sustainability

MDPI

Article

Modeling the Determinants of Smart Campus Success: An Empirical Study in Thailand

Zattra Blakong, Charuay Savithi * and Sommai Khantong

Mahasarakham Business School, Mahasarakham University, Mahasarakham 44150, Thailand; zblakong@gmail.com (Z.B.); sommail.k@msu.ac.th (S.K.)
* Correspondence: charuay.savithi@gmail.com

Abstract

This study investigates a theory-driven causal model explaining the determinants of Smart Campus success in Thailand, drawing on the Technology–Organization–Environment (TOE) framework. Data were collected from 96 senior administrators across 126 higher education institutions using a validated questionnaire (IOC $\geq$ 0.50; Cronbach's alpha = 0.992). Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) reveal that technological, organizational, and environmental factors each exert significant positive influences on four performance domains—economic, social, environmental, and governance—that together define Smart Campus success. The structural model shows a strong fit (χ^2 = 988.222, p = 0.0532; CFI = 0.998; TLI = 0.980; SRMR = 0.017; RMSEA = 0.059), and all sixteen hypotheses were supported ($p < 0.05$). Organizational readiness emerged as the most influential determinant, particularly for social outcomes (β = 0.326), emphasizing the importance of leadership commitment, institutional culture, and internal preparedness in digital transformation. Among the outcome domains, economic performance contributed most strongly to Smart Campus success (β = 0.416). Overall, the findings confirm the relevance of the TOE framework for understanding digital transformation in higher education and provide actionable guidance for policymakers and university leaders seeking to enhance innovation capacity, competitiveness, and sustainable development in Thai and similar institutional contexts.

Keywords: smart campus; digital transformation; TOE framework; Higher Education Institutions (HEIs); SEM; sustainability performance

check for updates

Academic Editor: Grigorios L. Kyriakopoulos

Received: 3 November 2025
Revised: 5 December 2025
Accepted: 5 December 2025
Published: 10 December 2025

Citation: Blakong, Z.; Savithi, C.; Khantong, S. Modeling the Determinants of Smart Campus Success: An Empirical Study in Thailand. *Sustainability* **2025**, *17*, 11048. https://doi.org/10.3390/su172411048

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Universities around the world are changing significantly as they respond to new technology, growing expectations for sustainability, and increased global competition. In this setting, the smart campus has become an important model for the future of higher education. The idea comes from the broader smart city movement [1] and goes beyond simply using digital tools. It involves rethinking how teaching, management, and services are delivered through intelligent, connected, and data-driven systems. Technologies such as the Internet of Things (IoT), artificial intelligence, cloud computing, and big data analytics now help create flexible learning environments, improve operational efficiency, and support long-term sustainability for institutions [2–4].

As a result, digital transformation is now a top priority for modern universities. Fast technological change, stronger competition, and shifting stakeholder expectations are leading institutions to rethink how they work, collaborate, and make decisions. Advanced

digital platforms, from cloud systems to analytics dashboards, help universities govern more effectively, improve service integration, and create new ways to engage with students, staff, and communities. However, technology alone does not ensure successful change. Research shows that organizational readiness—such as committed leadership, a supportive culture, and ongoing staff development—is key to the success of digital projects [5–7]. External factors like government policy, competition, and stakeholder needs also affect how quickly and in what direction universities change [8].

The Technology–Organization–Environment (TOE) framework, introduced by Tornatzky and Fleischer [9], offers a comprehensive lens for understanding how these interacting factors shape innovation adoption. Although widely applied in digital transformation research, empirical validation within Southeast Asian higher education remains limited, despite the region's rapid investment in digital modernization [5]. This gap underscores the need for a theoretically grounded examination of how technological capability, organizational conditions, and environmental support collectively influence smart campus development.

In response to this identified need, the present study develops and empirically tests a causal model of Smart Campus success within Thai higher education, grounded in the TOE framework. The model evaluates how three categories of readiness—technological, organizational, and environmental—are associated with four sustainability-oriented performance domains:

- economic (efficiency, innovation, resource use).
- social (learning quality, inclusivity, community engagement).
- environmental (green practices, energy management, sustainability).
- governance (transparency, cybersecurity, evidence-based decision making).

Collectively, these domains provide a comprehensive perspective on the determinants of Smart Campus success, aligning with global sustainable development objectives.

Accordingly, this study seeks to address the following research questions:

1. What theoretically derived causal factors are statistically associated with Smart Campus success across the four sustainability domains?

2. How does an integrated causal model combining TOE constructs and sustainability outcomes advance theoretical understanding and practical application of Smart Campus development?

3. Which structural relationships, as theoretically proposed, are empirically supported in the Smart Campus context?

This study employed a quantitative methodology utilizing structural equation modeling (SEM), drawing on data from 96 administrators across 126 Thai higher education institutions. The findings indicate that technological, organizational, and environmental factors all contribute to institutional change, with organizational readiness emerging as the most influential determinant. By affirming the applicability of the TOE framework in higher education, this research provides both theoretical insights and practical recommendations for policymakers and university leaders seeking to enhance digital transformation and competitiveness in Thailand and Southeast Asia.

2. Literature Review

2.1. Smart City as a Conceptual Foundation

The concept of the smart city has become central to contemporary approaches to urban development, governance, and service delivery in the digital era. Smart cities integrate advanced technologies, data systems, and citizen engagement to enhance efficiency, sustainability, and overall quality of urban life. Information and communication technologies (ICT) are employed for essential functions such as transportation management, building

operations, public service delivery, and environmental monitoring. Furthermore, these technologies contribute to increased transparency in governance and foster greater public participation [10].

Scholars frequently characterize smart cities through six interconnected domains: smart economy, smart people, smart environment, smart governance, smart mobility, and smart living [11]. Collectively, these domains provide a comprehensive framework that fosters innovation and supports urban resilience. In the context of Thailand, the framework is expanded to include a smart energy domain, which emphasizes the adoption of renewable energy, resource efficiency, and the promotion of sustainable consumption.

The smart city concept has significantly influenced the development of smart campus initiatives. Universities, often referred to as "micro-cities," require integrated management, data-driven decision-making, and a strong emphasis on sustainability, paralleling the needs of urban environments. Consequently, many universities adopt smart city principles to develop smart campus models that enhance teaching, streamline administrative processes, and advance research and innovation [12]. Thus, a smart campus functions as a scaled-down version of a smart city, facilitating digital transformation to achieve educational, social, and environmental objectives.

2.2. Smart Campus: Definitions, Characteristics, and Frameworks

2.2.1. Concept and Characteristics

The smart campus represents a significant advancement in the digital transformation of higher education, shifting from simple process digitization to a comprehensive reimagining of teaching, operations, and service delivery. Rather than treating technology solely as a tool, smart campuses employ interconnected systems, including the Internet of Things (IoT), artificial intelligence, cloud computing, and learning analytics, to enhance decision-making, optimize resource allocation, and facilitate personalized, adaptive learning experiences [13].

The smart campus functions as an integrated digital ecosystem. Data generated by sensors, devices, campus services, and learning platforms are continuously collected and analyzed to inform instructional and administrative enhancements. Prior literature identifies several key components:

- Smart Learning–flexible, data-informed pedagogy that supports personalized and collaborative learning;
- Smart Governance: transparent, efficient, and evidence-based institutional management;
- Smart Environment: sustainable campus design that prioritizes environmental quality and green innovation;
- Smart Energy: efficient energy production and consumption supported by real-time monitoring;
- Smart Mobility–intelligent transportation and campus access sysSmart People: digitally skilled students, faculty, and staff who participate effectively in innovation-driven environments [14].

Collectively, these components constitute a comprehensive model that integrates technological innovation with educational, social, and sustainability objectives.

2.2.2. Architectural Frameworks and Structural Models

Numerous frameworks have been developed to explain the evolution of universities into smart institutions. The iCampus framework is frequently referenced for its focus on four interconnected development domains: economy, society, environment, and governance. Each domain represents a specific strategic objective, including enhancing efficiency and innovation, strengthening community engagement and learning quality, advancing environmental sustainability and clean-energy practices, and promoting transparency, cy-

bersecurity, and evidence-based decision-making. Together, these dimensions situate smart campus development within the broader context of global sustainability goals [15,16].

Recent research on digital transformation in higher education indicates that achieving a smart campus requires more than the implementation of advanced technologies. Organizational culture, leadership commitment, staff engagement, infrastructure maturity, strategic governance, and collaboration with both internal and external stakeholders are consistently identified as critical determinants of success. These interconnected factors shape institutional readiness and significantly influence whether digital initiatives result in meaningful and sustainable outcomes [17].

2.3. Technology-Organization-Environment (TOE) Framework

2.3.1. Theoretical Foundation and Structure

Technology–Organization–Environment (TOE) framework, first introduced by Tornatzky and Fleischer [9], serves as a widely recognized theoretical approach for examining organizational adoption and implementation of technological innovations. According to this framework, successful digital transformation results from the interplay among three contextual dimensions: technological capability, organizational readiness, and environmental conditions. Each dimension influences both the likelihood and effectiveness of innovation adoption [6].

The technological context refers to the availability and appropriateness of technologies that an institution may implement. In the context of smart campuses, this includes IoT devices for sensing and monitoring, cloud computing platforms, data analytics systems, and intelligent learning technologies. These tools support real-time decision-making, enhance operational efficiency, and foster pedagogical innovation.

The organizational context addresses internal factors such as leadership commitment, institutional readiness, organizational culture, and ongoing staff development [18]. These elements influence both the decision to adopt new technologies and the effectiveness of integrating digital tools into teaching, research, and administrative functions [19].

The environmental context encompasses external factors such as government policy, competitive pressures, and stakeholder expectations. In the case of smart campuses, national digital strategies, sustainability initiatives, and global competition for students and research opportunities significantly shape institutional innovation pathways [8].

Collectively, these three dimensions establish the TOE framework as a comprehensive basis for analyzing digital transformation in higher education and for explaining the success or challenges of smart campus initiatives.

2.3.2. Empirical Applications and Validation

The TOE framework has been widely used across sectors to explain the organizational adoption, implementation, and adaptation of new technologies. In the context of higher education, recent research demonstrates that the framework effectively captures the dynamics of digital transformation, emphasizing organizational readiness and stakeholder collaboration as essential determinants of success. Evidence from related fields, such as healthcare and public administration, further substantiates the framework's validity. Empirical studies employing structural equation modeling (SEM) consistently indicate that technological, organizational, and environmental dimensions interact to explain significant variance in innovation adoption behaviors. Collectively, these findings establish the TOE framework as a robust analytical tool for investigating complex institutional change and for elucidating the multidimensional factors that influence digital transformation outcomes [19].

2.4. Empirical Research on Smart Campus and Digital Transformation

2.4.1. Smart Campus: Concepts and Empirical Studies

Recent empirical studies on smart campuses emphasize the dynamic relationship between technological innovation and organizational processes in establishing intelligent and sustainable learning environments. For example, Haggag et al. [4] introduced an IoT-based energy management platform for university buildings that combined low-cost sensors with automated control systems. This platform facilitated near–zero-energy operations by monitoring real-time consumption and optimizing energy flows, thereby illustrating the significant impact of digital infrastructure on campus sustainability.

Additional research has addressed broader dimensions of sustainability in smart campus initiatives. For instance, Al-Dmour [14] examined student engagement in green and smart campus projects and determined that energy efficiency had the most substantial structural effect on overall sustainability performance ($\beta = 0.627$), followed by waste management ($\beta = 0.320$) and sustainable transportation ($\beta = 0.187$). These results indicate that achieving significant sustainability outcomes necessitates coordinated efforts across various operational domains and that such initiatives enhance environmental performance, institutional reputation, and student participation.

Subsequent research by Haggag et al. [4] investigated the influence of emerging digital technologies, including augmented reality (AR), virtual reality (VR), artificial intelligence, and biometric systems, on learning experiences within smart campuses. The study found that these technologies support more personalized, interactive, and immersive learning environments and improve accessibility for students with diverse learning needs, including those with disabilities. This empirical evidence demonstrates the growing importance of smart technologies in advancing inclusive and high-quality education.

2.4.2. Digital Transformation and Organization Readiness

Digital transformation in universities encompasses more than the implementation of new technologies, as it fundamentally alters institutional strategy, governance, and daily operational processes. A study by Clark [20] examining higher education reform in the United Kingdom found that meaningful transformation is closely associated with organizational culture, leadership, and governance structures. The authors argue that strategic planning and fostering a culture of innovation are more critical to successful transformation than technology adoption alone.

Findings from other contexts support this pattern. Applying the Technology–Organization–Environment (TOE) framework, Suttidee and Savithi [21] investigated cloud computing adoption among Thai small and medium-sized enterprises (SMEs) and found that organizational readiness, particularly management support, was the most influential factor in adoption decisions. While technological capability and external pressures also contributed, their impact was less significant. These results indicate that effective digital transformation depends on both technological capacity, robust leadership commitment, and organizational preparedness.

Additional research in higher education further underscores the importance of organizational readiness. A study by Carmo et al. [22] analyzing digital transformation in university management identified persistent barriers such as inadequate managerial support, fragmented digital infrastructures, and limited staff digital competency. The study concluded that successful transformation relies on coherent institutional planning, decisive leadership, and a culture that encourages continuous learning and innovation. Collectively, these empirical findings demonstrate that organizational readiness, as emphasized in the TOE framework, is a fundamental determinant of digital transformation outcomes in universities.

2.4.3. Sustainability and Governance in Higher Education

Sustainability is now a central pillar of smart campus development, reflecting the expectation that universities balance resource efficiency, social responsibility, and effective governance with academic and economic objectives. According to Elbertsen et al. [23], achieving a smart and sustainable campus requires integrating advanced technologies with environmentally conscious practices and user-centered design. The study emphasized that digital tools have the greatest impact when aligned with broader sustainability initiatives, including energy-efficient systems, green building design, and smart transportation. The authors further argued that technology should be embedded within a comprehensive institutional strategy that connects innovation, policy, and organizational culture to create campuses that are both environmentally responsible and technologically advanced.

Further research by Singh et al. [24] developed and validated sustainability indicators for higher education through interviews and a case study at the American University of Sharjah. The findings identified ongoing challenges, such as limited financial resources, low awareness, and fragmented reporting structures. The authors recommended expanding sustainability assessment beyond operational metrics to encompass leadership, finance, academic development, and community engagement. They also advocated for integrated reporting platforms and cross-functional teams to support long-term institutional change.

From a governance perspective, Oliveira and Proenca [25] emphasized that leadership commitment and well-defined institutional structures are essential for implementing sustainability policies in daily practice. Their review demonstrated that transparency, accountability, shared decision-making, and equitable resource allocation are critical for sustainable development in teaching, research, and campus operations. Collectively, these studies indicate that sustainability and governance are foundational to effective smart campus development.

2.5. Research Gap and Theoretical Contribution

Despite extensive research on various aspects of the Smart Campus, much of the literature continues to examine technological, organizational, or environmental factors separately rather than as interconnected elements of a unified system. For instance, Chounta et al. [26] introduced a data-driven framework for assessing digital readiness in higher education and found that many institutions face challenges in integrating technology, organizational processes, and governance mechanisms into a cohesive transformation strategy. Likewise, Trevisan et al. [8] observed that universities frequently encounter departmental fragmentation, which leads to misaligned digital initiatives and limited institutional advancement. In the absence of an integrated perspective on the interaction among these dimensions, smart campus development remains incomplete and inconsistent.

Although structural equation modeling (SEM) is widely used in Technology-Organization-Environment (TOE) based innovation research globally, few studies have applied SEM to investigate how the three TOE dimensions collectively influence Smart Campus or Smart University development, especially within the ASEAN region and the Thai higher education context. Most empirical research continues to examine technological or organizational factors independently, rather than adopting a comprehensive TOE–Smart Campus approach. For example, Clark [20] utilized SEM to study AI adoption in healthcare, demonstrating that technological capability, organizational readiness, and environmental pressures interact to shape adoption outcomes. In contrast, higher education research often remains focused on technology use or digital adoption, with limited attention to the combined impact of technology, organization, and environment on broader institutional performance across economic, social, environmental, and governance domains [14].

To address these gaps, this study develops and empirically tests an integrated causal model that links technological readiness, organizational capability, and environmental support to Smart Campus success. Utilizing the TOE framework [9] and SEM analysis with data from administrators at 126 Thai higher education institutions, the research investigates how internal capacities and external pressures interact to influence performance in four sustainability-oriented domains: economic efficiency, social engagement, environmental responsibility, and transparent governance. This approach provides a comprehensive theoretical model that enhances understanding of digital transformation in higher education and offers evidence-based recommendations for institutions aiming to implement smart campus strategies.

3. Methods

3.1. Research Design and Model

A quantitative research design, based on the Technology–Organization–Environment (TOE) framework, was employed to investigate the associations between technological, organizational, and environmental factors and Smart Campus success in Thailand. The study utilized a deductive approach to test theoretically derived hypotheses. Data were collected through a structured questionnaire and analyzed using Structural Equation Modeling (SEM) to validate the proposed causal relationships.

The conceptual model (Figure 1) comprises three independent latent constructs: Technology (TECH), Organization (ORG), and Environment (ENV), which represent the three TOE dimensions. These constructs are hypothesized to influence Smart Campus success (smart_U) through four sustainability-oriented performance domains.

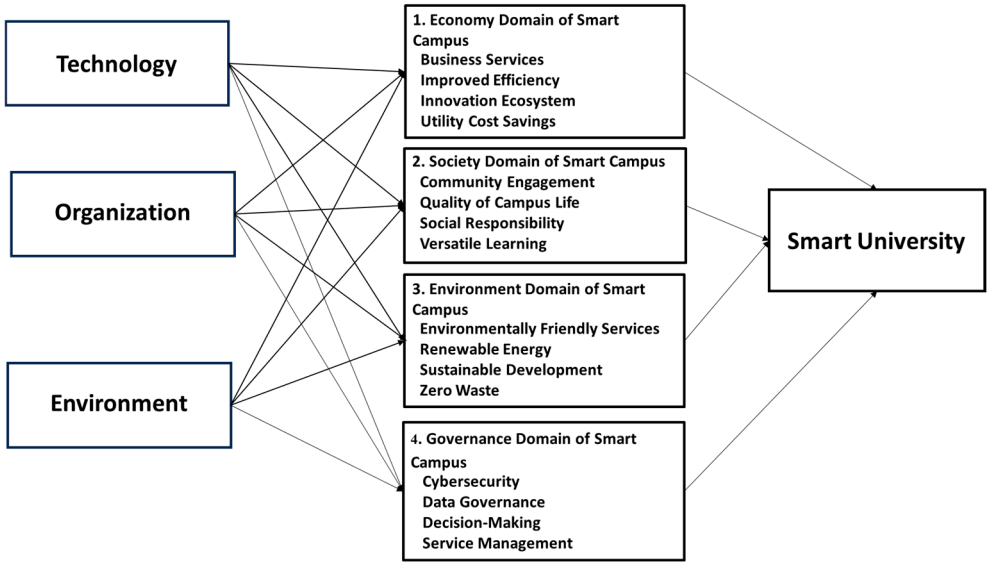

Figure 1. Conceptual Research Model.

- Economic domain: efficiency improvement, innovation ecosystem, business services, and cost reduction;
- Social domain: community engagement, quality of campus life, social responsibility, and flexible learning;
- Environmental domain: eco-friendly services, renewable energy, sustainable development initiatives, and zero-waste operations;

Governance domain: cybersecurity, data governance, evidence-based decision-making, and smart service management.

The model proposes that each TOE dimension exerts direct positive effects on the four Smart Campus domains, which in turn contribute to overall Smart Campus success. This structure results in sixteen hypotheses (H1 to H16) that capture the directional relationships among the latent constructs.

Technology Perspective (TECH)

H1: *The technology perspective positively influences the economic domain of Smart Campus development.*

H2: *The technology perspective positively influences the social domain of Smart Campus development.*

H3: *The technology perspective positively influences the environmental domain of Smart Campus development.*

H4: *The technology perspective positively influences the governance domain of Smart Campus development.*

Organization Perspective (ORG)

H5: *The organization perspective positively influences the economic domain of Smart Campus development.*

H6: *The organization perspective positively influences the social domain of Smart Campus development.*

H7: *The organization perspective positively influences the environmental domain of Smart Campus development.*

H8: *The organization perspective positively influences the governance domain of Smart Campus development.*

Environment Perspective (ENV)

H9: *The environment perspective positively influences the economic domain of Smart Campus development.*

H10: *The environment perspective positively influences the social domain of Smart Campus development.*

H11: *The environment perspective positively influences the environmental domain of Smart Campus development.*

H12: *The environment perspective positively influences the governance domain of Smart Campus development.*

Smart Campus Outcome Domains (smart_U)

H13: *The economic domain positively contributes to overall Smart Campus success.*

H14: *The social domain positively contributes to overall Smart Campus success.*

H15: *The environmental domain positively contributes to overall Smart Campus success.*

H16: *The governance domain positively contributes to overall Smart Campus success.*

This causal structure offers a comprehensive framework for analyzing the interaction between internal capabilities and external environmental conditions in supporting Smart Campus transformation. Structural Equation Modeling (SEM) was employed to empirically test the magnitude and direction of the hypothesized relationships among latent constructs.

3.2. Population and Sample

The study population consisted of senior administrators from 126 higher education institutions (HEIs) in Thailand, comprising 57 public universities, 26 autonomous universities, and 43 private universities. Given that the target respondents were high-level executives, who are relatively few and often difficult to access, the study obtained 96 valid responses. According to Hair [27], an appropriate sample size for Structural Equation Modeling (SEM) typically ranges from 10 to 20 times the number of free parameters. Further methodological guidance indicates that SEM can be reliably conducted with samples between 50 and 100 when models are theory-driven, structurally constrained, and exhibit strong factor loadings [28,29].

To further justify sample adequacy, the structural complexity of the final second-order TOE–Smart University model was evaluated. The model required estimation of 42 free parameters, including factor loadings, error terms, latent variances, covariances, and structural paths. With a sample size of N = 96, the parameter-to-sample ratio was 1:2.29, which is within acceptable limits for theory-based SEM, especially when supported by robust model identification and strong measurement properties.

A post hoc RMSEA-based power analysis, following MacCallum et al. [30], was conducted using $\alpha = 0.05$, df = 96, H_0: RMSEA = 0.05, and H_1: RMSEA = 0.08. The resulting statistical power of 0.84 exceeded the commonly accepted threshold of 0.80, indicating that the sample size is sufficient for detecting meaningful model misfit. Collectively, these diagnostics confirm that the sample of 96 respondents is statistically adequate and methodologically appropriate for estimating the proposed causal model.

A purposive sampling strategy was implemented to ensure inclusion of only administrators with institutional decision-making authority as key informants. In Thai HEIs, this authority is typically held by the President (Rector), Vice Presidents, and Assistant Presidents. Consequently, one questionnaire was sent to each institution and addressed directly to the President or a designated senior administrator authorized to respond on behalf of the institution. This approach ensured that each returned questionnaire reflected an official institutional position rather than an individual opinion.

A total of 126 administrators, one per HEI, were invited to participate. Of these, 96 completed the questionnaire, resulting in a response rate of 76.19%. As each institution contributed only one response from an authorized executive, the dataset represents leadership-level perspectives across Thailand's higher education system. To minimize potential self-selection bias common in online surveys, invitations were sent individually to named senior executives rather than through open distribution channels, ensuring that each response reflected an authenticated institutional viewpoint.

3.3. Research Instrument

A structured questionnaire was designed utilizing the Technology-Organization-Environment (TOE) framework and validated constructs from previous studies. The instrument comprised four distinct sections:

1. Respondent and institutional background information;
2. Independent variables reflecting technological, organizational, and environmental dimensions;

3. The dependent variable, Smart Campus success, assessed across four domains: economic, social, environmental, and governance; and
4. Open-ended questions soliciting additional comments or recommendations.

All closed-ended items utilized a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Mean scores were interpreted according to standard guidelines: 4.21–5.00 (very high), 3.41–4.20 (high), 2.61–3.40 (moderate), 1.81–2.60 (low), and 1.00–1.80 (very low).

To ensure clarity and consistency, each item was formulated as an evaluative statement requiring respondents to indicate their perceived level of implementation, presence, or effectiveness of specific practices within their institution. The initial instrument included 86 items. Following expert review, seven items with Index of Item–Objective Congruence (IOC) scores below 0.50 were eliminated, resulting in a refined set of items aligned with the TOE constructs and Smart Campus performance domains.

Content validity was evaluated by three expert raters specializing in higher education administration, digital transformation, and research methodology. Items with IOC scores of 0.50 or higher were retained for further testing. Although this threshold is more permissive than the commonly used cutoff of 0.67, it was applied during the preliminary screening stage. All retained items subsequently underwent confirmatory factor analysis (CFA), which demonstrated strong factor loadings and satisfactory construct validity. This two-stage validation process ensured that the final measurement items met acceptable standards of conceptual clarity and empirical rigor.

Due to institutional confidentiality requirements and the use of context-specific indicators designed for internal assessment within Thai higher education institutions, the full questionnaire cannot be reproduced verbatim in this manuscript. However, all constructs, sub-dimensions, and indicator descriptions are presented in the accompanying tables and methodological explanations, providing sufficient detail for evaluating the instrument's conceptual alignment, wording precision, and content validity.

3.4. Validity and Reliability

Content validity of the questionnaire was evaluated by five experts specializing in higher education administration, digital transformation, and research methodology. Each item was assessed using the Index of Item–Objective Congruence (IOC), and items with scores of 0.50 or higher were retained for further refinement. This threshold was deemed suitable for initial screening, as subsequent psychometric evaluation was planned through confirmatory factor analysis (CFA) during the main analysis phase.

Before the main data collection, a pilot study was conducted with 30 university administrators excluded from the primary sample. The pilot test aimed to assess item clarity, response consistency, and overall instrument usability. Feedback obtained from the pilot led to minor revisions in wording and formatting to improve respondent comprehension.

Reliability was assessed using Cronbach's alpha. All constructs exhibited reliability coefficients exceeding 0.70, indicating acceptable internal consistency. According to established guidelines, coefficients above 0.90 are considered excellent, those above 0.80 are regarded as good, and values above 0.70 are acceptable for research instruments. The results confirmed that all scales demonstrated stable and coherent measurement properties appropriate for SEM-based analysis.

3.5. Data Collection and Analysis

An online questionnaire was administered via Google Forms to collect data. The survey link was distributed individually to senior administrators through institutional email, LINE, and Facebook to maximize accessibility and encourage participation. Prior to

completing the questionnaire, respondents were informed of the study's purpose, confidentiality protections, and voluntary participation. Data collection was conducted from January to July 2025, and all returned questionnaires were screened for completeness before analysis.

Procedural remedies were implemented to reduce potential common method bias (CMB). Anonymity was assured, questionnaire sections were separated to minimize response pattern contamination, and items were phrased neutrally to avoid leading responses. These procedures, which are commonly recommended in behavioral research, mitigate systematic bias arising from single-source data collection.

Descriptive statistics, including frequency, percentage, mean, and standard deviation, were computed using SPSS version 29.0 to summarize respondent characteristics. Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) were conducted in Mplus version 8.3 to evaluate the measurement model and to test the theoretically derived structural relationships among the TOE constructs and Smart Campus performance domains.

Several diagnostic checks were conducted to address concerns regarding estimation stability and model robustness. Maximum Likelihood (ML) estimation converged normally without warnings, and no inadmissible solutions were observed. All standardized factor loadings were positive and below 1.0, and no negative error variances (Heywood cases) were detected. Examination of standardized residuals revealed no patterns indicative of misfit, and modification indices did not suggest omitted paths that would meaningfully improve the model. Collectively, these diagnostics indicate that the model was not overfitted and that parameter estimates were stable despite the modest sample size.

Model fit was evaluated using widely accepted indices, including χ^2/df, RMSEA, CFI, TLI, and SRMR. All criteria met recommended thresholds, demonstrating satisfactory global model fit and supporting the adequacy of the specified structural model. Due to the cross-sectional nature of the data, the estimated coefficients are interpreted as statistical associations consistent with the theoretical framework rather than as evidence of temporal causation.

Statistical assessments of common method bias were conducted to complement procedural remedies. Harman's single-factor test indicated that the first unrotated factor accounted for 28.4% of the total variance, which is well below the 50% criterion, suggesting that no dominant factor inflated the results. A full collinearity assessment following Kock [31] showed that all variance inflation factor (VIF) values ranged between 1.78 and 3.12, remaining below the conservative threshold of 3.3. These findings confirm that common method variance is unlikely to have substantially affected the structural relationships in the model.

4. Results

4.1. Descriptive Statistics

Descriptive statistics were computed to examine the response patterns of the 96 senior administrators and to assess the suitability of the data for subsequent confirmatory and structural analyses. The questionnaire items were grouped into three TOE dimensions—Technology, Organization, and Environment—and four Smart Campus performance domains: economic, social, environmental, and governance.

Across all measurement items, mean scores ranged from 3.89 to 4.51, indicating generally high levels of agreement and suggesting that respondents perceived substantial progress in Smart Campus development within their institutions. Standard deviations ranged from 0.66 to 1.05, reflecting adequate variability without evidence of extreme dispersion.

Assessment of univariate normality indicated that skewness and kurtosis for all items fell within the acceptable ±2 range, suggesting that the data did not exhibit significant deviations from normality. These descriptive characteristics confirm that the dataset is well-suited for Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM), meeting commonly accepted preliminary assumptions for multivariate analysis.

4.2. Reliability Analysis

A reliability analysis was conducted to evaluate the internal consistency of the measurement scales for the TOE dimensions and the Smart Campus performance domains. Cronbach's alpha assessed the degree of interrelation among items within each construct. According to the guidelines established by Hair et al. [27], reliability coefficients above 0.70 are considered acceptable, whereas values above 0.90 indicate excellent reliability.

Table 1 presents Cronbach's alpha values for the constructs, which ranged from 0.888 to 0.969. The overall reliability coefficient for the full scale was 0.992. These findings indicate a high level of internal consistency across all constructs, confirming that the measurement instrument is psychometrically robust and appropriate for subsequent confirmatory factor analysis (CFA) and structural equation modeling (SEM).

Table 1. Reliability coefficients of constructs.

Variable	Number of Items	Cronbach's Alpha
Independent Variables		
Technology Perspective	6	0.888
Organization Perspective	6	0.914
Environment Perspective	7	0.938
Economy	20	0.963
Society	20	0.968
Environment	20	0.958
Public Administration	20	0.963
Dependent Variable		
Smart Campus (Success)	16	0.969
Overall Reliability	—	0.992

4.3. Discriminant Validity

Discriminant validity was examined to determine whether the three constructs within the TOE framework—Technology, Organization, and Environment—represent empirically distinct concepts. Because these constructs exhibited relatively high correlations, a rigorous assessment was necessary to ensure that each construct measured a unique domain rather than overlapping latent factors.

4.3.1. Larcker Criterion

The Fornell–Larcker criterion states that the square root of the average variance extracted ($\sqrt{}$AVE) of each construct should exceed its correlations with other constructs. Table 2 presents the Fornell–Larcker matrix, with $\sqrt{}$AVE values on the diagonal and latent correlations in the off-diagonal cells.

Table 2. Fornell–Larcker Discriminant Validity Matrix.

Construct	$\sqrt{}$AVE	Technology	Organization	Environment
Technology	0.775	0.775	0.903	0.839
Organization	0.806	0.903	0.806	0.916
Environment	0.831	0.839	0.916	0.831

Although correlations between Technology–Organization (0.903) and Organization–Environment (0.916) are relatively high, each construct's $\sqrt{}$AVE remains higher than the corresponding correlation values. This indicates that the constructs retain acceptable discriminant validity under the Fornell–Larcker criterion.

4.3.2. AVE Versus Squared Correlation Comparison

To further evaluate discriminant validity, AVE values were compared with squared inter-construct correlations (r^2). Discriminant validity is supported when AVE exceeds r^2.

Although two construct pairs (Tech–Org and Org–Env) show r^2 values slightly higher than their AVEs, the Fornell–Larcker test still supports discriminant validity due to the higher $\sqrt{}$AVE values shown in Table 3. This pattern is typical in higher-order models where closely related organizational constructs exhibit inherently strong correlations.

Table 3. AVE versus Squared Correlation Comparison.

Construct Pair	r	r^2	AVE_1	AVE_2	Interpretation
Tech–Org	0.903	0.816	0.60	0.65	AVE < r^2 (borderline)
Org–Env	0.916	0.839	0.65	0.69	AVE < r^2 (borderline)
Tech–Env	0.839	0.704	0.60	0.69	AVE > r^2 (acceptable)

4.3.3. Note on HTMT

The Heterotrait–Monotrait (HTMT) ratio could not be computed because the measurement model employs aggregated (parceled) indicators for the three TOE constructs. Parceling eliminates item-level covariance information, which is required to compute HTMT values. Consistent with recommended practice for higher-order SEM models using composite indicators, discriminant validity was therefore assessed using the Fornell–Larcker criterion and AVE-versus-r^2 comparisons.

Overall, the Fornell–Larcker matrix and AVE–r^2 comparisons provide evidence that the constructs maintain acceptable discriminant validity. Despite high inter-construct correlations, the diagnostic results indicate that Technology, Organization, and Environment remain empirically distinguishable and conceptually meaningful within the TOE measurement model.

4.4. Testing and Presentation of Analysis Results

Confirmatory Factor Analysis (CFA) was performed to assess the measurement validity of the three latent constructs: Technology, Organization, and Environment, as defined within the TOE framework. The CFA aimed to determine whether the observed indicators accurately represented their respective theoretical constructs. Measurement validity was evaluated using standardized factor loadings (β), squared multiple correlations (R^2), average variance extracted (AVE), composite reliability (CR), and Cronbach's alpha.

The results, presented in Table 4, indicate that all standardized factor loadings were statistically significant (β = 0.672 to 0.890, $p < 0.001$), demonstrating that each item contributed substantially to its respective construct. Composite reliability values ranged from 0.89 to 0.95, exceeding the recommended threshold of 0.70. AVE values ranged from 0.60 to 0.69, surpassing the minimum criterion of 0.50 as suggested by Hair et al. [27]. Cronbach's alpha coefficients further confirmed strong internal consistency across all constructs.

Taken together, these findings confirm that the measurement model demonstrates satisfactory convergent validity and reliability. The results support the theoretical proposition that the three TOE dimensions—Technology, Organization, and Environment—are effectively represented by their observed indicators, thereby establishing a robust foundation for subsequent structural analysis.

Figure 2 displays the measurement model for the three latent constructs: Technology, Organization, and Environment, as defined within the TOE framework. Each construct was assessed using multiple observed indicators (Technology: T1–T6, Organization: O1–O6, Environment: E1–E7). All indicators showed positive and statistically significant factor loadings (β = 0.672–0.890, $p < 0.001$), indicating that the items effectively represented their respective constructs.

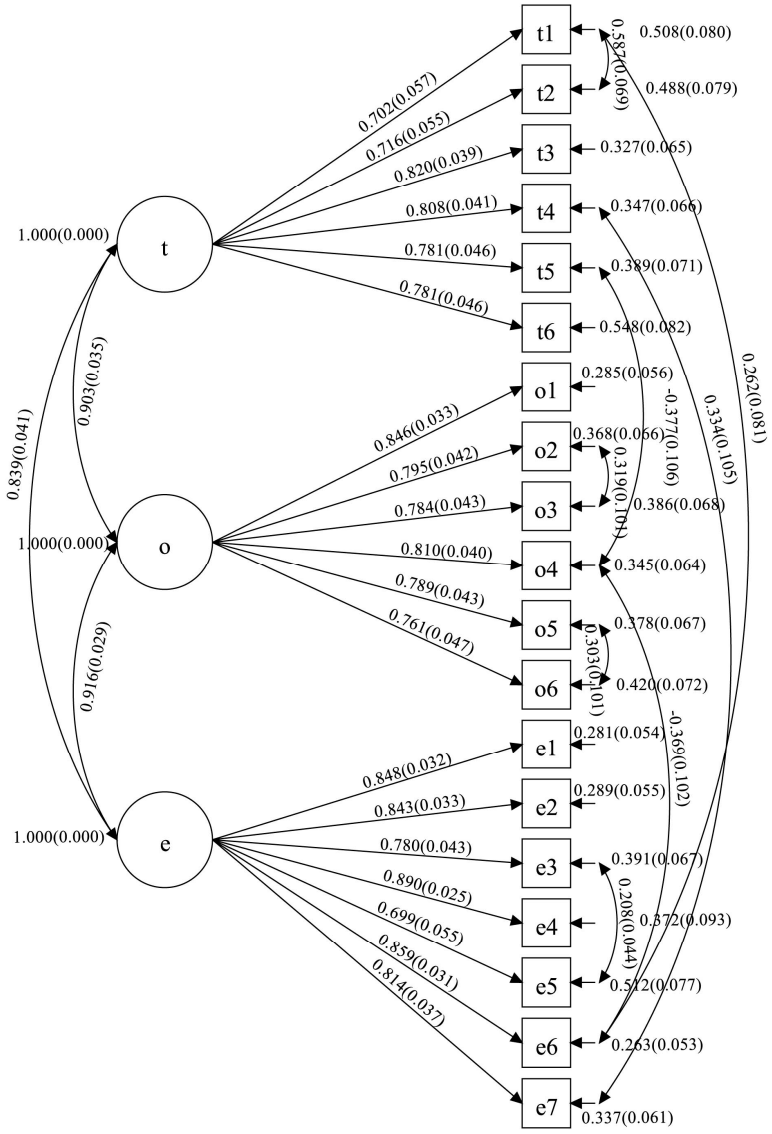

Figure 2. CFA of Technology–Organization–Environment (TOE). The figure presents the three TOE dimensions—technology (t), organization (o), and environment (e)—each measured by their respective indicators with significant standardized factor loadings ($p < 0.001$). The covariances among the three latent dimensions are shown on the left side of the model.

The correlations among the three TOE dimensions were strong and positive: Technology–Organization = 0.903, Technology–Environment = 0.839, and Organization–Environment = 0.916. These results suggest substantial interdependence among the constructs and reinforce the theoretical coherence of the TOE framework in the context of Smart Campus research.

Overall, these findings confirm that the measurement model demonstrates satisfactory validity and reliability, establishing a robust foundation for subsequent structural analysis.

Table 4. Reliability coefficients of measurement constructs.

Variables	Factor Loading			r^2	AVE	CR	Cronbach's Alpha
	Beta	SE	Z				
Technology							
T1	0.702	0.057	12.368	0.492			
T2	0.716	0.055	12.962	0.512			
T3	0.820	0.039	20.840	0.673			
T4	0.808	0.041	19.657	0.653	0.60	0.89	0.888
T5	0.781	0.046	17.138	0.611			
T6	0.672	0.061	11.032	0.452			
Organization							
O1	0.846	0.033	25.679	0.715			
O2	0.795	0.042	19.078	0.632			
O3	0.784	0.043	18.028	0.614			
O4	0.810	0.040	20.333	0.655	0.65	0.91	0.914
O5	0.789	0.043	18.546	0.622			
O6	0.761	0.047	16.108	0.580			
Environment							
E1	0.848	0.032	26.792	0.719			
E2	0.843	0.033	25.851	0.711			
E3	0.780	0.043	18.250	0.609			
E4	0.890	0.025	35.937	0.792			
E5	0.699	0.055	12.678	0.488	0.69	0.95	0.938
E6	0.859	0.031	28.038	0.737			

4.5. Confirmatory Factor Analysis and Structural Equation Modeling (SEM)

After validating the TOE measurement model, a second-order Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) were performed to evaluate the proposed Smart Campus success model. The structural model assessed the joint contributions of the Economic, Social, Environmental, and Governance performance domains to overall Smart Campus performance, as well as the influence of the three TOE dimensions on these domains.

Model quality and adequacy were assessed using several measurement indicators, such as standardized factor loadings (β), squared multiple correlations (R^2), average variance extracted (AVE), composite reliability (CR), and Cronbach's alpha. These indices confirmed convergent validity, internal consistency, and the robustness of both the measurement and structural components of the model.

The CFA results indicated that all indicators loaded significantly onto their respective latent constructs, and all reliability and validity criteria met recommended thresholds. These findings offered strong empirical support for advancing to the full structural analysis, in which the hypothesized causal relationships among the TOE dimensions and Smart Campus domains were formally tested.

Table 5 reports the results of the confirmatory factor analysis for the four Smart Campus performance domains. All standardized factor loadings surpassed the recommended threshold of 0.60 and were statistically significant at $p < 0.001$, demonstrating strong associations between observed indicators and their respective latent constructs. Composite reliability (CR) values ranged from 0.88 to 0.93, and average variance extracted (AVE) values ranged from 0.60 to 0.72. These results satisfy established criteria for internal consistency and convergent validity as recommended by [20].

Table 5. Standard weighting values of the smart campus measurement model.

Variables	Factor Loading			r^2	AVE	CR	Cronbach's Alpha
	Beta	SE	Z				
Economy							
Bus	0.731	0.055	13.300	0.535			
Imp	0.735	0.054	13.503	0.540			
Inno	0.836	0.039	21.350	0.699			
Utility	0.813	0.042	19.235	0.661	0.67	0.90	0.963
Society							
Commu	0.772	0.048	16.217	0.596			
Quality	0.661	0.060	11.103	0.437			
Social	0.835	0.033	24.935	0.697			
Versatile	0.835	0.037	22.644	0.697	0.60	0.88	0.968
Environment							
Envi	0.821	0.036	22.666	0.675			
Renew	0.815	0.041	19.835	0.665			
Sustain	0.771	0.045	17.033	0.594			
Zero	0.715	0.055	13.039	0.511	0.64	0.90	0.958
Governance							
Cyber	0.862	0.031	27.403	0.744			
Gover	0.858	0.032	26.907	0.737			
Making	0.777	0.045	17.346	0.604			
Service	0.894	0.027	33.583	0.799	0.72	0.93	0.963

Collectively, these findings confirm that the four latent constructs—Economy, Society, Environment, and Governance—were measured with reliability and validity. This establishes a robust empirical basis for subsequent structural modeling and hypothesis testing.

Table 6 presents the global fit indices for the structural model, which collectively demonstrate an excellent fit to the data. The χ^2/df ratio was 1.16, and the chi-square statistic was not significant (p = 0.0532), indicating no substantial discrepancy between the hypothesized model and the observed covariance matrix. The Comparative Fit Index (CFI = 0.998) and the Tucker–Lewis Index (TLI = 0.980) were both exceptionally high, confirming that the specified model closely reproduced the observed data. The standardized root-mean-square residual (SRMR = 0.017) indicated minimal residual variance, and the root-mean-square error of approximation (RMSEA = 0.059) was within the acceptable range for structural equation modeling applications. Collectively, these results provide robust empirical support for the proposed TOE–Smart Campus framework.

While the RMSEA value (0.059) is moderately higher compared to the near-perfect CFI and TLI values, this outcome aligns with the RMSEA's established sensitivity to small sample sizes and low degrees of freedom. RMSEA values tend to increase slightly when the sample size is less than 200 or when χ^2 values are close to zero, whereas incremental fit indices such as CFI and TLI remain more stable under these conditions. In the present study, the high CFI and TLI values indicate strong factor loadings and a coherent model structure, and the RMSEA value remains well within the recommended threshold of ≤ 0.08. Therefore, this divergence is attributable to sample-size characteristics rather than model misspecification.

Interpretation of model fit was not based solely on the χ^2 statistic, given its sensitivity to sample size. Standardized residuals and modification indices were reviewed to identify potential areas of misfit. No theoretically meaningful model adjustments were warranted, and no post hoc re-specifications were performed. The final model corresponds directly to

the original theoretical specification, and the diagnostic results collectively confirm that the model is well-specified and adequately represents the empirical data.

Figure 3 presents the structural relationships among the three exogenous TOE dimensions: Technology, Organization, and Environment, and the four endogenous Smart Campus performance domains: Economy, Society, Environment, and Governance. All standardized path coefficients were positive and statistically significant at $p < 0.05$, indicating that each TOE dimension had a meaningful and theoretically consistent effect on the corresponding outcome domains. These findings demonstrate that the hypothesized causal structure is both stable and empirically supported.

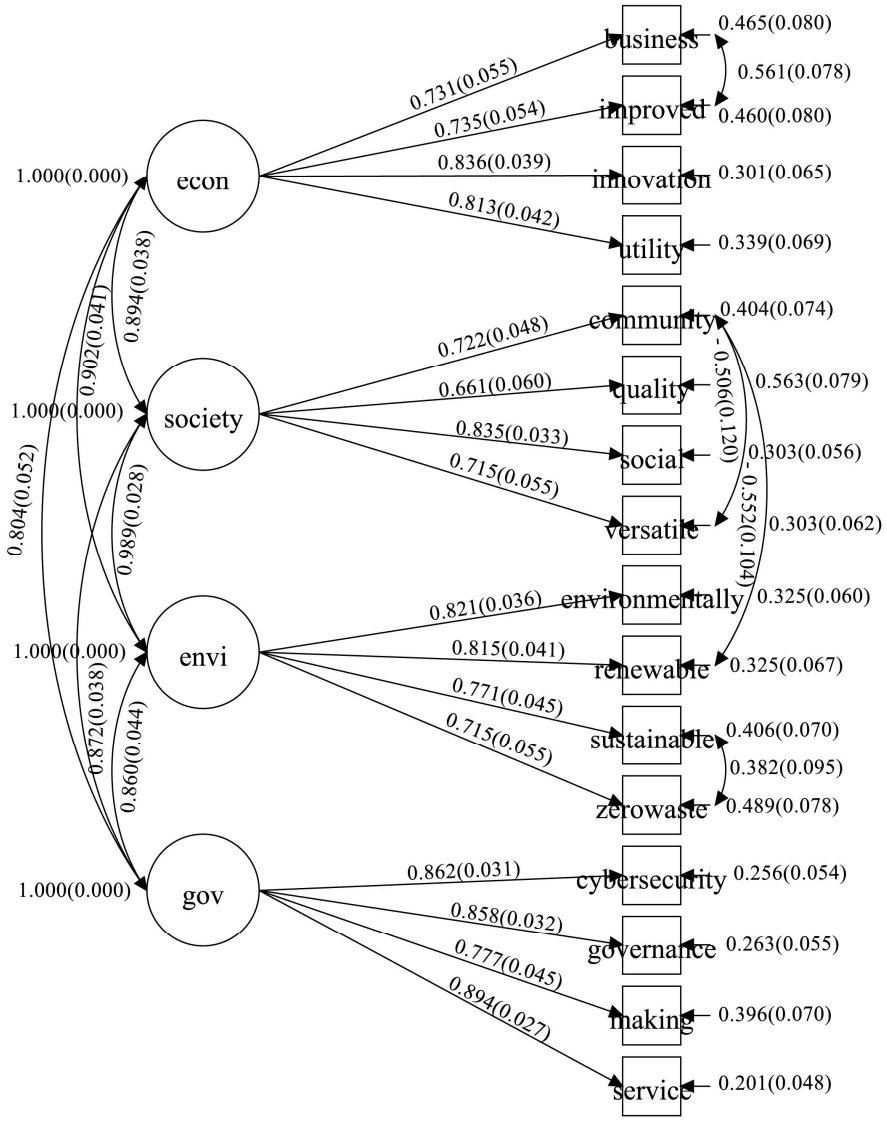

Figure 3. CFA of Smart Campus Performance Dimensions. The figure shows the four performance dimensions—economic, social, environmental, and governance—each measured by multiple indicators with significant standardized factor loadings ($p < 0.001$). Covariances among the four latent dimensions are shown with double-headed arrows.

The structural findings are consistent with earlier measurement tests. As shown in Table 4, the confirmatory factor analysis (CFA) results established strong reliability and convergent validity for all latent constructs. The model fit indices reported in Table 5 (χ^2/df = 1.16, CFI = 0.998, TLI = 0.980, RMSEA = 0.059, SRMR = 0.017) also indicate excellent overall model fit.

Table 6. Goodness-of-fit indices for the smart campus structural model.

Fit Index	Recommended Threshold	Observed Value	Interpretation/Result
Chi-square (χ^2)	$p \geq 0.05$	988.222 (df = 918, p = 0.0532)	Passed–non-significant difference between model and data
Relative Chi-square (χ^2/df)	≤2	1.1647	Passed–Excellent fit
p-value	≥0.05	0.3215	Passed–Model not significantly different from observed data
RMSEA	≤0.05 = Good; ≤0.08 = Acceptable	0.059	Marginal–Acceptable fit
TLI (Tucker–Lewis Index)	≥0.95	0.980	Passed–Excellent fit
CFI (Comparative Fit Index)	≥0.95	0.998	Passed–Excellent fit
SRMR (Standardized Root Mean Square Residual)	≤0.08 = Good; ≤0.05 = Excellent	0.017	Passed–Excellent fit
RMSEA (CFA Phase)	≤0.05	0.014 (90% CI = 0.000–0.020)	Passed–Excellent fit
CFI (CFA Phase)	≥0.95	0.995	Passed–Excellent fit
TLI (CFA Phase)	≥0.95	0.993	Passed–Excellent fit
SRMR (CFA Phase)	≤0.08	0.063	Passed–Good fit

Collectively, these results confirm that the TOE-based structural model is theoretically coherent and empirically robust, effectively explaining the multidimensional nature of Smart Campus success.

4.6. Hypothesis Testing and Path Analysis

Following confirmation that both the measurement and structural models exhibited satisfactory validity and fit, the hypotheses derived from the TOE framework were formally tested. Structural Equation Modeling (SEM) was used to estimate standardized path coefficients (β), standard errors (SE), critical ratios (C.R.), and p-values for all sixteen hypotheses (H_1–H_{16}). These estimates facilitated the identification of statistically significant relationships among the TOE dimensions and Smart Campus performance domains.

The results, summarized in Table 7 and illustrated in Figure 4, reveal structural relationships that collectively explain Smart Campus success. The significant pathways indicate that technological readiness, organizational capability, and environmental support each contribute to the economic, social, environmental, and governance outcomes of Smart Campus development. Collectively, these findings offer robust empirical support for the theoretical model and underscore the interconnectedness of the factors influencing Smart Campus performance.

Table 7. Goodness-of-fit indices for the smart campus structural model.

H	Path	Estimate (β)	S.E.	C.R.	p-Value	Result
H_1	Technology → Economy	0.132	0.045	2.927	0.003	Supported
H_2	Technology → Society	0.217	0.060	3.604	0.000	Supported
H_3	Technology → Environment	0.245	0.059	4.140	0.000	Supported
H_4	Technology → Governance	0.325	0.074	4.379	0.000	Supported
H_5	Organization → Economy	0.158	0.050	3.148	0.002	Supported
H_6	Organization → Society	0.326	0.066	4.918	0.000	Supported
H_7	Organization → Environment	0.265	0.058	4.569	0.000	Supported

Table 7. *Cont.*

H	Path	Estimate (β)	S.E.	C.R.	*p*-Value	Result
H_8	Organization → Governance	0.294	0.067	4.403	0.000	Supported
H_9	Environment → Economy	0.228	0.049	4.684	0.000	Supported
H_{10}	Environment → Society	0.210	0.061	3.426	0.001	Supported
H_{11}	Environment → Environment	0.319	0.061	5.228	0.000	Supported
H_{12}	Environment → Governance	0.342	0.068	5.030	0.000	Supported
H_{13}	Economy → Smart Campus	0.416	0.069	6.029	0.000	Supported
H_{14}	Society → Smart Campus	0.382	0.066	5.758	0.000	Supported
H_{15}	Environment → Smart Campus	0.287	0.068	4.220	0.000	Supported
H_{16}	Governance → Smart Campus	0.245	0.066	3.712	0.000	Supported

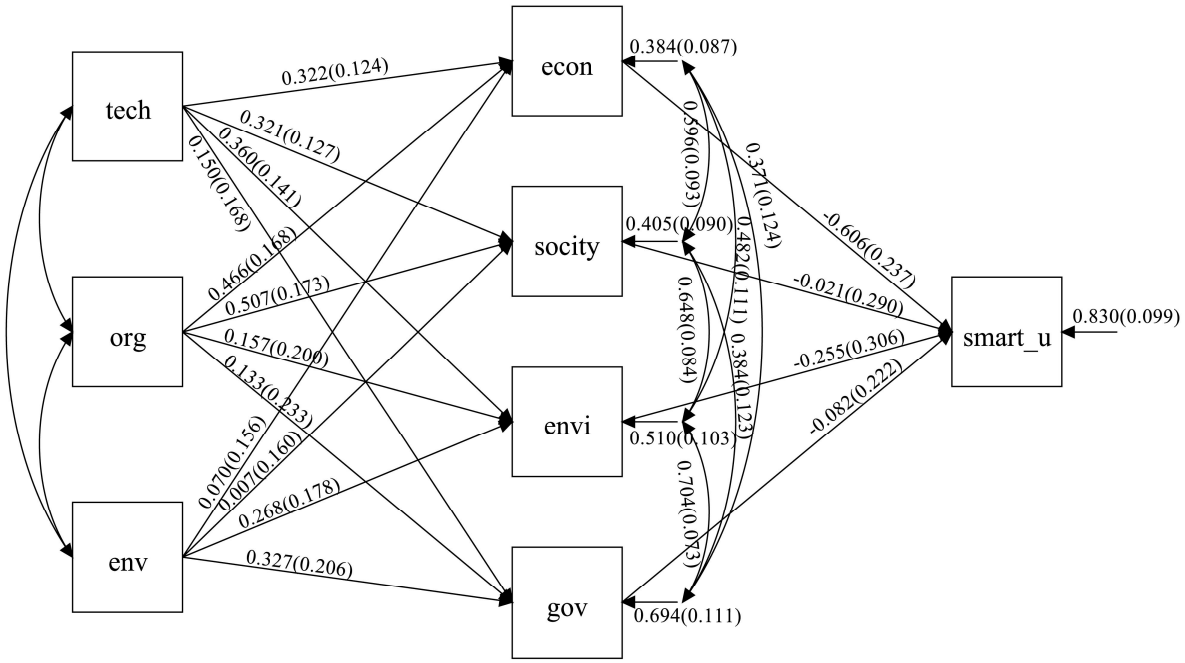

Figure 4. Structural Model of smart campus Success (SEM).

Table 5 summarizes the hypothesis testing results. All sixteen structural paths (H_1–H_{16}) reached statistical significance at $p < 0.05$, demonstrating that the relationships among the constructs align with the theoretical expectations of the TOE framework. The three exogenous factors, Technology, Organization, and Environment, each exhibited positive effects on the four Smart Campus performance domains, thereby supporting H_1–H_{12}.

Within the TOE dimensions, the strongest effects occurred between Organization and the Social domain (β = 0.326), as well as between Environment and the Governance domain (β = 0.342). These results underscore the importance of organizational readiness, including leadership commitment and institutional culture, and emphasize the influence of external environmental support, such as policy conditions and stakeholder expectations, in shaping Smart Campus development.

The four performance domains also had significant positive effects on overall Smart Campus success (H_{13}–H_{16}). The Economic domain contributed most substantially (β = 0.416), followed by the Social (β = 0.382), Environmental (β = 0.287), and Governance (β = 0.245) domains. These results indicate that enhancements in efficiency, innovation capacity, and resource management are closely associated with Smart Campus performance, while social engagement and environmental sustainability remain important contributors.

In summary, the results confirm that technological capability, organizational readiness, and environmental support collectively drive Smart Campus success in Thailand, providing robust empirical support for the TOE-based conceptual model.

Figure 4 presents the complete structural equation modeling (SEM) results, which illustrate the primary causal pathways linking the three Technology–Organization–Environment (TOE) predictors—Technology, Organization, and Environment—to the four Smart Campus performance domains: Economy, Society, Environment, and Governance. All standardized path coefficients were positive and statistically significant at $p < 0.05$, indicating that the structural relationships were stable and consistent with the theoretical expectations of the model.

As summarized in Table 6 and depicted in Figure 4, all sixteen hypotheses (H_1–H_{16}) received empirical support. These findings reinforce the robustness of the Technology–Organization–Environment (TOE) framework as an explanatory model for Smart Campus success. Among the three predictors, the organizational and environmental dimensions exerted the strongest effects, highlighting the significance of leadership commitment, institutional readiness, and supportive policy environments in facilitating digital transformation.

Collectively, these findings indicate that Smart Campus development is influenced not only by technological capability but also by institutional capacity for change management and by external conditions that support innovation.

5. Discussion

5.1. Overview of Key Findings

The findings indicate that the Technology–Organization–Environment (TOE) framework offers a robust and empirically validated explanation for Smart Campus success in the context of Thai higher education. All sixteen hypotheses (H_1–H_{16}) received statistical support, confirming that technological readiness, organizational capability, and environmental conditions collectively influence the four key performance domains: economic, social, environmental, and governance, which are integral to Smart Campus development.

Within the TOE dimensions, the organizational factor exerted the most substantial influence, particularly on the social domain ($\beta = 0.326$). This result emphasizes the significance of leadership commitment, institutional culture, and collective engagement in facilitating digital transformation. The environmental factor had the strongest effect on governance ($\beta = 0.342$), underscoring the impact of external pressures, national policy, and stakeholder expectations in promoting transparent and accountable digital management practices.

At the outcome level, the economic domain contributed most significantly to overall Smart Campus success ($\beta = 0.416$), indicating that efficiency gains, innovation capacity, and effective resource management are central to institutional advancement. The significant effects observed in the social, environmental, and governance domains further demonstrate that Smart Campus development is inherently multidimensional, integrating operational performance with social responsibility and sustainable practices.

The model demonstrated excellent overall fit ($\chi^2/df = 1.16$, CFI = 0.998, TLI = 0.980, RMSEA = 0.059, SRMR = 0.017), confirming both theoretical coherence and empirical adequacy. Overall, these findings establish the TOE-based framework as a valid and practical approach for understanding the evolution and success of Smart Campus initiatives in higher education settings.

5.2. Theoretical Implications

This study adds to the growing body of research that applies the Technology–Organization–Environment (TOE) framework to digital transformation in higher education.

The findings support previous research [32,33], demonstrating that technological capability, organizational readiness, and environmental pressures collectively influence institutional progress. The pronounced effect of organizational factors aligns with earlier studies that highlight the importance of leadership commitment, institutional culture, and structural support in fostering innovation and organizational change [34,35]. The positive influence of environmental conditions is consistent with research by [36], which shows that regulatory frameworks and policy initiatives improve institutional responsiveness. Similarly, the notable impact of the economic domain supports the arguments of [5,37] that efficiency, innovation, and strategic resource management are essential for successful Smart Campus initiatives. Overall, these results reinforce the TOE framework by demonstrating the interaction between internal capacities and external conditions in driving digital transformation in higher education.

In addition to confirming established theoretical relationships, this study advances Smart Campus scholarship in several key ways. It offers one of the few empirical investigations in the Thai and broader ASEAN context that integrates the TOE framework with a second-order Smart University Success construct, which includes four sustainability-oriented performance dimensions: economic, social, environmental, and governance. Previous studies in the region have primarily examined technology readiness, isolated adoption factors, or single performance domains. This research expands the theoretical landscape by modeling TOE antecedents and multi-domain institutional performance within a unified structural framework.

The research also contributes conceptually by defining Smart University Success as a higher-order latent construct. This approach advances Smart Campus theory beyond the first-order or single-factor measurement models commonly used in previous empirical studies and enables a more comprehensive understanding of performance outcomes relevant to digital transformation.

Additionally, the study is strengthened by its use of institution-level data collected from senior administrators, offering a governance-level perspective that is seldom addressed in ASEAN Smart Campus research, which typically relies on student or faculty samples. This perspective enhances theoretical understanding of the influence of leadership decision-making and institutional capacity on Smart Campus development.

The study also enhances methodological rigor in TOE-based Smart Campus modeling by providing explicit sample adequacy justification through free-parameter calculations and RMSEA-based power analysis, as well as detailed reporting of estimation diagnostics. These methodological contributions clarify the reliability and validity of TOE applications in higher education and establish a more transparent foundation for future theoretical development.

Collectively, these contributions strengthen and extend the theoretical utility of the TOE framework for explaining multi-dimensional Smart Campus performance, particularly within higher education systems in developing countries experiencing rapid digital transformation.

5.3. Practical Implications

The findings offer actionable insights for policymakers and university leaders aiming to advance Smart Campus development in Thailand and other developing countries. The recommendations are directly informed by the structural equation modeling (SEM) results and reflect the relative strengths of the technology-organization-environment (TOE) dimensions and Smart Campus performance domains.

As organizational readiness was identified as the strongest predictor among the TOE factors, strategic efforts should focus on enhancing leadership capacity, internal coor-

dination, and staff competencies. Organizational readiness can be cultivated through investment in digital skills development, leadership that prioritizes innovation, and participatory decision-making at all institutional levels. Collaboration with peer institutions, industry partners, and government agencies can further strengthen an ecosystem that supports digital transformation, sustainability, and effective governance.

The results also show that the economic domain exerted the greatest influence on overall Smart Campus success. This underscores the need for careful financial planning, evidence-based resource allocation, and investment strategies that link digital technologies—such as IoT systems, big data infrastructures, and cloud platforms—to clearly defined institutional priorities. Digital investments should not be evaluated solely on short-term efficiency gains but also on their contributions to long-term institutional resilience, research capacity, and sociMore broadly, the findings demonstrate that Smart Campus development requires a balanced approach integrating economic, social, environmental, and governance considerations. Universities that align digital transformation initiatives with sustainability objectives, inclusive community engagement, and transparent management practices are more likely to achieve meaningful and lasting benefits. The study underscores that Smart Campus success depends not only on technological innovation but also on the organizational capability and strategic vision necessary to translate digital tools into improved institutional performance.

5.4. Limitations and Future Research

While this study provides valuable empirical insights, several limitations must be considered. First, the data were collected exclusively from Thai higher education institutions, which may restrict the generalizability of the findings to other national systems or policy environments. Another limitation involves the potential for common method bias, as data collection relied on a single self-report instrument completed by senior administrators. Although procedural remedies such as anonymity assurances, neutral wording, and separated questionnaire sections were implemented, the possibility of common method variance remains. Future research should utilize multi-source or multi-level data and expand the analysis to regional or cross-country contexts, particularly within ASEAN.

The use of a cross-sectional design in this study limits the ability to observe digital transformation processes over time. Employing longitudinal, mixed-method, or case-based approaches could yield deeper insights into the evolution of Smart Campus adoption across various institutional types. Although the TOE framework demonstrated strong performance, incorporating additional theories such as the Unified Theory of Acceptance and Use of Technology (UTAUT) or the Resource-Based View (RBV) may offer a more comprehensive theoretical perspective.

Another methodological consideration concerns the exceptionally high overall Cronbach's alpha (0.992). While high internal consistency is anticipated in multidimensional instruments, such values may suggest item redundancy or limited uniqueness. Diagnostic checks indicated that item deletion did not reduce alpha or substantially increase average variance extracted (AVE) or composite reliability, and AVE values (0.60–0.69) confirmed adequate discrimination relative to error variance. Nonetheless, future research could refine or shorten item sets and apply exploratory techniques to optimize scale structure.

A further limitation pertains to the structural model. All hypothesized paths (H_1–H_{16}) were significant, which, although theoretically consistent, requires cautious interpretation since complex social-science models seldom yield uniformly significant coefficients. Future research should conduct additional robustness checks, including mediation analysis, common-latent-factor assessments, reverse-causality tests, or comparisons with alternative model specifications.

Finally, although the study employs causal terminology grounded in theory, the cross-sectional design precludes definitive causal inference. The estimated structural relationships should therefore be interpreted as correlational patterns consistent with the theoretical model. Longitudinal or experimental designs are necessary to establish temporal precedence and confirm causal directions.

6. Conclusions

A causal model was developed and empirically tested to explain the factors influencing Smart Campus success in Thailand, utilizing the Technology–Organization–Environment (TOE) framework as the theoretical foundation. Based on responses from 96 senior university administrators, the results indicate that technological capability, organizational readiness, and environmental support collectively enhance four core performance domains: economic, social, environmental, and governance, which together define Smart Campus success.

All sixteen hypotheses (H_1–H_{16}) were supported, and the structural model demonstrated strong fit ($\chi^2/df = 1.16$, CFI = 0.998, TLI = 0.980, RMSEA = 0.059, SRMR = 0.017). Among the TOE dimensions, organizational readiness exerted the greatest influence, highlighting the importance of leadership, institutional culture, and preparedness in facilitating digital transformation. Environmental factors, including government policy and stakeholder expectations, contributed to sustainable governance and effective resource management, while technological capability remained critical for innovation, efficiency, and system integration.

Among the four domains, the economic factor contributed most significantly to Smart Campus success ($\beta = 0.416$), emphasizing the importance of efficiency improvements, innovation ecosystems, and strategic resource allocation for long-term competitiveness and sustainability. These findings extend the TOE framework by demonstrating that Smart Campus development requires a balance between internal readiness and external support, resulting in multidimensional performance outcomes.

The results provide actionable guidance for policymakers and university leaders. Effective Smart Campus strategies should integrate technological investment, organizational development, and external collaboration. These approaches can produce sustainable, data-driven systems that improve learning, governance, and institutional capacity.

In conclusion, this research presents a validated conceptual model and offers both theoretical and practical insights for advancing Smart Campus transformation in Thailand and other higher-education systems pursuing sustainable digital evolution.

Author Contributions: Z.B.: Conducted the research, designed the study, collected the data, and analyzed the results. C.S.: Provided research supervision, served as the corresponding author, reviewed and edited the manuscript, and oversaw the overall research process. S.K.: Coordinated research activities and assisted with data collection. All authors have read and agreed to the published version of the manuscript.

Funding: Financial support for this study was provided by Mahasarakham Business School, Mahasarakham University, Thailand.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Mahasarakham University (MSU IRB) (protocol code was 374-382/2025 and date of approval was 13 June 2025).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author, Charuay Savithi, upon reasonable request. Due to institutional privacy

and ethical considerations, the raw datasets obtained from Thai higher-education institutions are not publicly available. Aggregated or anonymized data relevant to the analysis may be shared for academic and research purposes upon request.

Acknowledgments: This research project was financially supported by Mahasarakham Business School, Mahasarakham University, Thailand. The authors also wish to thank the senior administrators from all participating universities for providing their valuable responses. All individuals acknowledged in this section have provided their consent to be included.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Polin, K.; Yigitcanlar, T.; Limb, M.; Washington, T. The Making of smart Campus: A Review and Conceptual Framework. *Buildings* **2023**, *13*, 891. [CrossRef]
2. Uskov, V.L.; Bakken, J.P.; Howlett, R.J.; Jain, L.C. Smart Campus. In *Smart Innovation, Systems and Technologies*; Springer Nature: Berlin/Heidelberg, Germany, 2017. [CrossRef]
3. Luckyardi, S.; Hurriyati, R.; Disman, D.; Dirgantari, P.D. A Systematic Review of the IoT in smart campus: Model and Contribution. *Indones. J. Sci. Technol.* **2022**, *7*, 529–550. [CrossRef]
4. Haggag, M.; Oulefki, A.; Amira, A.; Kurugollu, F.; Mushtaha, E.S.; Soudan, B.; Hamad, K.; Foufou, S. Integrating advanced technologies for sustainable smart Campus development: A comprehensive survey of recent studies. *Adv. Eng. Inform.* **2025**, *66*, 103412. [CrossRef]
5. AbuAlnaaj, K.; Almulla, M.; Al-Hassan, S. Digital transformation in universities: Challenges and success factors. *Educ. Inf. Technol.* **2020**, *25*, 5801–5824.
6. Baker, J. The Technology–Organization–Environment (TOE) framework. In *Information Systems Theory: Explaining and Predicting our Digital Society*; Dwivedi, Y.K., Wade, M.R., Schneberger, S.L., Eds.; Springer: Berlin/Heidelberg, Germany, 2011; Volume 1, pp. 231–245. [CrossRef]
7. Mirata, V.; Bergamin, P. Role of organisational readiness and stakeholder acceptance: An implementation framework of adaptive learning for higher education. *Educ. Technol. Res. Dev.* **2023**, *71*, 21. [CrossRef]
8. Trevisan, L.V.; Eustachio, J.H.P.; Dias, B.G.; Filho, W.L. Digital transformation towards sustainability in higher education: State-of-the-art and future research insights. *Environ. Dev. Sustain.* **2024**, *26*, 2789–2810. [CrossRef] [PubMed]
9. Tornatzky, L.G.; Fleischer, M. *The Processes of Technological Innovation*; Lexington Books: Lanham, MD, USA, 1990.
10. Shao, J.; Min, B. Sustainable development strategies for smart Cities: Review and development framework. *Cities* **2024**, *158*, 105663. [CrossRef]
11. Dawodu, A.; Dai, H.; Zou, T.; Zhou, H.; Lian, W.; Oladejo, J.; Osebor, F. Campus sustainability research: Indicators and dimensions to consider for the design and assessment of a sustainable campus. *Heliyon* **2022**, *8*, e11864. [CrossRef]
12. Villegas-Ch, W.; Palacios-Pacheco, X.; Luján-Mora, S. Application of a smart City Model to a Traditional University Campus with a Big Data Architecture: A Sustainable smart Campus. *Sustainability* **2019**, *11*, 2857. [CrossRef]
13. Moura, P.; Moreno, J.I.; López López, G.; Alvarez-Campana, M. IoT Platform for Energy Sustainability in University Campuses. *Sensors* **2021**, *21*, 357. [CrossRef]
14. Al-Dmour, H. Green-smart campus Campuses: The mediating role of student engagement in enhancing corporate image. *SAGE Open* **2023**, *13*, 21582440231219591. [CrossRef]
15. Mattos, L.K.; Flach, L.; Costa, A.M.; Ocampo Moré, R.P. Effectiveness and sustainability indicators in higher education management. *Sustainability* **2023**, *15*, 298. [CrossRef]
16. Polin, K.; Yigitcanlar, T.; Limb, M.; Washington, T. Unpacking smart Campus Assessment: Developing a Framework via Narrative Literature Review. *Sustainability* **2024**, *16*, 2494. [CrossRef]
17. Alojail, M.; Alshehri, J.; Khan, S.B. Critical Success Factors and Challenges in Adopting Digital Transformation in the Saudi Ministry of Education. *Sustainability* **2023**, *15*, 15492. [CrossRef]
18. Fernández, A. Digital transformation initiatives in higher education institutions: A multivocal literature review. *Educ. Inf. Technol.* **2023**, *28*, 1339–1365. [CrossRef]
19. Yang, J.; Luo, B.; Zhao, C.; Zhang, H. Artificial intelligence healthcare service resources adoption by medical institutions based on TOE framework. *Digit. Health* **2022**, *8*, 205520762211260. [CrossRef] [PubMed]
20. Clark, D. Markets, metrics, and modernisation: Higher Education strategy makers' conceptualisations of digital empowerment. *Discourse Stud. Cult. Politics Educ.* **2024**, *46*, 550–565. [CrossRef]
21. Suttidee, A.; Savithi, C. Factors influencing the adoption of cloud computing for Thai SME businesses. *J. Comput. Sci.* **2025**, *21*, 273–278. [CrossRef]

22. Carmo, J.E.S.; Lacerda, D.P.; Klingenberg, C.O.; Piran, F.A.S. Digital transformation in the management of higher education institutions. *Sustain. Futures* **2025**, *9*, 100692. [CrossRef]
23. Elbertsen, M.; Kok, H.; Salimi, N. Designing the future smart campus: Integrating key elements to enhance user experience. *J. Sci. Technol. Policy Manag.* **2025**, *16*, 117–137. [CrossRef]
24. Singh, A.B.; Meena, H.K.; Khandelwal, C.; Dangayach, G.S. Sustainability Assessment of Higher Education Institutions: A Systematic Literature Review. *Eng. Proc.* **2023**, *37*, 23. [CrossRef]
25. Oliveira, M.C.; Proença, J. Sustainable campus operations in higher education institutions: A systematic literature review. *Sustainability* **2025**, *17*, 607. [CrossRef]
26. Chounta, I.-A.; Ortega-Arranz, A.; Daskalaki, S.; Dimitriadis, Y.; Avouris, N. Toward a data-informed framework for the assessment of digital readiness of higher education institutions. *Int. J. Educ. Technol. High. Educ.* **2024**, *21*, 59. [CrossRef]
27. Hair, J.F.; Anderson, R.E.; Tatham, R.L.; Black, W.C. *Multivariate Data Analysis*, 7th ed.; Pearson Education: London, UK, 2010.
28. Bentler, P.M. Comparative fit indexes in structural models. *Psychol. Bull.* **1987**, *102*, 238–246. [CrossRef]
29. Kline, R.B. *Principles and Practice of Structural Equation Modeling*, 3rd ed.; Guilford Press: New York, NY, USA, 2011.
30. MacCallum, R.C.; Browne, M.W.; Sugawara, H.M. Power analysis and determination of sample size for covariance structure modeling. *Psychol. Methods* **1996**, *1*, 130–149. [CrossRef]
31. Kock, N. Common Method Bias in PLS-SEM: A Full Collinearity Assessment Approach. *Int. J. e-Collab. (IJe-C)* **2015**, *11*, 1–10. [CrossRef]
32. Oliveira, T.; Martins, M.F. Literature review of information technology adoption models at firm level. *Electron. J. Inf. Syst. Eval.* **2011**, *14*, 110–121.
33. Benavides, L.M.C.; Tamayo Arias, J.A.; Arango Serna, M.D.; Branch Bedoya, J.W.; Burgos, D. Digital Transformation in Higher Education Institutions: A Systematic Literature Review. *Sensors* **2020**, *20*, 3291. [CrossRef] [PubMed]
34. Thong, J.Y.L. The adoption of information technology by small business: An integrated model. *Inf. Manag.* **1994**, *31*, 44–53.
35. Jewapatarakul, D.; Ueasangkomsate, P. Digital Organizational Culture, Organizational Readiness, and Knowledge Acquisition Affecting Digital Transformation in SMEs from Food Manufacturing Sector. *Sage Open* **2024**, *14*, 21582440241. [CrossRef]
36. Al-Ramahi, N.M.; Odeh, M.; Alrabie, Z.; Qozmar, N. The TOEQCC Framework for Sustainable Adoption of Cloud Computing at Higher Education Institutions in the Kingdom of Jordan. *Sustainability* **2022**, *14*, 12744. [CrossRef]
37. Polin, K.; Yigitcanlar, T.; Limb, M.; Washington, T. smart campus performance assessment: Framework consolidation and validation through a Delphi study. *Buildings* **2024**, *14*, 4057. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.