainability factors for effective smart campus design.
Q3	What approaches, models, or frameworks are proposed for smart campus design?	To evaluate existing models for systematic smart campus development.
Q4	Who are the key stakeholders or beneficiaries affected by smart campus design?	To understand the roles of students, educators, administrators, and others in DT success.
Q5	What are the gaps and challenges in designing and implementing smart campuses?	To uncover obstacles and knowledge gaps for comprehensive DT strategies.

Materials and Methodology

The search used Scopus, Web of Science, and IEEE Xplore, with the search fields shown in Table 3. The keywords have been adopted for collecting articles like "digital transformation," "smart campus," and "higher education", as depicted in Table 4. The combination of using Boolean operators (AND, OR) in Table 5 to improve data collection precision across databases has been used. Table 6 also discussed the Inclusion criteria prioritized peer-reviewed, English-language Q journal articles and CORE-ranked conference papers from developing countries, excluding studies from developed nations to maintain contextual relevance. Of the 87 selected studies, 56% were journal publications, and 44% were conference proceedings, as shown in Figure 2.

Table 3: Database Sources and Search Fields

Database	Source	Search Fields
DB-1	Web of Science	Abstract, Title, Keywords
DB-2	Scopus	Abstract, Title, Keywords
DB-3	IEEE Xplore	Abstract, Title, Keywords

In developing countries, a high number of research and development efforts in DT within HEIs have been reported. As shown in Figure 4, China contributes the most research articles in the domain of smart campus education, followed by Brazil, Saudi Arabia, and others. The study also analyzed the publishers of the selected studies, with Springer emerging as the leading publisher, accounting for the largest share of articles between 2021 and 2025, as illustrated in Figure 3.

Table 4: Search String

No.	Search DB	Search DB
1	“digital transformation” OR “smart education”	“higher education” OR “university” OR “college”
2	“smart campus” OR “digital campus”	“design” OR “infrastructure” OR “implementation”
3	“AI” OR “Internet of Things” OR “big data” OR “Blockchain”	“higher education” OR “smart campus”
4	“stakeholders” OR “students” OR “educators” OR “policymakers”	“digital transformation” OR “smart campus”
5	“challenges” OR “barriers” OR “gaps”	“digital transformation” OR“ smart campus”

Quality Assessment

In this section, the paper is thoroughly scrutinized, its scope and inclusion/exclusion criteria are identified, and the article provides clear answers to our questions. Regarding quality assessment, each primary study was evaluated against a predefined checklist of five quality questions (QA1–QA5), as outlined in Table 6. For every question, we assigned Yes = 1, Partial = 0.5, and No = 0; the per-question cores were then summed to produce an overall quality score for each study on a 0–5 scale. The studies and their relevant score are shown in Table 7. We considered a quality assessment scale of 3 or higher, which aligns well with our paper's theme, and its distribution is highlighted in Figure 5.

Table 5: Combination of strings for searching databases

No	Combination of Strings
1	(1, B1) AND (1, B2)
2	(2, B1) AND (2, B2)
3	(3, B1) AND (3, B2)
4	(4, B1) AND (4, B2)
5	(5, B1) AND (5, B2)
6	(1, B1) OR (2, B1) OR (3, B1) OR (4, B1) OR (5, B1) AND (1, B2) OR (2, B2) OR (3, B2) OR (4, B2) OR (5, B2)

Table 6: Inclusive and exclusive criteria

No.	Inclusive criteria	Exclusive criteria
1	Studies focusing on digital transformation, smart campus, or smart education in higher education institutions.	Studies unrelated to digital transformation or smart campus topics.
2	Articles written in English.	Articles written in other languages.
3	Peer-reviewed journal articles (Q1 only) and conferences listed in the CORE ranking.	Articles published in Q2, Q3, Q4 journals or non-ranked sources.
4	Studies conducted in or focused on developing countries.	Studies focused on developed countries
5	Full-text available and published articles.	Articles in press, unpublished, or missing essential metadata (DOI, author, keywords, EID.
6	Methodologically, sound studies that passed quality assessment screening.	Articles that do not meet quality assessment criteria.

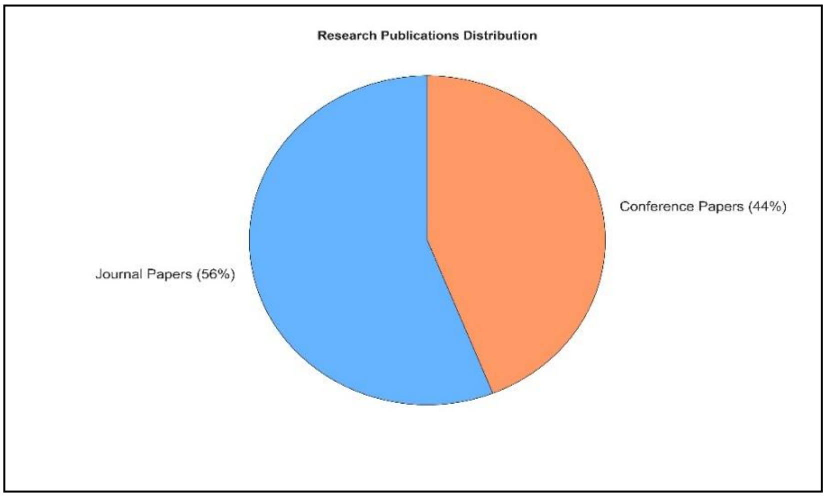

Fig. 2: Distribution of selected papers

FINDINGS AND DISCUSSION

This review synthesizes evidence from 87 scholarly contributions across 32 developing countries that examine how Industry 4.0 (IR4.0) technologies are being embedded in the digital transformation of higher education, with smart campus development as a central focus. The finding that cuts across all five research questions is unlikely to be comfortable for technology-focused researchers. In these contexts, determining whether smart campus adoption succeeds or fails is not based solely on the technology's viability. It has a great deal to do with the conditions in which institutions are trying to use them. Literature keeps treating the socio-technical dimensions as background considerations, which turn out, consistently, to be the main event. The discussion is framed around five guiding research questions:(Q1) conceptualizations of IR4.0 integration, (Q2) key design considerations, (Q3) models, frameworks, and methodological approaches, (Q4) the roles and perspectives of diverse stakeholders, and (Q5) unresolved challenges and research gaps. Rather than treating the literature descriptively, the analysis offers a comparative lens, highlighting conceptual strengths, identifying recurring shortcomings, and showcasing how particular studies attempt to address underexplored deficiencies.

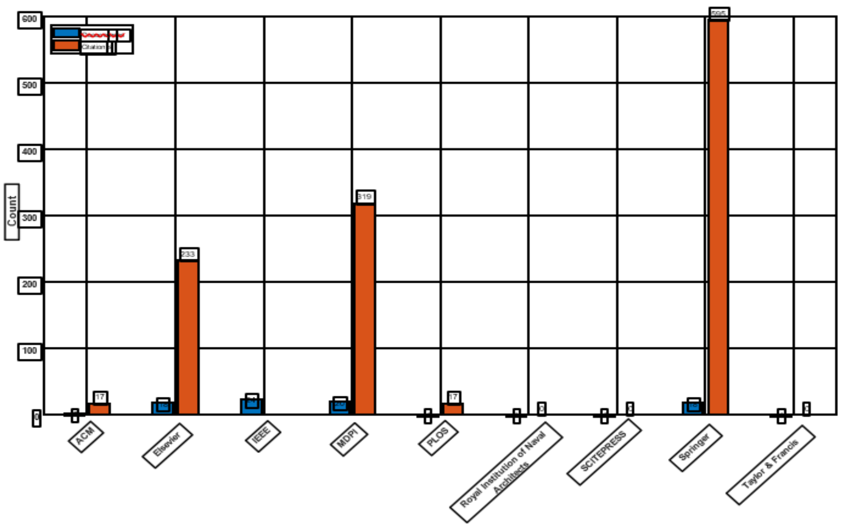

Fig. 3: Publisher and its Journal Citations

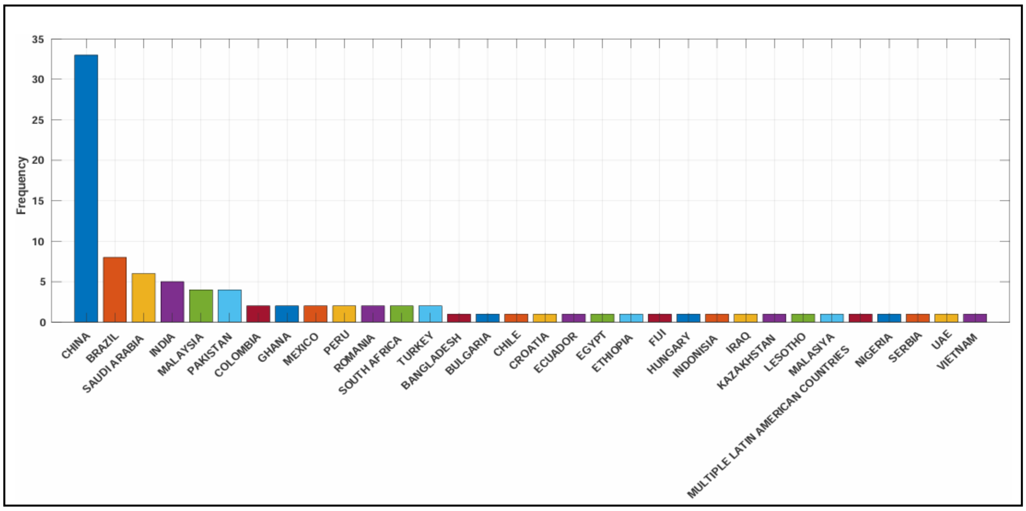

Fig. 4: Country Distribution

Table 7: Quality assessment

Study	QA1	QA2	QA3	QA4	QA5	Total Score
S1, S6, S8, S10, S12, S15, S16	1	0.5	0.5	0.5	1	3.5
S2	1	0	0.5	0.5	1	3
S3	0.5	0.5	0.5	0.5	1	3
S4, S14, S20, S23, S31, S33, S35, S87	1	1	1	0.5	1	4.5
S5, S7, S9, S40, S55, S62, S65, S70, S74	1	0.5	0.5	1	1	4.0
S11, S63	0.5	1	1	1	0.5	4
S13, S24, S37, S39, S41, S71, S78, S82	1	0.5	1	1	1	4.5
S17, S36, S38, S42, S59	0.5	0.5	1	1	1	4
S19, S43, S45	1	1	1	0.5	0.5	4
S22, S32, S26, S30, S34, S77, S80, S84	1	1	1	1	1	5
S27	0.5	1	1	1	0.5	4.0
S28	0.5	0	1	0.5	1	3
S29, S44	1	1	1	1	0.5	4
S46	1	0.5	1	0.5	1	4.0
S47, S64, S66, S69, S75, S76, S83	1	0.5	0	1	1	3.5
S48	0.5	0.5	1	0.5	1	3.5
S49	1	0.5	0	0.5	1	4
S21, S51, S53	1	0.5	1	0.5	1	4
S50	1	0.5	1	0.5	1	4
S52	0.5	0.5	1	0.5	0.5	3
S54, S60	1	0.5	1	0.5	0.5	3.5
S55	1	0.5	0.5	0.5	1	3.5
S57, S58	1	0.5	0.5	0.5	0.5	3
S58	1	0.5	0.5	0.5	0.5	3
S59	0.5	0.5	1	1	1	4
S60	1	0.5	1	0.5	0.5	3.5
S61, S67, S72	1	0.5	0.5	1	0.5	3
S73	1	0.5	0.5	1	0.5	3.5
S79	1	1	0.5	0.5	1	4
S81	0.5	0.5	0.5	0.5	1	3
S85, S86	1	1	0	1	1	4

Fig. 5: Quality assessment scores distribution

To strengthen coherence and cumulative insight, the findings are clustered thematically across domains such as AI and machine learning, blockchain applications, IoT, and digital twinning technologies, pedagogical innovation, sustainability, and governance or policy strategies, thereby linking theoretical advancements with actionable pathways for implementing smart campus initiatives.

These findings advance a progressive vision of smart camera transformation, conceptualized as an inherently socio-technical process. The analysis highlights the imperative for governance and strategic decision-making to evolve in parallel with the deployment of technological infrastructure, while also stressing the early incorporation of safeguards for data protection and interoperability. Equally, it emphasizes that investments should be guided not only by technical efficiency but also by pedagogical value creation and the overall quality of user experience. Each research question concludes with concrete recommendations that align with well-established evidence, expose critical knowledge gaps, and offer practical roadmaps or maturity models that translate strategic aspirations into measurable outcomes, particularly relevant for institutions in developing regions. This study establishes a robust platform, including the thesis's operational framework, that informs subsequent recommendations on policy formulation, architectural design, and organizational change management in higher education.

Integration of IR Technologies

Q1: What perspectives on the integration of IR technologies (advanced technologies) for DT in higher education (the smartization process) are conceptualized in the study?

The 87 studies conceptualize IR4.0 technology integration through five primary perspectives:

Strategic Transformational Perspective:

Many reviewed studies frame integrating IR technologies into higher education as a strategic and transformational undertaking. These works emphasize the necessity of institutional vision, leadership commitment, and structured planning to successfully implement digital transformation (DT) and smart campus initiatives. The Strategic Transformation perspective is that getting closer to the socio-technical reality, this SLR keeps returning to Mei, Feng [6], Li, Sun [17], Mohamed Hashim, Tlemsani [26], Mijač, Jadrić [65], Asamoah, Darko [70], Yıldırım and Tunçalp [71], Anggadwita, Indarti [72], Xie, Zhan [73]. For instance, (S1) Mijač, Jadrić [65] and (S2) Li, Sun [17] argue that the success of smart campus adoption is deeply embedded in how universities design their information systems and align them with organizational goals. This includes digital governance mechanisms and leadership-driven innovation strategies. (S16) Asamoah, Darko [70] and (S17) Yıldırım and Tunçalp [71] expand this view by presenting national or institutional policy frameworks that position higher education as a pivotal sector for IR4.0 deployment, thus linking transformation to public sector innovation. Several studies also underscore the role of change management in enabling transformation. (S12) Mohamed Hashim, Tlemsani [26] highlight how the lack of a clear digital strategy or executive leadership can stall transformation, while (S5) Anggadwita, Indarti [72] demonstrate how institutional agility in responding to crises (such as COVID-19) accelerated digital adaptation across Indonesian HEIs. These findings support the argument that digital transformation should not be perceived as a purely technical upgrade but rather as a redefinition of educational purpose, driven by strategic priorities and organizational commitment.

(S18) Xie, Zhan [73] further identify decision-making structures and executive readiness as critical factors influencing DT success in developing contexts. Collectively, these studies suggest that HEIs in developing countries must approach IR technology adoption not as isolated projects, but as part of an overarching transformative agenda. This perspective aligns digital investment with institutional missions, long-term vision, and sustainable development goals.

Collectively, these studies suggest that HEIs in developing countries must approach IR technology adoption not as isolated projects, but as part of an overarching transformative agenda. This perspective aligns digital investment with institutional missions, long-term vision, and sustainable development goals.

Technical Operational Perspective:

The reviewed literature often presents the integration of Industry 4.0 technologies in higher education from a technical and operational viewpoint. This line of work focuses on developing digital infrastructure, platforms, and cyber-physical systems to support smart campus initiatives. This perspective dominates the literature [32, 35, 65, 72-77]. For example, (S1) Mijač, Jadrić [65] and (S4) Mishra, Rani [74] discuss how system architecture and design enable digital service delivery in universities, with particular attention to scalability and integration.

The studies also examine specific technologies. Blockchain (S9) Chen, Zou [75], artificial intelligence (S10) Zheng, Wang [76], and machine learning (S11) Sneesl, Jusoh [35] are presented as tools that enable automated decision-making, personalized learning, and efficient campus management. These technologies serve both as instruments for improving pedagogy and as building blocks of a smart campus ecosystem. (S9) Chen, Zou [75] further classify blockchain applications into three areas: authentication, certification, and transaction-level transparency, all of which are tied to operational integrity.

The role of IoT is also highlighted (S11) Sneesl, Jusoh [35] describes IoT infrastructure as central to real-time campus operations, enabling continuous data collection and interaction between digital and physical spaces. (S8) Wang, Li [77] stress that technical readiness must be aligned with drivers of digital transformation, noting that integrated infrastructure is key to moving beyond simple adoption toward meaningful transformation.

The collective evidence shows that smart campus development relies on strong digital foundations, modular technology deployment, and the smooth flow of operational data. Without these technical elements, strategic or pedagogical goals remain difficult to achieve in practice.

Pedagogical Perspective:

The reviewed studies also present a strong pedagogical perspective on the role of Industry 4.0 technologies in higher education. This view highlights how digital tools reshape teaching and learning, support personalized instruction, and introduce new curriculum models suited to smart campus environments [6, 35, 65, 71-73, 75, 76, 78]. For instance, (S1) Mijač, Jadrić [65] stresses that student-focused design and digital services must be guided by regular evaluation of learning outcomes. (S6) Mei, Feng [6] propose a competency-based approach, arguing that curricula should embed technologies such as artificial intelligence and learning analytics to prepare graduates for emerging labor markets.

Several works focus on technology-enabled learning platforms. (S11) Sneesl, Jusoh [35] show how machine learning and adaptive algorithms create intelligent systems that personalize instruction and improve learning paths. (S9) Chen, Zou [75] describes blockchain as a tool for transparent, secure assessment that supports fair and accountable educational practices. (S5) Anggadwita, Indarti [72] discusses how the COVID-19 pandemic pushed universities in Indonesia to adopt digital tools quickly, forcing greater agility in teaching methods.

(S26) Guo and Xia [78] Add that big data analytics can reveal patterns in student learning behavior, enabling more flexible and responsive instructional models. Taken together, these studies suggest that IR technologies do more than enhance existing teaching practices. They require a rethinking of pedagogy, curriculum structures, and assessment approaches to align with the demands of digital transformation.

Ethical–Behavioral Perspective:

The reviewed literature also addresses the ethical and behavioral aspects of digital transformation in higher education. These studies move beyond technical feasibility and raise issues of privacy, digital rights, trust, and responsible use [35, 43, 75, 77-82]. (S9) Chen, Zou [75] explain that blockchain platforms can improve transparency and security, but they also create new questions about data ownership and accountability. (S15) Wang, Kang [79] examines how students perceive risks in smart campus settings, showing that concerns about surveillance and data misuse affect their acceptance of digital systems.

Digital behavior forms another key focus. (S26) Guo and Xia [78] analyze learning patterns to identify engagement trends, but they also highlight risks such as algorithmic bias, over-surveillance, and manipulation of learning behavior. (S11) Sneesl, Jusoh [35] and

(S35) Mohd Rahim, A. Iahad [80] stress that digital literacy, user empowerment, and behavior management are essential to the ethical use of AI tools such as chatbots and intelligent agents.

Cybersecurity studies add further insight. (S24) Arshad, Azam [81] and (S30) Abdalzaher, Fouda [82] argue that secure, trustworthy digital environments are critical to the success of smart campuses. They caution that weak security controls may lead to data breaches and increased exposure to cyber threats. The collective evidence suggests that ethics and behavior cannot be treated as secondary concerns. They must be built into smart campus design as core principles. Without clear attention to trust, user acceptance, and data justice, the long-term sustainability of IR4.0-based campuses is unlikely.

Sustainability-Oriented Perspective:

The reviewed literature also points to sustainability as a critical dimension of digital transformation in higher education. This perspective treats smart campus initiatives not only as technical projects but as tools to advance long-term societal goals, including the United Nations' Sustainable Development Goals (SDGs) Mei, Feng [6], Adarkwah, Okagbue [7], Truong and Diep [34], Sneesl, Jusoh [35], [36, 65], Mishra, Rani [74]. (S1) Mijač, Jadrić [65] and (S3) Adarkwah, Okagbue [7] argue that universities should act as drivers of sustainable innovation, leveraging digital technologies to support modernization while promoting inclusive, future-oriented education systems.

Several studies focus on curriculum design. (S6) Mei, Feng [6] call for the integration of sustainability competencies, ensuring that students become both digitally skilled and prepared to contribute to green and resilient economies. (S7) Truong and Diep [34] extend this argument by proposing policy frameworks that align higher education with national sustainability agendas, supported by digital infrastructure.

Operational perspectives also receive attention. (S4) Mishra, Rani [74] and (S65) Salas-Pilco and Yang [36] show how digital tools improved institutional resilience during the COVID-19 pandemic, enabling both continuity of education and system adaptability. (S11) Sneesl, Jusoh [35] connect IoT systems to environmental sustainability, noting their potential for energy optimization and smart facility management.

The overall evidence indicates that sustainability should be treated as a guiding principle in digital transformation, rather than an additional objective. For institutions in developing contexts, this means framing smart campus projects within wider strategies for sustainable education and environmentally responsible growth.

Essential Factors in Smart Campus

Q2: What are the essential factors for designing a smart campus in higher education?

Infrastructure Factors:

There are multiple essential factors for designing a smart campus, as shown in Figure 6.

1. **Infrastructure Foundations:** Studies such as (S14) dos Santos Sá, do Nascimento da Silva [83], (S17) Yıldırım and Tunçalp [71], (S18) Xie, Zhan [73], (S20) Zarpellon,

Arenas [84] , (S21) Lu, Hu [85], (S82) Ferreira, Oliveira [86], (S8) Wang, Li [77], and (S30) [82] emphasize the importance of robust campus infrastructures. These include IoT meshes, cloud edge orchestration, and digital twins for real-time monitoring and simulation. With evidence from (S14) dos Santos Sá, do Nascimento da Silva [83] and (S17) Yıldırım and Tunçalp [71], hardware-heavy IoT and digital-twin systems create high costs and ongoing maintenance burdens. Cloud-centric designs, noted in (S8) and (S21), further increase bandwidth use and operational expenses. For recommendations, studies (S2&S86) suggest cloud–edge balancing with optimized workload placement. Others, such as (S47) Carlos-Mancilla, Luque-Vega [87], propose relying on existing WiFi and commodity infrastructure for sensing to reduce the need for specialized hardware.

2. **Interoperability:** Interoperability is a key challenge addressed in (S4) Mishra, Rani [74], (S71) Llerena-Izquierdo, Mendez-Reyes [88], (S64) Al-Zahrani and Alasmari [89], (15) Wang, Kong [90], (S16) Asamoah, Darko [70], (S18) Xie, Zhan [73], (S19) Tleubayeva, Mitroshina [91], and (S20) Zarpellon, Arenas [84]. These studies explore API-centric platforms and standards that integrate learning management systems (LMS), facility services, and mobility systems. With evidence from S4 and S64, fragmented platforms slow down integration and raise the risk of vendor lock-in. For recommendations, researchers (S20, S18, S16) promote modular, standards-based architecture. Others (S4, S71, S15) stress the need to enforce ontology and API governance to ensure consistent data exchange.
3. **Data Security and Privacy:** Security remains a central concern in (S82) Ferreira, Oliveira [86], (S15) Wang, Kang [79], (S16) [70], (S72) Rana, Siddiqee [92], (S64) Al-Zahrani and Alasmari [89], (S63) Alotaibi [64], and (S11) Sneesl, Jusoh [35]. Approaches include encryption, access control, and privacy-aware frameworks. Based on evidence from (S15) and (S72), security stacks add operational complexity and require specialized staff. For recommendations, researchers (S82, S64, S11) suggest lightweight, staged security patterns. Others propose progressive controls to balance protection with usability.
4. Analytics and Decision Support: Several studies (S2) Li, Sun [17], (S16) Asamoah, Darko [70], (S63) Alotaibi [64], (S9) Chen, Zou [75], (S11) [35], (S26) Guo and Xia [78], (S78) Okoye, Arrona-Palacios [13], and (S12) Mohamed Hashim, Tlemsani [26] show how sensor, LMS, and operations data can feed dashboards and predictive decision pipelines. With evidence from (S2), (S9), and (S11), analytics pipelines remain fragile without consistent data models. For recommendations, studies (S2, S63, S26, S78) emphasize stronger data standardization and ontology alignment. They also call for governance frameworks that support the long-term sustainability of analytics.
5. Real-time processing: The Low-latency performance is emphasized in several studies, including (S14) dos Santos Sá, do Nascimento da Silva [83], (S17) Yıldırım and Tunçalp [71], (S18) Xie, Zhan [73] , (S21) Lu, Hu [85] , (S29) Chen, Guo [32], (S86) Ding, Mei [93], (S87), and (S38) Ouyang, Zheng [31]. These works point to edge pipelines and streaming frameworks as key solutions. For weaknesses, (S29) and (S86) underline that sustaining real-time services requires specialized expertise and ongoing optimization. In response, studies (S21) Lu, Hu [85], (S86) Ding, Mei [93]

recommend balancing workloads across cloud and edge nodes. Others highlight the use of lightweight, adaptive edge services to preserve responsiveness even when resources are constrained.

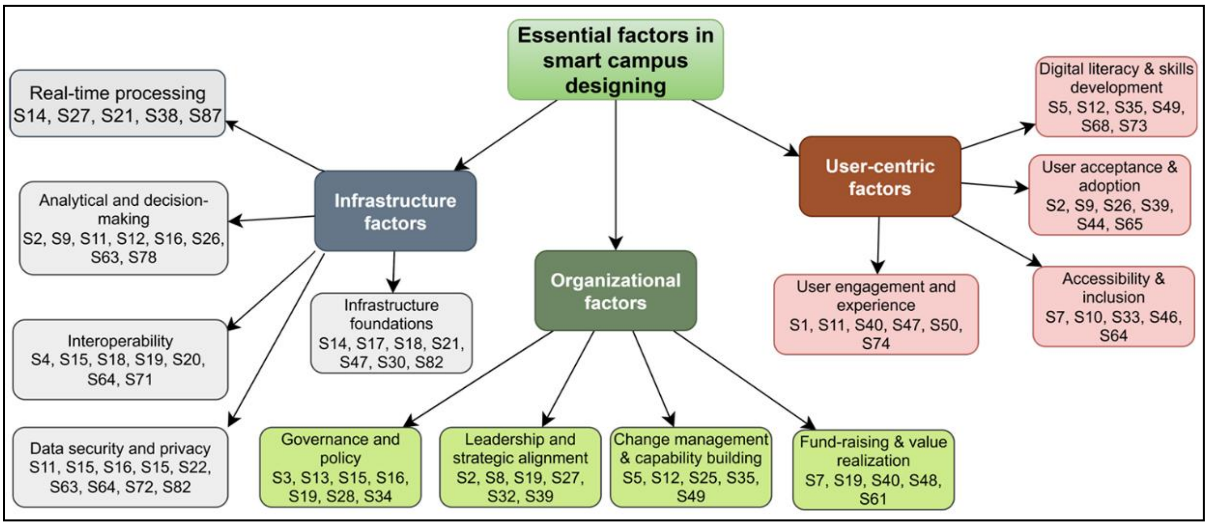

Fig. 6: Essential factors in smart campus designing

Organizational Factors:

This category focuses on the institutional and strategic elements that support smart campus projects, ensuring their sustainability and alignment with long-term objectives.

1. **Governance& Policy:** The importance of governance, policy alignment, and standardization for stable and scalable operations is emphasized across studies, such as (S3) Adarkwah, Okagbue [7], (S13) Berdnikova, Smagina [94], (S15) Wang, Kang [79], (S16) Asamoah, Darko [70], (S19) Tleubayeva, Mitroshina [91], (S28) Fernandez, Dhingra [20], (S34) Essel, Vlachopoulos [95] and (S44) Xiao, Jiao [96]. For instance, (S15) Wang, Kang [79] highlights the role of national policy alignment in supporting technology adoption, while (S16) Asamoah, Darko [70] and (S19) Tleubayeva, Mitroshina [91] emphasize the importance of institutional policies that balance innovation and compliance. For weaknesses, (S13) Berdnikova, Smagina [94] and (S19) Tleubayeva, Mitroshina [91] point out that many governance approaches are reactive, often addressing gaps only after systems are deployed. Similarly, (S28) Fernandez, Dhingra [20] identifies the absence of centralized oversight as a cause of fragmented and inconsistent projects. In response, (S16) introduces an integrated model that connects data policies with API and architecture standards to reduce fragmentation, while (S34) shows that embedding digital transformation (DT) goals into institutional statutes ensures continuity across leadership cycles, ultimately strengthening governance resilience.
2. **Leadership & Strategic Alignment:** Leadership commitment and alignment with institutional missions are highlighted in studies such as (S2) Li, Sun [17], (S8) Wang, Li [77], (S19) Tleubayeva, Mitroshina [91], (S27) Dong, Cao [97], (S32) Ferreira, Oliveira [98], and (S39) Jokhan, Chand [99]. For example, (S2) Li, Sun [17] link leadership vision to targeted investments in enabling technologies, while (S27) Dong

et al. (2023) underscore the role of strategic partnerships in building shared infrastructure. However, weaknesses remain: (S8) Wang, Li [77] and (S39) Jokhan, Chand [99] show that strategic plans are often broad and lack measurable goals, while (S19) notes that leadership turnover can disrupt the progress of long-term programs. To address these gaps, (S32) Ferreira, Oliveira [98] demonstrate the effectiveness of steering committees in sustaining continuity despite leadership changes, and (S2) employs balanced scorecards to tie technology adoption directly to institutional and academic KPIs, thereby ensuring accountability and sustained progress.

3. **Change Management & Capability Building:** Preparing people and processes for change is discussed in studies such as (S5) Anggadwita, Indarti [72], (S12) Mohamed Hashim, Tlemsani [26], (S25) Muñoz, Mancipe [100], (S35) Mohd Rahim, A. Iahad [80], (S49) Jain and Chawla [101], and (S68) Dabis and Csáki [102]. (S5) Anggadwita, Indarti [72] highlights the importance of ongoing stakeholder engagement, while (S35) and (S49) emphasize digital literacy training for faculty and staff. Nonetheless, challenges persist, including limited training budgets (S25, S68), which restrict long-term capacity building; one-off workshops (S12) fail to create lasting impact, and resistance to change (S35) often arises when benefits are not clearly communicated. To address these issues, (S5) proposes embedding change management throughout the project lifecycle, with funding for continuous training, while (S49)'s train-the-trainer model cultivates internal champions who sustain and extend capacity-building efforts.
4. **Funding & Value Realization:** Studies such as S7 Truong and Diep [34], S19 Tleubayeva, Mitroshina [91], S40 Chivu, Popa [103], S46 Razzaq, Mahar [104], and S61 de Moraes, Pisani [105] emphasize the importance of long-term financing and transparent value assessment. S40 demonstrates how cost–benefit analysis supports IoT and analytics investments, while S61 de Moraes, Pisani [105] develops performance indicators that track value creation beyond financial returns. However, funding models in S19 and S46 often rely on short-term grants, undermining continuity, and ROI evaluations in S7 tend to focus narrowly on operational savings while overlooking wider institutional benefits. To overcome these limitations, S40 recommends lifecycle costing and phased investment approaches that ease financial pressures, while S61 expands evaluation frameworks by integrating both quantitative KPIs and qualitative measures, including student satisfaction and institutional innovation.

User-Centric Factors:

This category addresses the human-facing aspects of smart campus design, ensuring that systems are usable, inclusive, and aligned with the needs and capabilities of diverse stakeholders.

1. **Digital Literacy & Skills Development:** Studies such as S5 Anggadwita, Indarti [72], S12 Mohamed Hashim, Tlemsani [26], S35 Mohd Rahim, A. Iahad [80], S49 Jain and Chawla [101], S68 Dabis and Csáki [102], and S73 Ayanwale and Molefi [106] emphasize the importance of developing digital competencies among students, faculty, and staff to maximize the benefits of smart campus technologies. While S35

and S73 highlight structured training for academic and administrative staff, and S5 embeds skill development into the early implementation phases, many initiatives still fall short. Short-term or one-off training programs, as noted in S12 and S68, often fail to create lasting capabilities, while faculty development is sometimes sidelined in favor of student-focused initiatives (S35). To address these weaknesses, S49 introduces a continuous professional development model that integrates technology training with pedagogical upskilling, enabling staff to adapt to evolving tools and practices. Similarly, S5 links digital literacy programs to practical use cases, thereby enhancing immediate relevance and encouraging greater uptake across stakeholder groups.

2. **User Acceptance & Adoption:** Research such as S2 Li, Sun [17], S9 Chen, Zou [75], S26 Guo and Xia [78], S39 Jokhan, Chand [99], S44 Xiao, Jiao [96], and S65 Salas-Pilco and Yang [36] explores factors shaping technology acceptance, focusing on perceived usefulness, ease of use, and trust. For instance, S26 applies the UTAUT framework to examine behavioral intentions toward smart services, while S9 integrates blockchain to enhance trust in academic records. However, several adoption models, such as those in S39 and S44, rely heavily on perception-based surveys without validating whether technologies are sustained in actual practice, and trust-building approaches like blockchain (S9) remain technically demanding, creating barriers to uptake. To address these gaps, S26 strengthens acceptance analysis by combining behavioral modeling with pilot trials, while S65 employs incremental rollouts and feedback loops to gradually build confidence and reduce resistance.
3. **Accessibility & Inclusion:** Studies such as S7 Truong and Diep [34], S10 Zheng, Wang [76], S33 Cruz, Ferreira [107], S46 Razzaq, Mahar [104], S53 da Silva Júnior, Casanova [108], and S64 Al-Zahrani and Alasmari [89] highlight the importance of designing systems that are inclusive of diverse users, including people with disabilities, varying levels of digital literacy, and different socio-economic backgrounds. For example, S46 and S53 emphasize universal design principles, while S33 employs multilingual interfaces to broaden accessibility. A recurring weakness, however, is that accessibility is often considered late in the development process, reducing its effectiveness, as observed in S10 and S64. Furthermore, some projects, such as S7, lack a systematic evaluation of their accessibility outcomes. These limitations can be mitigated by approaches such as S46, which integrates accessibility from the requirements stage to ensure compliance with universal design, and S33, which develops multilingual support alongside core features to maintain consistency and inclusivity.
4. **User Engagement & Experience:** Research such as S1 Mijač, Jadrić [65], S11 Sneesl, Jusoh [35], S40 Chivu, Popa [103], S47 Carlos-Mancilla, Luque-Vega [87], S50 Aspilcueta Narvaez, Núñez Fernández [109], and S74 Zhou [110] explores strategies to improve engagement through personalized services, intuitive interfaces, and responsive feedback mechanisms. For instance, S47 applies IoT-based interactive systems to support campus navigation, while S1 develops adaptive dashboards tailored to user preferences. A common weakness is that engagement tools can unintentionally increase cognitive load, as seen in S40 and S50, while real-time feedback systems such as S74 may overwhelm users if not properly filtered. To

address these issues, S11 demonstrates how iterative, user-centered design can refine features to match user needs, and S50 shows that context-aware guidance can adapt to user profiles, reducing overload and improving overall usability.

Frameworks and Models for Smart Campus Designing

Q3: What approaches, models, or frameworks are proposed for smart campus design?

The literature introduces many approaches, models, and frameworks for smart campus development as depicted in Figure 7. These works cover technical, governance, pedagogical, and operational areas. Some studies focus on broad conceptual designs, while others present detailed architectures, IoT or digital twin systems, data analytics, and governance structures. Practical contributions include maturity models, assessment tools, and phased implementation roadmaps. The following discussion groups these studies into 10 categories, each with its focus, common limitations, and proposed strategies to address them.

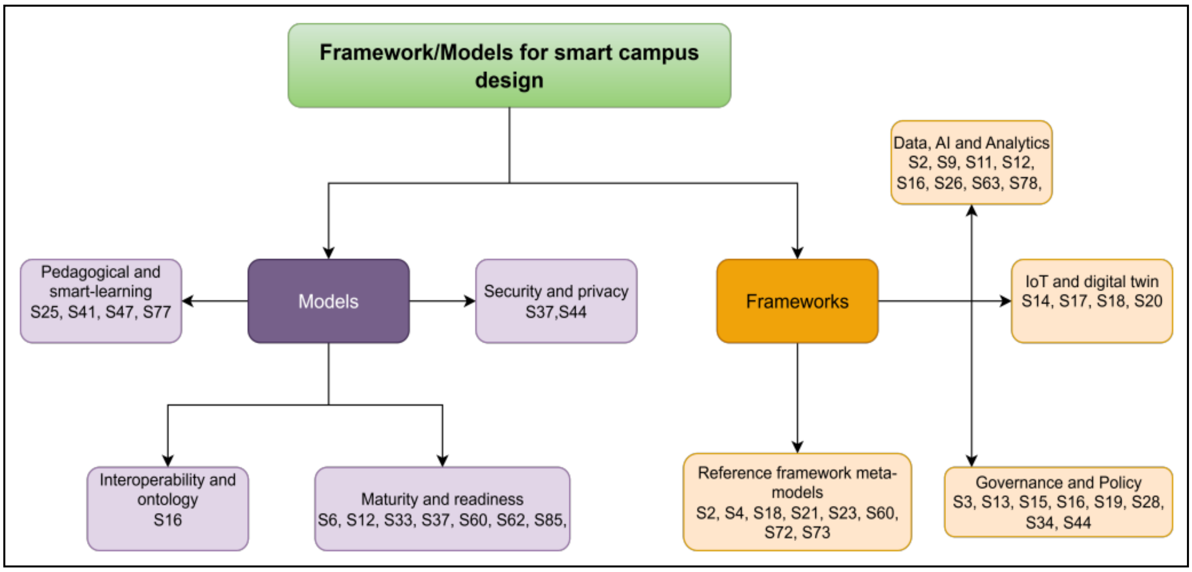

Fig 7: Frameworks and models for smart campus designing

Reference Frameworks & Meta-models:

Studies such as S2 Li, Sun [17], S72 Rana, Siddiqee [92], S18 Xie, Zhan [73], S21 Lu, Hu [85], S23 Ruan, Yang [111], S4 Mishra, Rani [74], S73 Ayanwale and Molefi [106], and S60 Zhang, Zhang [55] introduce conceptual frameworks and meta-models that define capability layers such as data, analytics, applications, and services, and explain how these interact to align technology with educational and institutional goals. However, many of these frameworks remain at a high-level conceptual stage, with limited implementation detail or empirical validation, as highlighted in S72 and S73. This limits their practical utility. To bridge this gap, more applied models, such as S2 and S18, embed frameworks into governance structures, APIs, and data contracts, ensuring they are not only theoretically sound but also scalable and replicable in institutional settings.

Platform and Architectural Models:

Research such as S20 Zarpellon, Arenas [84], S10 Zheng, Wang [76], S24 Arshad, Azam [81], S27 Dong, Cao [97], S74 Zhou [110], S36 Bjelobaba, Paunovic [112], S44 [96], and S47 Carlos-Mancilla, Luque-Vega [87] present detailed architectural designs, including microservices, event-driven, and service-oriented models that enable diverse campus services such as learning platforms, safety systems, and facilities management to connect through a shared backbone. A recurring weakness, however, lies in the complexity of runtime management and the potential risk of vendor lock-in when proprietary solutions dominate, as seen in S10 and S24. To counter this, modular and open designs supported by API gateways and message buses, as demonstrated in S20 and S27, provide a more scalable and adaptable pathway. These approaches not only simplify integration but also minimize long-term dependence on a single vendor, making the architecture more sustainable.

IoT and Digital Twin Frameworks:

Studies including S14 dos Santos Sá, do Nascimento da Silva [83], S17 Yıldırım and Tunçalp [71], S18 Xie, Zhan [73], and S20 Zarpellon, Arenas [84] investigate IoT-based frameworks and digital twin models for mobility, building use, and energy management, integrating sensing, simulation, and operational control. A key weakness in these approaches is the high dependence on hardware and the significant integration costs when linking with existing building systems, as reported in S14 and S17. This challenge can be mitigated through incremental development strategies and the reuse of current infrastructures, such as Wi-Fi and retrofitted gateways, combined with open data standards, as demonstrated in S18 and S20. Such approaches lower costs while maintaining scalability and interoperability.

Data, AI, and Analytics Frameworks:

Studies such as S2 Li, Sun [17], S16 Asamoah, Darko [70], S63 Alotaibi [64], S9 Chen, Zou [75], S11 Sneesl, Jusoh [35], S26 Guo and Xia [78], S78 Okoye, Arrona-Palacios [13], and S12 Mohamed Hashim, Tlemsani [26] propose analytics pipelines and AI-driven systems to support learning analysis, institutional prediction, and data-informed decision-making. These systems typically use dashboards, automated alerts, and KPI feedback loops to close the data-action gap. A recurring weakness, however, lies in data inconsistency and limited model transparency, which hinder institutional trust and adoption (S9, S11). To address these barriers, studies such as S16, S2, S63, and S26 emphasize the use of ontologies, API governance, and hybrid analytics approaches, thereby improving both reliability and interpretability.

Governance and Policy Frameworks:

Research such as S3 Adarkwah, Okagbue [7], S13 Berdnikova, Smagina [94], S15 Wang, Kang [79], S16 Asamoah, Darko [70], S19 Tleubayeva, Mitroshina [91], S28 Fernandez, Dhingra [20], S34 Essel, Vlachopoulos [95], and S44 Xiao, Jiao [96] highlight governance mechanisms that establish decision-making rights, compliance processes, and stewardship roles to minimize duplication of efforts. A common weakness, however, is that many of these approaches remain reactive and insufficiently embedded in institutional policies, resulting in fragmented, short-lived initiatives (S13, S28). To overcome this, studies such as S16 and S34 demonstrate that aligning governance with data standards and formally embedding it into institutional statutes not only strengthens continuity but also ensures that governance practices persist beyond leadership cycles.

Maturity and Readiness Models:

Studies including S62 Alotaibi and Alshehri [63], S6 Mei, Feng [6], S33 Cruz, Ferreira [107], S60 Zhang, Zhang [55], S85 [113], S12 Mohamed Hashim, Tlemsani [26], S78 Okoye, Arrona-Palacios [13], and S37 Son-Turan [114] propose readiness and maturity models to benchmark campus capabilities. A key limitation is that many models rely heavily on surveys, which can introduce perception bias and produce results that do not fully align with operational realities (S12, S33). To address this, S60 and S85 suggest combining survey data with telemetry and audit results to provide more reliable and actionable assessments of campus readiness.

Interoperability and Ontology Models:

S16 Asamoah, Darko [70] presents ontology-based and API-first models to ensure consistent data exchange between systems, such as learning platforms and facilities management systems. However, a limitation is the lack of clear metadata stewardship and version control. To overcome this, S16 recommends assigning dedicated data steward roles and maintaining versioned API catalogs, thereby enhancing the long-term sustainability and reliability of data exchanges.

Security and Privacy Models:

Studies such as S37 Son-Turan [114] and S44 Xiao, Jiao [96] develop privacy and security models, including zero-trust patterns and privacy-preserving analytics. A key challenge is the high operational complexity and unclear trade-offs, which can hinder adoption. To address this, layered controls and clear privacy-by-design metrics are recommended to improve practical usability and adoption.

Pedagogical and Smart Learning Models:

Research such as S25 Muñoz, Mancipe [100], S41 Garg, A [115], and S47 Carlos-Mancilla, Luque-Vega [87] connect campus infrastructure with teaching through adaptive learning, AR/VR, and context-aware guidance. Weaknesses include a lack of curricular integration and limited testing (S41, S77). Co-design with faculty and stronger evaluation methods (S25, S47) help enhance pedagogical impact and scalability.

Implementation Methods and Roadmaps:

Studies such as S60 Zhang, Zhang [55], S85 Sáez, Morales [113], S6 Mei, Feng [6], S62 Alotaibi and Alshehri [63], S78 Okoye, Arrona-Palacios [13], S12 Mohamed Hashim, Tlemsani [26], S33 Cruz, Ferreira [107], and S37 Son-Turan [114] propose implementation methods, including phased rollouts and design science approaches. However, many roadmaps are generic and overlook local constraints such as legacy systems or limited resources (S6, S12). Context-sensitive roadmaps with dependency mapping and clearly defined KPIs (S60, S85, S62) improve feasibility and ensure smoother implementation.

Key Stack Holders in HEI's

Q4: Who are the key stakeholders or beneficiaries affected by smart campus design?

In this study, we extract the multiple stakeholders and beneficiaries from selected studies, as shown in Figure 8.

Students and Learners:

In studies S1, S2, S9, S11, S25, S33, S47, and S73, students are identified as the primary users of smart campus systems. With these tools, they gain personalized learning dashboards, guidance platforms, and easier access to mobility and safety services. In addition, the systems improve their educational opportunities and support more flexible learning. For weaknesses, some studies highlight risks of over-surveillance and the stress of constant monitoring. In response, researchers such as S9 and S25 suggest privacy-by-design approaches. They also recommend context-aware feedback and stronger student involvement in shaping system design.

Faculty/Educators:

Among studies such as S8, S10, S15, S27, and S36, educators are described as key drivers of digital adoption.

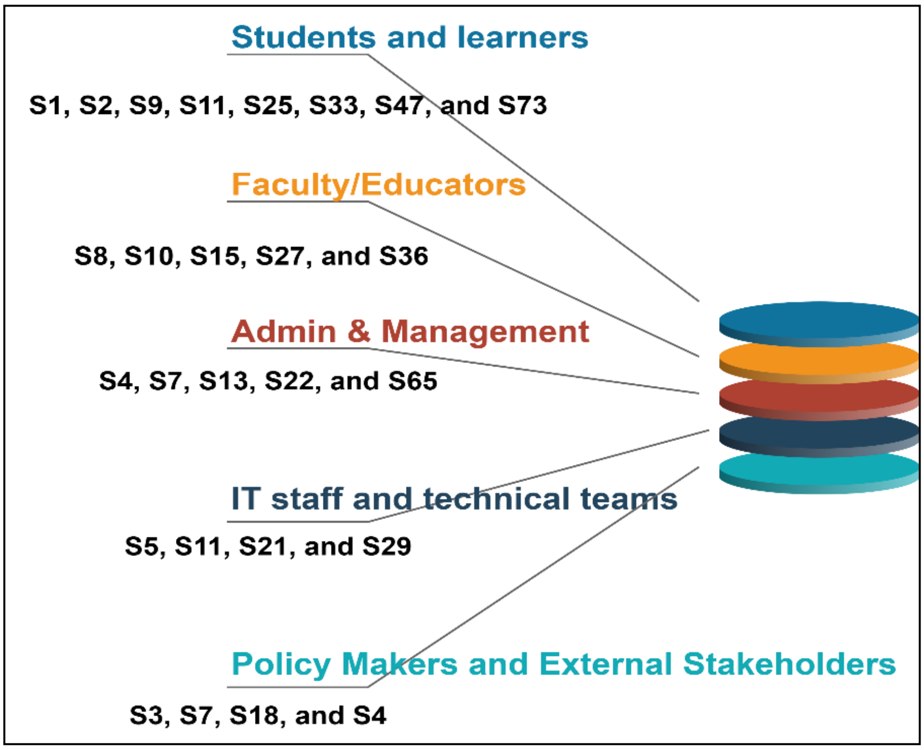

Fig.8: Keystack holders' consideration for smart campus designing

With smart campus platforms, they can use data-driven teaching, new pedagogical tools, and adaptive assessments. In this way, technology supports more flexible instruction and richer student interactions. For weaknesses, some studies note barriers such as a lack of digital skills and resistance to change. In S15 and S36, this challenge is addressed with professional development and faculty training programs. Other studies, like S10, also highlight the need for institutional incentives to encourage adoption.

Administrators and Management:

In studies such as S4, S7, S13, S15, and S65, administrators are shown as decision-makers who guide resource use and governance. With digital systems, they gain predictive analytics, efficient facility management, and stronger data-based policy support. These tools also allow better alignment with sustainability goals. For weaknesses, some studies point to high upfront costs and complex integration. In response, S7 and S65 recommend phased adoption, national-level frameworks, and sustainability-oriented planning.

IT Staff and Technical Teams:

Based on evidence from S5, S11, S21, and S29, IT staff appear to be enablers of system reliability and security. They manage IoT infrastructure, ensure interoperability, and build data protection measures. These roles are central to maintaining smooth and safe operations. For weaknesses, several studies highlight challenges such as limited budgets, rapid technological change, and cybersecurity threats. In S5 and S29, researchers suggest modular architecture, capacity-building, and partnerships with external providers to ease the burden.

Policy Makers and External Stakeholders:

In studies such as S3, S7, S18, and S41, policymakers and external actors are described as essential to scaling smart campus initiatives. They create governance frameworks, national strategies, and funding mechanisms that guide institutional efforts. With their support, higher education can align with long-term visions such as sustainability and digital inclusion. For weaknesses, some studies show a gap between policy design and local implementation. In response, S3 and S18 emphasize stronger coordination and bottom-up feedback from institutions.

CHALLENGES AND FUTURE DIRECTIONS

Q5: What are the Challenges and future direction for designing and implementing Smart Campuses?

The studies reviewed show that building and running smart campuses in higher education is a complex task shaped by multiple challenges. These include technical hurdles, organizational barriers, financial pressures, human factors, data-related issues, and sustainability concerns. Often, these challenges overlap; for instance, technical complexity may be exacerbated by limited budgets or a shortage of skilled staff, necessitating the adoption of integrated socio-technical solutions. While many works highlight the weaknesses of existing systems and practices, others propose forward-looking strategies to create campuses that are scalable, sustainable, and inclusive. The following synthesis groups these insights into major challenge areas, presenting both the observed shortcomings and the potential solutions or future directions outlined in the literature.

Challenges

Technological Challenges

1. In many cases, integration of IoT, AI, blockchain, and digital twins is held back by inconsistent standards and technical barriers. Because of scalability limits, systems like blockchain, IoT platforms, and AI-based models struggle to work across larger or diverse campuses.
2. On IoT devices and LPWAN sensors, accuracy and reliability are often affected by malfunctions or environmental disruptions.
3. Across different smart campus applications, data tends to be inconsistent and heterogeneous, which makes analysis and integration harder.
4. With complex methods such as MCDM, ANN, or deep learning, implementation and replication become difficult for institutions with limited expertise.
5. During times of peak demand, cloud or IoT systems can experience service interruptions and reliability issues.
6. During times of peak demand, cloud or IoT systems can experience service interruptions and reliability issues.
7. In indoor navigation or LPWAN systems, signal interference and environmental conditions reduce precision.
8. During times of peak demand, cloud or IoT systems can experience service interruptions and reliability issues.
9. When predictive models encounter class imbalance, their accuracy drops, especially in areas like detecting depression or forecasting student performance.
10. At the early stages, recommendation engines and predictive tools face problems like cold starts and sparse datasets.

Institutional and Policy Challenges

1. Without clear policies and coordinated governance, digital transformation in universities struggles to move forward.
2. Since many frameworks are only tested in controlled settings, their use in real-world institutions remains uncertain.
3. Across regions, proposed solutions often fit only specific contexts and fail to generalize to others.
4. For technologies such as blockchain-based credentials, regulatory gaps and legal restrictions make adoption difficult.

5. The weak collaboration between universities, industries, and policymakers slows down innovation and adoption.

Human and Behavioral Challenges

1. Limited digital literacy of students, teachers, and administrators makes it hard to engage with advanced tools like AI, IoT, or AR/VR.
2. Stakeholders are often hesitant to adopt new technologies due to mistrust, resistance, and concerns about transparency.
3. When cultural or behavioral expectations differ, approaches such as gamification or AI-driven systems face low acceptance.
4. Lack of teacher preparation and curriculum alignment, AR/VR or AI tools fail to deliver meaningful outcomes.
5. In behavioral analytics, subjective interpretations of actions and labels make engagement models less reliable.

Financial and Resource Challenges

Limited funding and weak infrastructure are the root causes of many institutions' inability to implement or sustain smart campus systems, including the high cost of deployment and maintenance. For these reasons, advanced technologies such as 5G, IoT, and large-scale infrastructure remain out of reach.

Ethical and Social Challenges

1. With growing concerns about surveillance, technologies such as blockchain or facial recognition face barriers related to privacy and trust.
2. Across AI applications, biases and ethical issues raise doubts about fairness and accountability.
3. When access to technology remains unequal, the digital divide widens across regions and socio-economic groups.
4. Since most research only looks at short-term effects, the long-term social and ethical impact of these systems is rarely addressed.
5. By focusing mainly on technical fields such as engineering or programming. Many solutions fail to engage with broader ethical or social questions.

Future Directions in Smart and Sustainable Higher Education

The future of higher education is moving toward a transformative vision in which advanced technologies such as AI, IoT, blockchain, and digital twins create connected, sustainable, and student-focused ecosystems. Each direction opens new possibilities but also introduces its own challenges.

AI and IoT Integration:

AI combined with IoT can create adaptive and data-driven learning environments. These systems could personalize education, improve campus operations, and enhance safety. For example, classroom content might adjust in real time based on engagement data collected from IoT sensors. At the same time, issues like data privacy, scalability, and system compatibility remain major hurdles. To overcome them, institutions need strong protocols, ethical frameworks, and reliable algorithms.

Blockchain and Decentralized Systems:

Blockchain has the potential to make education more trans parent and trustworthy. It could be used for secure credentialing, reducing fraud, and even enabling global portability of degrees. It can also help in sharing resources more efficiently by preventing duplication. In the long run, blockchain may support a decentralized educational infrastructure. However, challenges such as scalability, integration with legacy systems, and stakeholder acceptance require pilot projects, regulations, and interoperable formats.

Digital Twins and Multimodal Data:

Digital twin technology can deliver immersive, highly efficient campus models. A digital twin could, for example, simulate campus-wide energy use, helping institutions cut costs and reduce carbon emissions. By combining 3D visualization, IoT, and AI, universities can improve sustainability and optimize resources. Still, problems such as overwhelming data volumes and a lack of system interoperability necessitate the development of modular frameworks and the promotion of cross-domain collaboration.

Smart Mobility and Navigation:

Smarter mobility systems are essential for making campuses more efficient and accessible. AI and IoT could enable autonomous shuttles, optimize parking, and provide real-time navigation for complex buildings. These technologies might even serve as prototypes for future smart cities. Yet, issues such as sensor inaccuracy and environmental changes demand better algorithms and infrastructure upgrades.

Pedagogical Transformation:

Teaching methods are also shifting toward technology-driven models. Gamified platforms, adaptive content, and immersive tools such as AR and VR can make learning more engaging and interactive. Over time, these methods could build global, student-centered learning systems. However, differences in digital literacy and teaching practices mean that institutions need proper training, subject-specific strategies, and policy backing.

Ethical and Inclusive AI Adoption:

Widespread use of AI in education must be accompanied by ethical considerations. Universities need policies that protect privacy, prevent bias, and ensure transparency. Doing so builds trust and guarantees inclusivity. A global framework for ethical AI in education could eventually ensure fairness across diverse contexts. But achieving this requires standardized rules, stakeholder involvement, and cross-cultural validation.

Sustainability and SDGs:

Smart campus projects should align with the Sustainable Development Goals. Integrating IoT, AI, and digital twins can support sustainability, equity, and well-being. For example, linking air quality data with health outcomes can encourage healthier learning environments. Over time, this vision could establish a global model for sustainable education. Yet gaps in infrastructure and fragmented data systems must be addressed through supportive policies and investments.

Predictive Analytics and Behavioral Insights:

AI-powered predictive analytics can play a key role in student success. Early warning systems can identify risks, while spatiotemporal models and psychological data can give insights into behavior. These tools could help improve academic performance and mental well-being. However, their success depends on diverse datasets, strong algorithms, and transparent frameworks.

Collaborative and Interdisciplinary Ecosystems:

Collaboration between researchers, developers, and institutions is vital for driving innovation. Faculty working alongside AI developers, or universities partnering with industries, can lead to stronger research and economic impact. Over time, this can build global collaborative ecosystems. Yet challenges such as limited initial data and weak partnerships call for deeper engagement and stronger support.

Infrastructure and Network Optimization:

Finally, the success of all these directions depends on a strong infrastructure. Expanding 4G/5G testbeds, leveraging scalable cloud systems, and integrating IoT for energy use monitoring can improve connectivity and resilience. Such efforts can turn campuses into models of digital transformation. Still, issues such as bandwidth limits and deployment complexity require continuous optimization and integration with analytics tools.

CONCLUSION

This study provides a comprehensive review of digital trans formation in higher education institutions, with a particular focus on smart campus design. We examined the integration of emerging technologies, essential adoption factors, and the frameworks and models applied in prior studies. The analysis also identified the roles of multiple stakeholders, highlighting how organizational readiness and cultural contexts shape implementation outcomes. Using the PRISMA 2020 methodology, we applied clear quality assessment criteria and systematically analyzed 87 selected articles. Our findings reveal persistent challenges such as limited stakeholder involvement, inadequate institutional coordination, and the absence of context-sensitive frameworks– issues that are especially critical in developing countries where infrastructure and digital skills remain uneven. At the end, we proposed future directions to guide both research and practice. These include developing adaptable models that account for regional constraints, stronger alignment between technology and institutional strategy, and greater emphasis on cultural and organizational factors in adoption. By addressing these gaps, policymakers, university leaders, and campus planners can advance smart campus initiatives that are both effective and sustainable, helping HEIs achieve inclusive and context-aware digital transformation.

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