SCIENTIFIC CULTURE

www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 12, No. 2.1, (2026), pp. 11568-11581
Open Access. Online & Print

DOI: 10.5281/zenodo.20200676

TECHNOLOGY-DRIVEN INNOVATION IN CAMPUS FACILITIES MANAGEMENT: A CASE STUDY OF A PREFABRICATED PRIMARY SCHOOL IN CHINA

Mi Li[1*], Minghao Huang[2]

[1]aSSIST University(South Korea). Email: mli833670@gmail.com*
[2]aSSIST University(South Korea). Email: mhuang@assist.ac.kr

Received: 07/02/2026
Accepted: 08/04/2026

Corresponding Author: Mi Li
(mli833670@gmail.com)

ABSTRACT

This study examines how technology-driven approaches reshape campus facilities management in educational settings, based on a case study of a primary school project in Hangzhou, China. Drawing on planning documents, meeting records, technical reports, and BIM-related materials, the study employs a theory-driven thematic analysis to explore how digital and modular technologies are embedded into management practices. The findings reveal that the role of technology extends beyond project delivery and reconfigures facilities management through three interrelated mechanisms: digital collaboration, modular governance, and campus operational governance. These mechanisms collectively drive innovation in campus facilities management models, supporting a transition from construction-oriented management toward integrated, process-oriented, and governance-oriented facilities management. In particular, digital technologies enhance cross-phase information integration and dynamic coordination, modular approaches improve lifecycle traceability and maintenance support, and spatial and operational arrangements strengthen efficiency, order, and adaptability in campus management. Overall, the study demonstrates that technology-driven innovation transforms campus facilities from physical assets into governance infrastructures that support educational operations and organizational coordination.

KEYWORDS: Technology-Driven Innovation; Campus Facilities Management; BIM; Modular Governance; Educational Governance.

1. INTRODUCTION

A new wave of digital and engineering technologies is reshaping not only the delivery of public infrastructure but also the ways in which such infrastructures are managed, operated, and governed. Existing studies suggest that Building Information Modeling (BIM) enables the integration of information across design, construction, and operational stages, thereby providing a data foundation for lifecycle-oriented facilities management (Muhammad & Mustapa, 2020; Kassem et al., 2015). Prefabrication, characterized by standardized design, modular production, and industrialized processes, enhances efficiency and consistency, and is widely regarded as an important pathway toward sustainable and industrialized infrastructure systems (Li et al., 2022; Liu et al., 2023). In addition, emerging technologies such as digital twins further extend these capabilities by supporting data-driven operation, dynamic monitoring, and real-time decision-making in facility systems (Pedral Sampaio et al., 2023; Hakimi et al., 2024). While these technologies originate from engineering domains, their growing importance lies in enabling new forms of coordination, information integration, and operational control within facilities management systems (Dahanayake & Sumanarathna, 2022; Atta & Talamo, 2019). At the organizational level, digital transformation is increasingly recognized as a key driver of changes in management processes and coordination mechanisms (Thản & Nếp, 2026). In the context of educational infrastructure, this shift implies that technology is not merely transforming how schools are built, but more fundamentally how campus facilities are organized, managed, and aligned with educational activities. Accordingly, facilities are increasingly understood not only as physical assets but also as integral components of organizational systems that support service delivery, coordination, and governance functions (Hakimi et al., 2024; Naji et al., 2024). As a result, campus facilities are evolving from passive physical assets into dynamic infrastructures that enable monitoring, coordination, and institutional functioning. Despite growing attention to the role of technology in facilities management and lifecycle operations, existing research has not sufficiently examined how such technologies reshape campus facilities management models from an educational management perspective. In school settings, facilities management is inherently multi-dimensional, involving not only physical maintenance but also space utilization, safety governance, equipment coordination, and resource allocation (Mahmoud et al., 2024). These functions are closely intertwined with teaching activities, user behavior, and organizational arrangements, making campus facilities management a critical component of educational governance rather than a purely technical task (Gunduz et al., 2024; Mohammed & Amoah, 2025). However, prior studies have largely focused on operational decision-making in higher education contexts (Mohammed & Amoah, 2025), with limited attention to primary and secondary education, where governance structures and management priorities differ significantly. Against this background, there remains a need to systematically examine the mechanisms through which technology shapes campus facilities management, particularly in terms of how it reconfigures management processes, coordination patterns, and governance structures (Ba et al., 2023). Addressing this gap requires moving beyond a technology-centric perspective and instead situating technological applications within a broader "technology–management–governance" framework. This study takes a prefabricated primary school project as an empirical case to explore how technology-driven approaches are embedded into campus facilities management practices and how they contribute to management model innovation. Rather than focusing solely on technical implementation, the study emphasizes how digital and modular technologies interact with management mechanisms and organizational processes. Specifically, it addresses three research questions. First, how are technology-driven approaches integrated into campus facilities management systems, and how do they reshape management processes? Second, how do these technologies facilitate a shift from construction-oriented management toward information-based, collaborative, and governance-oriented facilities management? Third, what are the implications of such transformations for campus spatial organization, safety management, and resource allocation? This study aims to deepen the understanding of technology-driven innovation in facilities management from an educational management perspective. It further seeks to provide empirical insights into how campus facilities can function as governance infrastructures that support educational operations, organizational coordination, and institutional effectiveness.

2. THEORETICAL BACKGROUND

2.1. Educational Facilities Management and the Shift toward Technologies

With the development of public management, facilities management, and asset management theories, educational facilities management has gradually shifted from one-time investment in the construction stage to lifecycle governance. Research has also expanded from planning and design to operational issues such as space management, occupancy evaluation, and optimization decisions (Di Giuda et al., 2024).

On this basis, school facilities are increasingly viewed as long-term public assets that require systematic management to improve utilization efficiency and service quality. At the same time, the advancement of sustainability concepts has led educational facilities management to place greater emphasis on energy monitoring, operation and maintenance management, and the sustainability of campus environments (Shamsuddin et al., 2025).

In the context of digitalization, technologies such as BIM and digital platforms have been introduced into public facilities management to enhance data integration, decision support, and cross-stakeholder collaboration. Studies show that BIM integrates information across design, construction, and operation, providing a unified data foundation for lifecycle building management (Muhammad & Mustapa, 2020).

When connected with facilities management tools, it can further improve maintenance decision-making and asset management capabilities (Lourenço et al., 2025). At the same time, prefabricated construction improves efficiency through standardized design, prefabricated production, and modular assembly. It also enhances the identifiability and traceability of components, providing a stronger information basis for subsequent maintenance, upgrading, and facilities management (Ismail et al., 2023). Driven by green building and sustainability agendas, engineering technologies are also regarded as important tools for improving project sustainability performance and resource management capability (Zhang et al., 2023).

However, existing studies mainly focus on the application of technologies in general building management, with limited analysis of how engineering technologies drive systematic transformation in campus facilities management within the context of educational management. In primary and secondary education, campus facilities not only support teaching activities but also involve multiple governance objectives, including student safety, spatial organization, after-school services, and home–school interaction.

Therefore, it is necessary to further examine how engineering technologies influence the organizational logic, operational modes, and governance mechanisms of campus facilities management from an educational management perspective.

2.2. *Technology-Driven Campus Facilities Management*

Campus facilities management models can generally be categorized into three types: traditional support-oriented models, information-integrated models, and technology-driven governance models, with the third receiving particular research attention. School facilities are not neutral physical spaces but complex governance carriers that support teaching organization, student activities, safety management, and home–school interaction. Existing studies note that facilities and asset management in educational institutions should link lifecycle planning, digital tools, and organizational decision-making (Purnawan, 2025). Their performance is reflected not only in maintenance quality but also in multidimensional operational and managerial outcomes (Gunduz et al., 2024).

In this study, an engineering technology–driven campus facilities management model is defined as an integrated management approach in which digital, intelligent, and modular engineering technologies are embedded in campus construction and operation. By connecting information across design, construction, operation, and user feedback, this model reshapes coordination relationships, organizational units, and operational boundaries in facilities management, thereby optimizing lifecycle governance of facilities. The key of this model lies not in the adoption of individual technologies but in how technologies reshape the operational logic of campus facilities management through specific managerial mechanisms. In this study, engineering technologies are therefore not treated as isolated variables but examined within an analytical framework of "engineering technology embedding–management mechanism reconstruction–management model innovation." Based on this framework, the following analysis uses the case study to examine how engineering technologies reconstruct campus facilities management mechanisms and drive innovation in campus facilities management models through three mechanisms: digital collaboration, modular governance, and campus operational governance.

3. RESEARCH DESIGN

3.1. *Case Selection and Data Collection*

This study selects a prefabricated primary school construction project in Binjiang District, Hangzhou, China, as the research case. Single-case studies provide empirical evidence for understanding complex management mechanisms and model innovation through in-depth analysis of a typical project (Gomes Araújo & Lucko, 2022). During construction, the project integrated prefabricated construction, building information modelling (BIM), and green building design, and achieved the Three-Star Green Building certification. It also demonstrates a systematic approach to facilities management in campus operation and safety management, making it suitable for examining the interaction between engineering technologies and campus facilities management.

The data used in this study mainly come from project planning and design documents, including design descriptions, master plans, traffic organization schemes, meeting records involving experts, managers, design institutions, and users, as well as technical evaluation reports on prefabricated construction and BIM design and construction documents. These materials include both textual and graphical data. All materials were obtained and used in accordance with relevant ethical requirements, and no personal or sensitive information was reported in the analysis.

3.2. Analytical Method

This study applies a theory-driven thematic analysis to examine the case materials, guided by the analytical framework of "engineering technology embedding–management mechanism reconstruction–management model innovation" from the perspective of educational facilities management. Given the type and scale of the data, coding was mainly conducted using Microsoft Excel, where textual and graphical materials were systematically organized, coded, compared, and grouped. Specifically, the analysis followed a three-stage coding process. First, open coding was conducted to extract concepts from the case materials, focusing on how engineering technologies appear in campus planning, construction, and operational support. This process produced 373 initial codes.

Second, theme aggregation was performed by comparing and grouping the initial codes, resulting in six second-order themes (Table 1). Third, mechanism abstraction was conducted by analyzing the relationships among the second-order themes, leading to the identification of three mechanisms (Table 2).

To enhance analytical trustworthiness, this study employed data triangulation, constant comparison, author-based cross-checking, and external review during coding. Planning and design documents, traffic organization schemes, meeting records, technical evaluation reports, BIM-related documents, and graphical materials were cross-checked to verify whether the identified themes were supported by multiple sources. The researchers also traced the consistency among original semantic units, preliminary conceptualizations, second-order themes, and mechanism-level categories, and conducted trace-back checks to ensure that mechanism abstraction remained grounded in the empirical materials. The first author completed the initial coding, while the second author independently reviewed selected original materials, initial codes, and thematic classifications. Disagreements were resolved through discussion between the two authors. In addition, an external researcher familiar with qualitative research methods reviewed the coding logic, thematic classification, and mechanism abstraction, thereby strengthening the transparency and robustness of the analysis.

4. FINDINGS

Through open coding and theme aggregation of the case materials, this study finds that the impact of engineering technologies on campus facilities management extends beyond the construction stage and gradually influences multiple aspects of campus facility development, operation, and governance. Table 1 presents the process through which second-order themes were derived from the original materials through concept extraction and theme aggregation.

Based on the relationships among these themes, the findings are further summarized into three aspects: technology-driven digitalization of facilities management, prefabricated construction and modular management, and the optimization of comprehensive campus management. The case analysis indicates that technology-driven innovation in campus facilities management is not the result of isolated technical applications, but of the interaction among technology embedding, management mechanism reconstruction, and campus operational needs.

The incorporation of BIM, prefabricated construction, and operational support systems into facilities management shifts it from a construction-oriented approach toward collaborative, process-oriented, and governance-oriented management, while also affecting campus spatial organization, safety management, and resource allocation.

Table 1: Excerpt of Open Coding and Thematic Aggregation.

Original Semantic Units (Excerpt)	Preliminary Conceptualization	Second-Order Themes
The constructed BIM model of the construction drawings contains all the information represented in the drawings.	BIM full information integration	BIM information integration and cross-stage collaboration
Integrate all disciplines—architecture, structure, and MEP—into a single model.	Unified modeling of multiple disciplines	
Achieve zero clashes in pipelines	Pipeline clash resolution	
A BIM collaboration platform should be established… to ensure that design, production, construction, and finishing work can be coordinated on the platform.	The BIM collaboration platform connects multiple project stages.	
The project is equipped with a sub-metering system for electricity consumption.	Institutionalized electricity metering	Intelligent monitoring and data-driven operational control
A building equipment monitoring and management system is used to automatically control and monitor air conditioning equipment, pumps, various fans, electrical lighting, and other electrical devices in real time.	Automated equipment monitoring	
The underground parking garage ventilation system automatically operates based on the CO concentration inside the garage.	Adaptive control of parking garage ventilation	
Approximately 75% of components such as beams, slabs, stairs, balconies, and air-conditioning panels are used.	Prefabrication of primary structural components	Standardized components and prefabricated construction
Adopt wall and pipeline integration (ALC interior partition panels) ≥80%	Wall-pipeline integration	
The construction unit should specify a detailed construction plan for processes such as storage, hoisting, installation positioning, and connection with cast-in-place concrete of prefabricated components.	Planned management of key prefabrication processes	
Each component is assigned a unique identifier to ensure that the model file can accurately extract the required data.	Unique identifier for components	Component traceability and full lifecycle operation and maintenance support
Establish a component production management system… to trace and manage the production quality and progress of components.	Component production database and traceability	
The BIM model in the project's operation and maintenance phase should use a fully detailed as-built BIM model.	As-built model supporting operation and maintenance	
The overall framework can be summarized as "one axis, four zones, and two courtyards."	Overall coordination of campus structure	Spatial organization and functional zoning governance
Divided into four functional zones: teaching area, conference area, cultural and sports service area, and outdoor sports area.	Functional zoning management	
Ordinary classrooms for two age groups are arranged on the same floor in segments, with nearby specialized classrooms and auxiliary teaching spaces.	Age-segmented teaching with nearby auxiliary spaces	
The design channels all types of pick-up and drop-off traffic into the basement pick-up hall.	Centralization of pick-up and drop-off spaces in the basement	Traffic organization and safety boundary control
Students are picked up and dropped off in batches and time slots from the basement pick-up hall by their parents, facilitating management and effective flow separation.	Time- and batch-based pick-up and drop-off management	
The public parking lot and internal parking area are separated by barriers, access to the parent pick-up and drop-off area is controlled by gates, and firewalls separate them from the rest of the school buildings.	Multiple barriers delineate the underground safety boundary	
Fire exits should connect to municipal vehicle roads, and sidewalks should slope downward to ensure normal access for fire trucks.	Fire exits directly connected to municipal roads	

4.1. Technology-Driven Digitalization of Facilities Management

In this case, the reshaping of the campus facilities management model by engineering technologies is first reflected in the digital transformation of facilities management. Unlike traditional approaches characterized by discipline-based design, stage-based implementation, and post hoc coordination, BIM technology was embedded throughout the entire campus construction process. Project documents indicate that the BIM model for construction drawings “contains all information represented in the drawings” (C66) and “integrates architectural, structural, and MEP disciplines into a single model” (C67). Based on this model, BIM was used for design review (C68) and for positioning reserved openings for equipment and pipelines (C70), ultimately achieving “zero collision” among pipelines (C71).

The project also proposed that “a building information model should be established from the design stage, with information sharing, effective transmission, and collaborative work implemented throughout project design, component production, and construction” (C146). A BIM collaborative platform was further required to support coordination across design, production, construction, and interior finishing (C149). These practices indicate that engineering technologies not only enhance the visualization of design but also transform facilities management from a process relying on post-stage adjustments and on-site corrections to a digital management approach based on model integration and early-stage collaboration.

The digitalization of management is also reflected in intelligent monitoring and data-based control during the operational stage. Case materials show that the project established a sub-item electricity metering system (C161), requiring all electricity metering devices to support remote data transmission and to be connected to an energy consumption metering and billing management system (C163). A building equipment monitoring and management system was also adopted to automatically control and monitor air conditioners, pumps, fans, and lighting equipment in real time (C165), enabling centralized management, program-based control, and energy-efficient operation (C166).In addition, the ventilation system in the parking garage is automatically controlled based on carbon monoxide concentration (C178), while carbon dioxide sensors are installed in high-density areas to regulate the fresh air volume of the air-conditioning system (C177). The energy management system periodically analyzes energy consumption data, reports equipment anomalies, and continuously optimizes operational modes (C167, C168).

These findings indicate that the digitalization of facilities management in this case is not a single technological application but a systemic transformation combining BIM-based information integration, cross-stage collaboration, sub-item metering, intelligent monitoring, and automated control. Its core effect is a shift in the management logic of campus facilities from “experience-based coordination and post-stage maintenance” to “information integration and dynamic control,” representing the first key empirical finding identified in this study.

4.2. Prefabricated Construction and Modular Management

Corresponding to the digitalization of facilities management, the second impact of engineering technologies on the campus facilities management model is the shift toward modular management driven by prefabricated construction. Traditional campus construction mainly relies on on-site wet operations and fragmented construction processes. In such contexts, component production, installation, and subsequent maintenance lack unified interfaces, and facilities management largely depends on on-site coordination during construction and case-by-case repairs during operation. In this case, however, prefabricated construction—through standardized design, integrated building components, and regulated construction organization—reshapes the organizational logic of facility development and management.

Project documents show that the project “adopts unified modular coordination dimensions, reflecting standardized design” (C200), and requires prefabricated building design to follow the principles of “generalization, modularization, and standardization” (C199). At the same time, prefabricated components—including beams, slabs, stairs, balconies, and air-conditioning panels—account for about 75% of all elements (C47). The proportion of non-load-bearing enclosure walls constructed without masonry is at least 80% (C48), the proportion of non-masonry interior partition walls is at least 50% (C49), and the integration rate of wall structures with pipelines is at least 80% (C50).These features indicate that from the main structural system to the enclosure system and internal pipeline interfaces, the building exhibits strong characteristics of standardized components.

As a result, campus facilities shift from being on-site construction objects to systems composed of standardized modules that can be prefabricated, installed, and replaced.

Modular management is also reflected in the planned and controllable organization of the construction process. Case materials show that contractors were required to develop detailed plans for the storage, lifting, positioning, and joint casting of prefabricated components (C214). The general contractor had to arrange the construction site in advance, plan transportation routes and component storage areas (C215), and inspect component identification numbers and product quality upon delivery (C216). In addition, the lifting methods for prefabricated components and the spacing of temporary supports for composite floor slabs were specified in clear technical standards (C217, C218).This indicates that prefabricated construction not only changes structural forms but also shifts construction management toward planning, stage-based coordination, and standardization. More importantly, this modular advantage extends into the operation and maintenance stage. The project established standardized databases for unit layouts, products, and component information (C144), requiring each component to have a unique identification code (C152). A component production management system was used to record production quality and progress, enabling full-process traceability (C155, C156).

In addition, the project proposed that the operation and maintenance stage should rely on a BIM as-built model containing complete information, which can support the maintenance, repair, and upgrading of buildings and equipment (C223, C224). Therefore, prefabricated construction in this case promotes a modular management model characterized by standardized components, unified interfaces, and full lifecycle traceability. This represents the second key empirical finding regarding engineering technology–driven innovation in campus facilities management.

4.3. Optimization of Comprehensive Campus Management

In this case, the further influence of engineering technologies on the campus facilities management model is reflected in the overall optimization of comprehensive campus management. This optimization does not stem from a single technological tool but from the combined effects of spatial organization, functional configuration, pickup and drop-off systems, and operational support facilities. First, at the spatial level, the project forms a clear campus structure through the overall layout of “one axis, four zones, and two courtyards” (C02), along with functional divisions such as teaching areas, conference areas, cultural and sports service areas, and outdoor sports areas (C04). In addition, the courtyard-based cluster layout and age-based zoning design (C102, C103) transform campus space from a simple arrangement of buildings into governance units that support teaching organization and daily management. Furthermore, covered corridors connect the teaching clusters and lead directly to the comprehensive cultural and sports service building (C29). The provision of shared courtyards, rest platforms, and communication corridors (C90) enhances the linkage among teaching activities, social interaction, and shared use, thereby improving spatial allocation and management efficiency.

Second, the optimization of comprehensive campus management is also reflected in improvements to campus operational order through underground composite spaces and organized pickup and drop-off systems. The project incorporates an underground pickup and drop-off hall and staggered scheduling arrangements (C33, C34), integrating peak-time traffic pressures into the campus’s internal governance system. At the same time, the underground space accommodates multiple functions, including a model aircraft exhibition hall, a student theater, club classrooms, after-school programs, a parent waiting hall, and a library (C108, C114). This indicates that the underground area has evolved from a simple parking facility into an important component of the campus operational support system. Finally, this optimization is also reflected in improved supporting facilities oriented toward user needs. Examples include expanding transitional spaces between functional zones (C264, C265), refining accessibility facilities in the cafeteria and elevator halls (C288, C289), and designing the auditorium to balance evacuation capacity with usability for primary school students (C371).Overall, the optimization of comprehensive campus management in this case shows that engineering technologies not only improve construction methods and operational conditions but also enhance campus management through spatial reorganization, integrated underground use, optimized pickup and drop-off circulation, and improved support facilities. These changes strengthen the orderliness, adaptability, and managerial efficiency of campus operations, representing the third key empirical finding on engineering technology–driven innovation in campus facilities management.

The analysis of the case materials shows that the influence of engineering technologies on campus facilities management extends beyond technical applications in construction and further reshapes the organizational logic and operational modes of facilities management. Specifically, digital technologies drive the digital transformation of facilities management, prefabricated construction promotes modularization and maintainability, and the optimization of spatial organization and operational support systems improves overall campus operational efficiency. These findings indicate that engineering technologies in this case function not only as construction tools but also as key drivers of innovation in campus facilities management models, providing an empirical basis for the subsequent discussion of three mechanisms: digital collaboration, modular governance, and campus operational governance.

5. DISCUSSION

Building on the preceding empirical analysis, this study further examines engineering technology–driven innovation in campus facilities management models from the theoretical perspectives of educational management and facilities governance. This section analyzes how engineering technologies reconstruct the mechanisms of campus facilities management (Table 2), explaining how mechanism reconstruction drives innovation in campus facilities management models. While the findings identify what changed in the case, the discussion explains how these changes can be understood as management mechanisms. In this sense, digital collaboration, modular governance, and campus operational governance are not separate empirical themes but mechanism-level explanations of how engineering technologies reshape campus facilities management.

Table 2: Mechanism Abstraction from Second-Order Themes.

Mechanism type	Second-order theme	Theoretical implication
Digital collaboration	BIM information integration and cross-stage collaboration	Engineering technology, through unified modeling, cross-disciplinary integration, and multi-stage collaboration, restructures the information flow and collaboration methods in campus facility construction, shifting facility management from dispersed coordination to platform-based collaboration.
	Intelligent monitoring and data-driven operational control	Engineering technology, through sub-metering, equipment monitoring, and environmental data feedback, shifts campus facility operations from static maintenance to dynamic monitoring and real-time control, promoting digitalized facility management.
Modular governance	Standardized components and prefabricated construction	Prefabricated construction, through modular design, standardized components, and regulated construction, transforms campus facility construction into a process organized around standard units, enhancing construction efficiency and management consistency.
	Component traceability and full lifecycle operation and maintenance support	The establishment of unique component identifiers, production databases, and as-built models creates a traceable chain from production and installation to maintenance and updates, providing information support for subsequent operational governance.
Campus operational governance	Spatial organization and functional zoning governance	Through functional zoning, cluster layouts, shared gray spaces, and age-segmented teaching organization, campus facilities are transformed into a governance structure that supports teaching operations, public activities, and spatial order.
	Traffic organization and safety boundary control	Through underground pick-up and drop-off areas, separation of pedestrians and vehicles, fire evacuation routes, safety barriers, and boundary management, the campus forms a comprehensive governance system that accommodates daily operations, peak pick-up periods, and emergency safety.

5.1. Digital Collaboration Mechanism

Engineering technologies first reshape the operational logic of campus facilities management through information integration and data connectivity, forming a digital collaboration mechanism. In this case, BIM models, collaborative platforms, sub-item metering systems, and equipment monitoring systems incorporate previously fragmented information from the design, construction, and operational stages into a unified chain. The project not only established an integrated model covering architectural, structural, and MEP disciplines, but also used model-based collaboration to conduct early clash detection and process coordination. In addition, energy metering and equipment monitoring data were connected to the management system to support operational identification and continuous feedback. These practices indicate that digital technologies have evolved from auxiliary tools into management infrastructures that link construction and operation.

Existing studies show that the value of BIM, the Internet of Things, and digital twins mainly lies in cross-stage information integration, real-time status perception, and continuous decision support. These technologies enable facilities management to shift from segmented handling to integrated collaboration (Adeniyi et al., 2025; Ghansah, 2025; Wang et al., 2026), while improving governance efficiency by enhancing information transparency, reducing information asymmetry, and strengthening relational coordination (Liu & Wang, 2026).In this case, the digital collaboration mechanism not only moves facilities management considerations forward to the design and construction stages but also expands management objects from physical buildings to a composite system that includes physical facilities, operational data, and collaborative processes. As a result, campus facilities management shifts from static maintenance toward data-driven dynamic governance, laying the foundation for subsequent modular governance and campus operational governance.

5.2. Modular Governance Mechanism

The core of the modular governance mechanism lies in reducing system complexity and enhancing controllability across the entire process through standardized boundaries and interface rules. Existing studies show that the value of prefabricated and modular construction lies not only in improving construction efficiency but also in shifting complex processes to the design and production stages. By relying on standardized modules and organizational rules, these approaches reduce on-site uncertainty and enhance coordination and traceability throughout the process (Parracho et al., 2025; Laovisutthichai et al., 2025).From the perspective of modularity theory, its governance significance lies in decomposing complex systems into relatively independent but interoperable units, thereby providing a clearer managerial basis for supervision, replacement, upgrading, and continuous optimization (Baldwin & Clark, 2000). Prefabricated construction therefore changes not only construction speed but also the way campus facilities are organized, controlled, and maintained.

This case clearly illustrates the modular governance mechanism. The standardized and integrated application of structural components, enclosure elements, and parts of the pipeline system forms a modular system with clear boundaries and defined interfaces. Correspondingly, component production, installation, and quality control are incorporated into unified planning. As a result, organizational challenges in campus facility construction shift from on-site ad hoc coordination to upstream standard setting, interface matching, and process execution. At the same time, the project established component information databases, identification codes, and data records, and employed an as-built BIM model containing complete component information to support subsequent maintenance and upgrading. This ensures that modules remain identifiable, traceable, and replaceable during the operation and maintenance stage. Existing studies also indicate that the integration of modular construction with digital information management improves information visibility and management continuity across the lifecycle of building assets, providing stable support for maintenance decisions, component replacement, and renovation (Elghaish et al., 2025). In the context of educational facilities, the modular governance mechanism therefore provides an institutional foundation for flexible maintenance and continuous upgrading of campus facilities.

5.3. Campus Operational Governance Mechanism

The campus operational governance mechanism focuses on how engineering technologies influence daily campus order, spatial use relationships, and safety boundary control, shifting facilities management from a construction-oriented approach to an operation-oriented one. Existing studies indicate that campus management increasingly emphasizes the interaction among spatial configuration, operational coordination, and boundary governance. In this context, the value of facility systems lies not only in providing physical space but also in supporting campus operations, resource allocation, and risk control (Moghayedi et al., 2024).In this case, the overall layout, age-based zoning, and the connectivity among teaching clusters essentially represent the prior structuring of campus operational order. Through spatial organization, engineering technologies translate teaching, activity, and circulation needs into relatively ordered and coordinated operational relationships, thereby improving the controllability of daily campus governance. At the same time, for high-frequency and risk-related scenarios—such as parent pickup and drop-off, after-school activities, campus openness, and the use of underground composite spaces—the project incorporates an underground pickup hall, staggered traffic arrangements, and facilities such as access control, vehicle barriers, and fire compartmentation. These measures reintegrate pickup-related pressures into the campus's internal governance system, reflecting an operational governance logic in which campus order is actively shaped through facility layout, circulation routes, and access boundaries. As noted in previous studies, facilities management in open and smart campus environments must establish clear and enforceable boundary structures between openness and security control (Adipat & Chotikapanich, 2024).

In addition, the campus operational governance mechanism is reflected in the role of composite spaces in supporting multi-period campus use. In this case, the underground space not only accommodates pickup and parking functions but also includes facilities such as a student theater, club classrooms, after-school programs, and a library. This indicates that underground development is not merely an expansion of floor area but a way to strengthen the campus's capacity to support after-school services, extracurricular activities, and multi-period use. Existing studies suggest that modern campuses are increasingly understood as multifunctional, composite, and continuously operating organizational spaces. Accordingly, management priorities are shifting from static space occupancy to dynamic scenario support and coordinated operations (Surmiková & Džupka, 2026). In this context, the expansion of transitional spaces, refinement of accessibility facilities, and adjustments to supporting spaces all represent concrete measures to enhance the resilience and adaptability of campus operations. The campus operational governance mechanism shows that engineering technologies—through spatial organization, circulation control, boundary setting, and composite functional configuration—transform campus facilities into operational systems that support teaching activities, after-school services, home–school interaction, and safety management. This also indicates that educational facilities management should be regarded as an integral component of the broader governance system of schools.

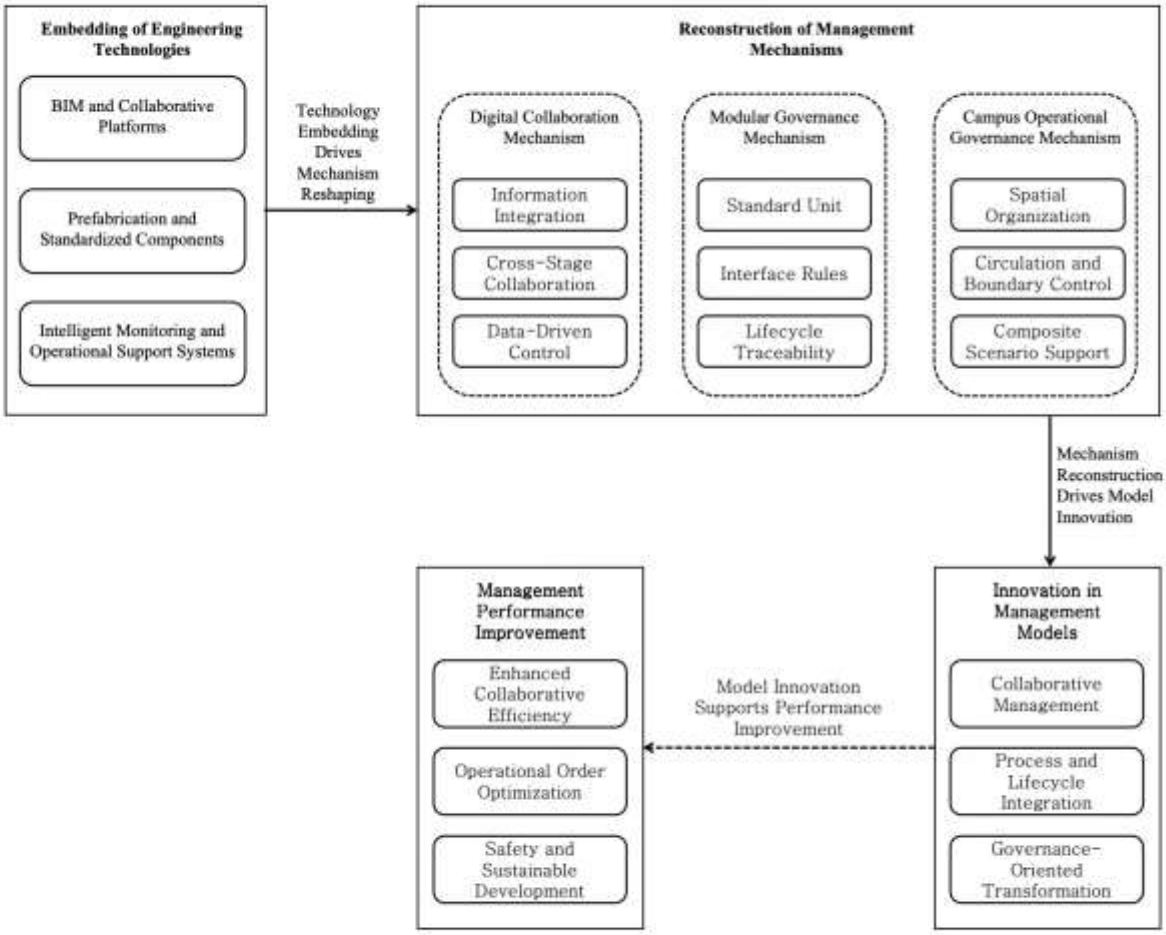

Figure 1: Theoretical Framework Model Diagram.

The role of engineering technologies in campus facilities management is not limited to the application of individual technologies or improvements in construction efficiency. Rather, through three mechanisms—digital collaboration, modular governance, and campus operational governance—engineering technologies reconstruct information flows, governance units, and operational order, thereby driving innovation in campus facilities management models (Fig. 1). These three mechanisms are interconnected: digital collaboration enhances cross-stage information integration, modular governance reconstructs the organizational foundation of facilities management, and campus operational governance translates technological effects into teaching support, circulation organization, boundary control, and the management of composite usage scenarios. Together, these mechanisms support three forms of management model innovation: collaborative management, process and lifecycle integration, and governance-oriented transformation. These forms of model innovation further support improvements in collaborative efficiency, operational order, safety, and sustainable development.

6. RESEARCH CONTRIBUTIONS AND FUTURE PROSPECTS

The theoretical contributions of this study are reflected in three aspects. First, at the level of educational facilities management theory, this study extends the field from a "maintenance–operation" perspective toward a "governance–operation" perspective. While existing research emphasizes technology integration, lifecycle management, and organizational support functions (Mohammed & Amoah, 2025; Karanasios, 2026), this study shows that engineering technologies influence not only facility construction and maintenance but also reshape spatial organization, collaborative relationships, and operational boundaries. Through these changes, campus facilities become governance carriers that support teaching organization, home–school interaction, safety control, and after-school services, thereby extending the explanatory focus of educational facilities management from facility asset management to campus operational governance. Second, at the level of technology-driven management innovation theory, this study moves beyond the linear explanation that "technology improves management performance." Building on the view that the effects of technology depend on mediating processes such as organizational coordination, governance arrangements, and capability reconstruction (Wang & He, 2026; Liu & Wang, 2026), this study proposes an analytical framework of "engineering technology embedding–management mechanism reconstruction–management model innovation." It further identifies three mechanisms—digital collaboration, modular governance, and campus operational governance—showing that engineering technologies drive innovation in campus facilities management models through the reconfiguration of information flows, governance units, and operational order. Third, methodologically, this study employs a theory-driven thematic analysis that integrates case materials, coding procedures, and mechanism abstraction. This approach facilitates the transition from empirical theme identification to theoretical explanation and offers a useful analytical pathway for qualitative research in the field of educational facilities management (Moghadam & Besiktepe, 2025).

The practical implications of this study are threefold. First, for school administrators, campus facility planning should not remain within a segmented logic of "construction completion–subsequent maintenance." Instead, operational needs—such as teaching organization, home–school interaction, safety management, and after-school services—should be incorporated at the early stages of projects, enabling coordinated design between facility development and school governance goals. Second, for construction and operation stakeholders, the integrated application of BIM, prefabricated construction, and operational monitoring systems should be strengthened. Information collaboration, component traceability, and operational feedback should be connected into a lifecycle management chain to enhance the controllability of facility upgrading, maintenance decisions, and operational support. Third, for policymakers and standard-setting bodies, standards for the digital delivery, modular construction, and operational evaluation of educational facilities should be further improved, guiding schools to shift from a "construction-focused, governance-light" approach toward integrated "construction–operation–governance" management. This study still has several limitations. First, the analysis is based on a single case. Future research could expand to comparative studies across different regions, educational levels, and types of schools to test the applicability and boundaries of the mechanisms proposed here. Second, methodologically, future studies may combine multiple cases, longitudinal research, and quantitative testing to more systematically examine the relationships within the "engineering technology embedding–management mechanism reconstruction–management model innovation" framework, as well as the subsequent performance effects of such model innovation. Finally, in terms of research scope, further attention could be given to topics such as digital twins, smart operation and maintenance, green and low-carbon development, and campus safety governance. These directions would help explore how engineering technologies interact with school organizational structures, governance capacities, and institutional environments, thereby advancing research on educational facilities management toward more dynamic, integrated, and mechanism-oriented approaches.

REFERENCES

Adeniyi, O., Rathnasiri, P., Ojo, L. D., et al. (2025). The evolution of digital twin applications in construction and the built environment: Analysis of trends, research clusters and future directions. *Intelligent Buildings International*. https://doi.org/10.1080/17508975.2025.2558616

Adipat, S., & Chotikapanich, R. (2024). Advancing higher education with the transition to smart universities: A focus on technology. *Shanlax International Journal of Education, 12*(3), 29–36. https://doi.org/10.34293/education.v12i3.7635

Atta, N., & Talamo, C. (2019). Digital transformation in facility management (FM): IoT and big data for service innovation. In *Digital transformation of the design, construction and management processes of the built environment* (pp. 267–278). https://doi.org/10.1007/978-3-030-33570-0_24

Baldwin, C. Y., & Clark, K. B. (2000). *Design rules: The power of modularity* (Vol. 1). MIT Press.

Ba, Z., Wang, Q., Chen, C., Liu, Z., Peh, L., & Tiong, R. (2023). Change management of organizational digital transformation: A proposed roadmap for building information modelling-enabled facilities management. *Buildings, 14*(1), 27. https://doi.org/10.3390/buildings14010027

Dahanayake, K. C., & Sumanarathna, N. (2022). IoT-BIM-based digital transformation in facilities management: A conceptual model. *Journal of Facilities Management, 20*(3), 437–451. https://doi.org/10.1108/JFM-10-2020-0076

Di Giuda, G. M., Meschini, S., Gasbarri, P., et al. (2024). BIM, GIS and BI tools for a university asset management system supporting space management, occupancy evaluation and optimization strategies. *Journal of Information Technology in Construction*. https://iris.unito.it/handle/2318/2075310

Elghaish, F., Mohandes, S. R., Rahimian, F., et al. (2025). Predictive digital monitoring of construction resources: An integrated digital twin solution. *Engineering, Construction and Architectural Management.* https://doi.org/10.1108/ECAM-04-2025-0604

Elyasi, N., Bellini, A., & Klungseth, N. J. (2023). Digital transformation in facility management: An analysis of the challenges and benefits of implementing digital twins in the use phase of a building. *IOP Conference Series: Earth and Environmental Science, 1176*(1), 012001. https://doi.org/10.1088/1755-1315/1176/1/012001

Ghansah, F. A. (2025). Digital twins for smart building at the facility management stage: A systematic review of enablers, applications and challenges. *Smart and Sustainable Built Environment, 14*(4), 1194–1221. https://doi.org/10.1108/SASBE-08-2023-025

Gomes Araújo, L., & Lucko, G. (2022). Best practices for case studies in construction engineering and management research. *Journal of Construction Engineering and Management.* https://doi.org/10.1061/(ASCE)CO.1943-7862.0002312

Gunduz, M., Naji, K. K., & Maki, O. (2024). Evaluating the performance of campus facility management through structural equation modeling based on key performance indicators. *Journal of Management in Engineering*. https://doi.org/10.1061/JMENEA.MEENG-5641

Hakimi, O., Liu, H., & Abudayyeh, O. (2023). Digital twin-enabled smart facility management: A bibliometric review. *Frontiers of Engineering Management, 11*(1), 32–49. https://doi.org/10.1007/s42524-023-0254-4

Ismail, S., Hon, C. K. H., Crowther, P., & Skitmore, M. (2023). The drivers and challenges of adopting the Malaysia industrialised building system for sustainable infrastructure development. *Construction Innovation, 23*(5), 1054–1077. https://doi.org/10.1108/CI-05-2021-0088

Karanasios, K. (2026). Sustainable facilities management: A sociotechnical system perspective and a review of the literature. *Journal of Facilities Management, 24*(1), 21–43. https://doi.org/10.1108/JFM-03-2024-0031

Kassem, M., Kelly, G., Dawood, N., Serginson, M., & Lockley, S. (2015). BIM in facilities management applications: A case study of a large university complex. *Built Environment Project and Asset*

Management, 5(3), 261–277.

Laovisutthichai, V., Lu, W., & Low, S. P. (2025). Design for excellence (DfX) for high-rise modular buildings: From DfX considerations to module design guidelines using the case of Hong Kong. *Architectural Engineering and Design Management.* https://doi.org/10.1080/17452007.2024.2390964

Li, C. Z., Li, S., Li, X., Wu, H., Xiao, B., & Tam, V. W. Y. (2022). A scientometric review of management of prefabricated construction from 2011–2021. *Buildings, 12*(10), 1515. https://doi.org/10.3390/buildings12101515

Liu, C., Song, Y., Li, R., Ma, W., Hao, J. L., & Qiang, G. (2023). Three-level modular grid system for sustainable construction of industrialized residential buildings: A case study in China. *Journal of Cleaner Production, 389*, 136152. https://doi.org/10.1016/j.jclepro.2023.136152

Liu, Z., & Wang, N. (2026). The effects of emerging digital technologies on construction project resilience: The mediating role of relational governance. *Building Research & Information.* https://doi.org/10.1080/09613218.2025.2482961

Lourenço, M. P., Arantes, A., & Costa, A. A. (2025). Barriers to building information modeling (BIM) implementation in late-adopting EU countries: The case of Portugal. *Buildings, 15*(10), 1651. https://doi.org/10.3390/buildings15101651

Mahmoud, A. S., Hassanain, M. A., & Alshibani, A. (2024). Evolving trends and innovations in facilities management within higher education institutions. *Buildings, 14*(12), 3759. https://doi.org/10.3390/buildings14123759

Moghadam, M. A., & Besiktepe, D. (2025). Synthesis of multi-criteria decision-making applications in facilities management and building maintenance: Trends, methods, and future research directions. *Buildings, 15*(18), 3258. https://doi.org/10.3390/buildings15183258

Moghayedi, A., Michell, K., Le Jeune, K., & Massyn, M. (2024). Assessing the influence of technological innovations and community-based facilities management on the safety and security of universities: A case study of an open campus. *Facilities, 42*(3/4), 223–244. https://doi.org/10.1108/F-05-2023-0041

Mohammed, A. S., & Amoah, C. (2025). Integration of technology in decision-making in university facilities management: A literature review. *Facilities, 43*(13–14), 1018–1052.

Muhammad, M. Z., & Mustapa, M. (2020). A review of facilities information requirements towards enhancing building information modelling (BIM) for facilities management (FM). *IOP Conference Series: Materials Science and Engineering, 884*, 012033. https://doi.org/10.1088/1757-899X/884/1/012033

Parracho, D. F. R., Nour El-Din, M., Esmaeili, I., Freitas, S. S., et al. (2025). Modular construction in the digital age: A systematic review on smart and sustainable innovations. *Buildings, 15*(5), 765. https://doi.org/10.3390/buildings15050765

Pedral Sampaio, R., Aguiar Costa, A., & Flores-Colen, I. (2023). A discussion of digital transition impact on facility management of hospital buildings. *Facilities, 41*(5/6), 389–404. https://doi.org/10.1108/F-07-2022-0092

Purnawan, R. (2025). Systematic literature review: Asset management system for educational institutions. *Technovasia: Journal of Technology & Computer Applications.* https://journal-iam.com/index.php/technovasia/article/view/10

Shamsuddin, M. M., Ismail, W. N. W., Arabi, F., & Norazman, N. (2025). Cultivating sustainability facility management in Malaysian higher education institutions: A review on operation and maintenance (O&M) practices.

Surmiková, D., & Džupka, P. (2026). From the 15-minute city to the 15-minute university: A new paradigm for university campuses. *Cities.* https://doi.org/10.1016/j.cities.2026.106303

Thản, N. V., & Nếp, V. T. (2026). Digital transformation readiness level of enterprises in the Mekong Delta. *Journal of Management Research and Review, 2*(3). https://doi.org/10.65150/ep-jmrr/v2e3/2026-01

Wang, D., & He, B. (2026). Revealing the mechanism of digital empowerment for the green transformation of manufacturing companies: Evidence from China. *Management and Organization Review.* https://doi.org/10.1017/mor.2025.31

Wang, Y., Rezaei, A., & Hicks, S. J. (2026). Digital twins in the construction industry: A systematic review of current practices and future directions. *Journal of Information Technology in Construction.* https://wrap.warwick.ac.uk/id/eprint/197571/

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage.

Zhang, M., Fan, L., Liu, Y., Zhang, S., & Zeng, D. (2023). The relationship between BIM application and project sustainability performance: Mediation role of green innovation and moderating role of institutional pressure. *Buildings, 13*(12), 3126. https://doi.org/10.3390/buildings13123126