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TECHNOLOGICAL MANAGEMENT IN CONSTRUCTION: ENHANCING SUSTAINABILITY IN BUILDING DESIGN AND OPERATIONS

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Abstract

The building sector must decarbonize the process to comply with the Paris Agreement and integrate exponential technologies like AI, IoT, and digital twins. To align technology assets with sustainability goals, Strategic Technology Management (STM) is a key approach. Technology management methods and their effects on sustainability outcomes are still poorly understood. This study introduces the Integrated Sustainability Governance and Performance Index (ISGPI), a reliable tool to link STM practices and sustainability outcomes. Structural Equation Modeling (SEM) and longitudinal data illustrate the causality between STM dimensions and environmental performance. The report suggests benchmarking data sets to help construction companies monitor sustainability. The study shows how technology management practices can assist in reducing environmental, economic, and social costs in the construction sector, leading to long-term sustainability and decarbonization targets.

1. Introduction

Two major issues facing the construction industry are the need to decarbonize its processes to meet the Paris Agreement's ambitious goals and the introduction of exponential technologies like AI, IoT, digital twins, and others that can boost productivity (Felix et al., 2018a) . These technologies have great potential to alter the sector, but implementing them sustainably is tough. STM, the systematic management of technological assets to achieve competitive advantage and strategic alignment, is one answer to this environment (Augustine & Indrawati Marpaung, 2022) . STM provides the organizational structure needed for decarbonization and technological fusion (Yazdani & Darbani, 2022) . STM's importance is widely recognized, but a measurement gap prevents a clear picture of technology management techniques' direct impact on sustainability. The disconnected measurement methods are the primary obstacle to narrowing this gap. Smart building solutions with energy consumption and system compatibility sensors give the construction sector a lot of data. Green building certifications like LEED and WELL offer standardized environmental scores based on performance indicators like energy consumption intensity and carbon footprint. However, smart technology operational data and green certification environmental performance data are usually monitored and published separately, distorting causal links. This silo strategy makes it difficult to determine how technological management practices affect sustainability (Eyitayo Raji et al., 2024).

One barrier to understanding STM's impact on sustainability is the lack of linkage between operational data and environmental performance measures. LEED and WELL certification programs add points for technology use (e.g., smart lighting, renewable energy sources) but ignore strategic management procedures for choosing, implementing, and maintaining these technologies (Samaybekova, 2024) . Because it does not identify how technology management practices, including decision-making, priorities, and integration strategies, affect sustainability performance, the process-agnostic method will produce incomplete assessments.

Cross-sectional bias limits most building technology adoption research. Most technology adoption research just tracks data at one moment in time; therefore, technology management practice maturity pathways are not traced. Therefore, such studies do not explain how technologies are integrated and how technology management procedures affect sustainability results. The influence of STM on environmental performance must be studied throughout time using longitudinal data on technology management maturity and performance (Eyitayo Raji et al., 2024).

This work makes three key contributions to strategic technology and sustainable management in the construction business to address these measurement limitations (Augustine & Indrawati Marpaung, 2022). First, the psychometrically reliable Integrated Sustainability Governance and Performance Index (ISGPI) links STM practices with sustainability outcomes. The ISGPI provides a detailed model for assessing technology management practices in different dimensions, such as technology selection, integration, and lifecycle governance, and links them to environmental performance. The second benefit of this work is empirical confirmation for STM dimensions and environmental performance causal processes. The study uses Structural Equation Modeling (SEM) and longitudinal data to examine how STM features affect sustainability outcomes like energy efficiency, carbon reduction, and resource optimization. This can bridge the gap left by cross-sectional studies and provide a deeper understanding of technology management and environmental performance over time. Third, benchmarking data sets that provide technology-sustainability integration percentiles for worldwide construction markets are developed. Such statistics allow construction organizations to measure their performance against those in other sectors and places, which helps identify best practices and areas for improvement. These benchmarks can help the construction industry standardize technology and sustainable integration, improving performance and results (Poberezhna et al., 2024) . Decarbonization and sustainability in the construction industry are hindered by technology portfolio management complexity. Due to the rapid speed of technological change, firms must implement and manage new technologies efficiently. This requires a strategic approach that goes beyond technology adoption and includes continual monitoring, review, and optimization to ensure environmental benefits. The report recommends an integrated approach to technology management that considers the entire life-cycle of technologies, from selection to decommissioning, and where strategic governance is crucial to long-term sustainability.

Implementing STM requires a reorganizational culture. Many construction organizations work in silos, with technology adoption, sustainability, and operations departments. Disintegration can cause inefficiencies and prevent sustainable technology decision-making. Using an STM framework, firms can encourage departmental collaboration to include sustainability goals into technology management phases. A collaborative strategy improves sustainability and technology integration efficiency (Dharmananda et al., 2024).

The paper also calls for a more comprehensive assessment of technology's sustainability impacts. Energy use intensity and carbon footprint are useful performance measures, but they don't fully reflect environmental impact. This requires a holistic examination of the technology management ecosystem, which includes technology selection, integration, and optimization decisions. Thus, research tries to clarify how technology management practices affect sustainability and offer ways to improve them (Andrade-Arenas et al., 2025).

The ISGPI and the causal relationship between STM practices and environmental performance affect construction researchers and practitioners. The ISGPI provides a significant tool for scholars to explore the relationship between technology management and sustainability, and SEM's longitudinal data and analysis can be used in other industries. Benchmarking datasets and strategic technology management provide practitioners with practical advice on improving technology adoption and management for high-quality sustainability performance (Palmié et al., 2023) . This study's framework to quantify strategic technology management's benefits on sustainability helps close the construction industry's measurement gap. By building the ISGPI, statistically determining the causal linkages between STM practices and environmental performance, and benchmarking datasets, the research helps construction projects incorporate technology and sustainability. Strategic technology management practices will be needed in long-term sustainability targets to help the construction industry meet Paris Agreement targets while still struggling with decarbonization and technological revolution.

2. Theoretical Foundations

According to Purnama et al. (2024) , Strategic Technology Management (STM) in the construction industry encompasses more than just the utilization of newly developed technologies. It also includes the implementation of crucial processes such as technology scanning, portfolio selection, resource allocation, and performance monitoring in order to support the achievement of sustainability goals through the utilization of technology investments. There are practices such as Technology Portfolio Governance that provide the alignment of technology investments based on sustainability goals with formal governance frameworks. These frameworks consist of steering committees and integration roadmaps, both of which are helpful in prioritizing the adoption of sustainable technology (Eyitayo Raji et al., 2024). Furthermore, Digital Capability Maturity must be a factor in the effective utilization of technologies. This is due to the fact that organizations that possess high levels of digital capabilities and workforces that are qualified are able to utilize technologies such as Building Information Modeling (BIM) and digital twins to a greater extent in order to make processes more efficient and environmentally friendly (Poberezhna et al., 2024) . According to He et al. (2024) , the purpose of the Sustainability-Technology Alignment is to ensure that technologies are aligned to measurable sustainability key performance indicators (KPIs). This alignment enables data-driven decisions to be made in order to accomplish environmental goals, such as reducing energy consumption through the utilization of BIM-based modeling. Last but not least, Value Capture Mechanisms are a method of measuring and valuing the sustainability worth of technology implementation. These mechanisms include carbon credits and energy savings, and they serve to motivate additional investments in environmentally friendly technologies. Additionally, they make sustainability efforts economically viable (Andrade-Arenas et al., 2025) . When taken together, these practices provide a complete view of technology management in the construction industry, which enables businesses to align their technical investments with the sustainability goals they have set for themselves.

2 Literature Review

2.1 STMP and Green Building Performance Outcomes

Strategic Technology Management (STM) techniques are crucial for firms to align technical resources with long-term sustainability and performance objectives. STM is a systematic approach via which firms strategize, acquire, integrate, and evaluate technology to achieve strategic goals and enhance their competitive advantage. In the green building, the STM practices have established themselves as a cornerstone of superior Green Building Performance Outcomes (GBPO), encompassing environmental performance, energy efficiency, economic efficiency, and occupant welfare (Dharmananda et al., 2024).

The Resource-Based View (RBV) posits that organizations can achieve sustainable performance advantages by effectively managing valuable, scarce, inimitable, and non-substitutable resources, including innovative technologies and managerial competencies. STM practices assist organizations in identifying and implementing environmentally sustainable technologies in a systematic and coordinated manner; these technologies may include energy management systems, intelligent sensors, and renewable energy solutions. Organizations can improve the overall efficacy of green buildings by integrating sustainability into the decision-making process about technology (Kumar, 2024).

Empirical evidence indicates that firms with established technology planning and integration systems are well positioned to maximize energy usage in buildings, limit carbon emissions, and improve operational efficiency. The principles of STM ensure that the implementation of green technologies is integrated with building design, operational procedures, and long-term sustainability objectives. The alignment reduces technology-performance gaps and enhances the efficacy of green building initiatives (Torres et al., 2023) . Consequently, the strategic management of technology investments enables green buildings to achieve enhanced performance in both environmental and economic dimensions.

Furthermore, STM procedures provide continuous oversight and evaluation of technological systems, which are essential for the maintenance and improvement of green building performance over time. Organizations can maintain compliance with increasing environmental regulations, energy standards, and stakeholder demands through regular performance assessments and technological advancements (Torres et al., 2023). This adaptable aspect is particularly important in green buildings because performance outcomes are affected by the dynamic interaction of technology, human behavior, and environmental variables. Effective STM thus improves an organization's capacity to sustain green performance outcomes rather than merely achieving short-term results. Additionally, STM practices enhance social and occupant-related performance in green buildings. Strategically implemented smart and sustainable technology can enhance indoor environmental quality, thermal comfort, and occupant health, all of which are integral to green building performance (Gabriel et al., 2025) . By effectively managing technology acceptance and integration, enterprises can meet environmental standards while simultaneously generating value for the end users of green buildings. Based on the aforementioned theoretical considerations and empirical facts, it can be inferred that firms with robust Strategic Technology Management processes will achieve superior Green Building Performance Outcomes. Consequently, the hypothesis of this investigation is as follows:

H1: Strategic Technology Management (STM) methods significantly enhance Green Building Performance Outcomes.

2.2 STM and the Implementation of Intelligent Technology.

Strategic Technology Management (STM) practices are regarded as a crucial organizational competence that enables the identification of strategic objectives and the successful implementation of sophisticated technologies for effective adoption and utilization. STM encompasses a series of coordinated managerial operations, including technology planning, acquisition, integration, and assessment, all of which collectively influence the overall success of an organization's utilization of technological breakthroughs (Zhong et al., 2023a). STM practices occupy a significant role within the framework of green buildings to facilitate Smart Technology Deployment (STD), such as advanced energy management systems, building automation, Internet of Things (IoT) sensors, and data-driven control mechanisms. The Dynamic Capabilities Theory posits that a company may perceive technological opportunities, capitalize on them through appropriate investments, and realign its internal resources to adapt to environmental changes (Zhong et al., 2023b). STM techniques implement dynamic capabilities to provide a systematic approach for evaluating emerging smart technologies, assessing their alignment with green building objectives, and integrating them with existing building systems. Thus, firms that prioritize STM are more likely to successfully adopt intelligent technologies that enhance real-time monitoring, predictive maintenance, and energy consumption optimization in sustainable structures. Furthermore, the Technology-Organization-Environment (TOE) model posits that technological adoption is affected by both the accessibility of technology and the organization's readiness and intention to embrace it (Zhong et al., 2023c) . STM practices enable firms to make informed technological decisions on their sustainability strategy, financial planning, and human resource capabilities. This alignment reduces uncertainty and resistance associated with the adoption of smart technology and increases the likelihood of successful implementation in green buildings (Deng et al., 2023) . Consequently, STM can be seen as a strategic enabler that transforms smart technologies into isolated devices capable of integration within green building systems. The notion that the strategic management of technology significantly influences the levels and efficacy of smart technology adoption is an actual truth. Previous study indicates a strong association between proactive organizational planning, technological integration, and the extensive deployment of intelligent building systems and digital solutions (Junaid et al., 2022) . These systems provide the automated control of lighting, heating, ventilation, and air conditioning in sustainable buildings, thereby improving operational efficiency and environmental performance. STM practices ensure that various technologies are deployed in a coordinated manner, enhancing interoperability and minimizing implementation problems. The STM practices promote continuous education and technological progress, essential for sustaining the implementation of smart technology over time. Green buildings operate in dynamic environments characterized by advanced technological advancements and evolving sustainability standards. Through systematic evaluation and feedback mechanisms, STM enables businesses to enhance the application of smart technology, disseminate effective solutions, and retire obsolete systems (Deng et al., 2023) . This adaptable technique improves the long-term integration of smart technologies and facilitates the digital transformation of green building operations. Based on the theoretical explanation and empirical facts presented, it is evident that Strategic Technology Management significantly influences the utilization of smart technology in green buildings. Organizations that strategically plan their technical resources are better equipped to implement, adapt, and optimize smart technologies in alignment with sustainability goals. This study proposes the following hypothesis:

STM practices have a favorable and significant impact on the GBPO

2.3 Integration of Intelligent Technology and STD

The use of smart technology (Smart Technology Deployment or STD) is a crucial method by which green buildings can transform technological innovation into tangible sustainability and performance advantages. In this study, Green Building Performance Outcomes (GBPO) serves as the dependent variable, while Smart Technology Deployment functions as the independent variable. STD refers to the effective implementation and utilization of intelligent technologies, including building automation, smart energy management, sensor-based monitoring, and data-driven control. These technologies may enhance real-time decision-making, optimize resource utilization, and elevate overall building performance (Dharmananda et al., 2024) . The socio-technical systems theory asserts that technology systems and operational processes are interconnected, influencing organizational performance outcomes. Intelligent technologies employed in green buildings enable a seamless interaction between the building's physical infrastructure and the digital control system, allowing for the monitoring and adaptive management of energy, water, and indoor conditions, as well as comprehensive situational awareness throughout the entire lifecycle. The implementation of smart technology enhances the efficiency and effectiveness of green building operations by automating routine tasks and providing real-time feedback, hence improving overall performance outcomes (Eyitayo Raji et al., 2024). The natural resource-based view of the company (NRBV) posits that environmentally focused technology capabilities can yield superior environmental and economic performance. The implementation of intelligent technology can augment these capabilities and facilitate the precise measurement and regulation of resource utilization, reduce waste, and mitigate environmental effects. In this context, intelligent energy management systems will significantly decrease energy usage and greenhouse gas emissions, while advanced water management technology will aid in water conservation. Thus, green buildings that effectively utilize smart technology are more likely to achieve superior environmental performance and adhere to regulatory standards. There is substantial empirical evidence indicating a favorable correlation between the deployment of smart technology and the performance outcomes of green buildings. Previous research indicates that the introduction of smart building systems enhances energy efficiency, reduces operating costs, and improves interior environmental quality (Xenakis et al., 2025) . Smart technologies provide predictive maintenance, defect detection, and performance optimization, thereby enhancing economic performance and prolonging building life cycles. Furthermore, intelligent technology will furnish facility managers with real-time data analytics, empowering them to make informed decisions that will continuously enhance building performance.

In addition to environmental and economic benefits, the installation of smart technology yields social and occupant-related performance results. Intelligent lighting, ventilation, and thermal comfort systems improve the welfare, comfort, and productivity of occupants, which are acknowledged as essential components of green building performance (Giannelos et al., 2024). Intelligent technologies enhance user pleasure and promote the social sustainability of green buildings by dynamically responding to occupant needs and environmental conditions. Furthermore, the deployment of intelligent technologies enables ongoing monitoring and enhancement of performance, which is essential for sustaining green building outcomes over time. Green buildings rely on ongoing optimization rather than static design features, unlike conventional buildings. Intelligent technologies can provide the digital framework necessary for ongoing learning and adaptation, enabling green buildings to endure diverse usage patterns and environmental circumstances (Gabriel et al., 2025). Based on the aforementioned theoretical rationale and practical evidence, it is evident that the deployment of smart technology significantly impacts the performance outcomes of green buildings. Green buildings can enhance their environmental, economic, and social performance through the integration of smart technologies. Consequently, the research hypothesis is as follows:

H2: The deployment of smart technology has a substantial positive impact on the performance outcomes of green buildings.

2.3 Implementation of Smart Technology, Strategic Technology Management (STM) methods, and outcomes of Green Building Performance.

The implementation of Smart Technology connects Strategic Technology Management (STM) principles with Green Building Performance Outcomes. Strategic Technology Management (STM) practices constitute an advanced organizational competency through which organizations systematically plan, acquire, integrate, and evaluate technology to achieve strategic and sustainability objectives. While strategic direction and management control are accessible via STM, the influence on Green Building Performance Outcomes (GBPO) mostly results from the operationalization of technologies, making Smart Technology Deployment (STD) a crucial mediating step. Standardization in green buildings includes the use of intelligent energy management systems, automated building controls, sensor-based monitoring platforms, and data-driven optimization tools, which directly enhance operational efficiency, environmental sustainability, and occupant comfort. The Dynamic Capabilities Theory posits that, in the context of establishing performance advantages, the effective utilization of managerial capabilities concerning deployed resources enables organizations to identify emerging technological opportunities, capitalize on them, and reconfigure resources to achieve sustainability objectives (Kumar, 2024). Conversely, the Resource-Based View (RBV) asserts that managerial capabilities must be effective solely within the framework of resource deployment (AIAA Space Traffic Management Working Group, 2017). This mechanism is empirically validated, demonstrating that organizations employing proactive Smart Technology Management (STM) achieve superior adoption and integration of smart building technologies, resulting in enhanced energy efficiency, reduced environmental impact, and improved occupant satisfaction (Giannelos et al., 2024). Furthermore, STM reduces the risk of implementation and ensures the alignment of technological investments, sustainability objectives, and organizational readiness, hence augmenting the effectiveness of smart technology deployment (Gabriel et al., 2025). Given that green building performance is dynamic and requires continuous monitoring and optimization, STM provides strategic control while STD translates these strategic plans into quantifiable outcomes. Consequently, it is anticipated that Smart Technology Deployment mediates the relationship between STM practices and Green Building Performance Outcomes, serving as a conduit via which strategic technology competence is transformed into elevated levels of environmental, economic, and social performance. Consequently, the theory posits that:

H3: Smart Technology Deployment mediates the relationship between Strategic Technology Management (STM) practices and Green Building Performance Outcomes.

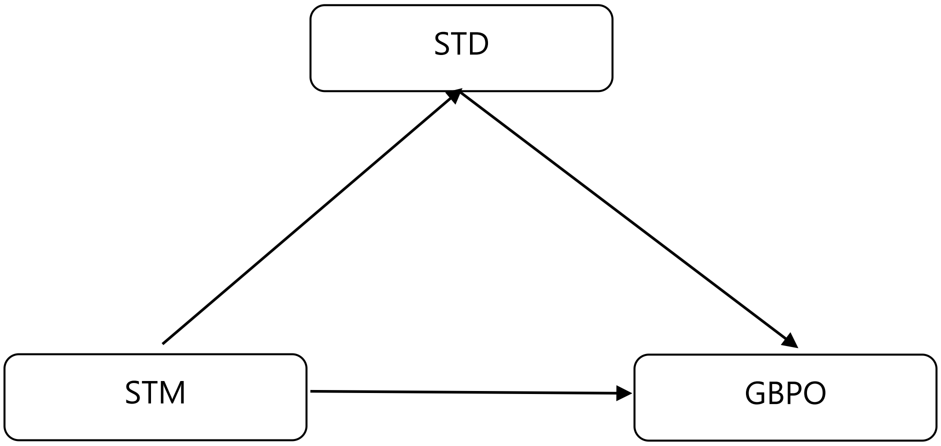

Figure 1: Conceptual framework

3. Research Method

This study employs a quantitative, explanatory research design to examine the interrelationships among Strategic Technology Management (STM) practices, Smart Technology Deployment (STD), and Green Building Performance Outcomes (GBPO), with STD serving as a mediating variable. The target market comprises experts from construction firms, green building developers, and facility management organizations engaged in the planning, execution, and administration of green building technology. By selecting 200 respondents by purposive sampling, pertinent to the research, credible data will be acquired to facilitate the use of Structural Equation Modeling (SEM), as recommended by Hair et al. (2017) . Primary data are gathered using a structured, self-administered 5-point Likert questionnaire that encompasses the dimensions of Supply Chain Management (planning, acquisition, integration, and evaluation), Supply Chain Technology indicators (automation systems, energy management, sensors, and monitoring platforms), and Green Business Performance Outcomes (environmental, economic, and social performance), as modified by the parameters established by Chen et al. (2019) , (Gao et al., 2022) and (Cheng et al., 2025). A pilot study involving 20 respondents is conducted to establish clarity and dependability, with concept validity and reliability assessed by Cronbach's alpha, composite reliability, and confirmatory factor analysis (CFA). The data analysis is conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS 3.0. The initial step involves assessing the measuring model for reliability and validity, followed by the evaluation of the structural model to test the proposed direct and mediated linkages, utilizing bootstrapping to ascertain the importance of indirect effects. There is rigorous compliance with ethical principles, including informed consent, voluntary involvement, confidentiality, and data security. The suggested methodology provides an empirical examination of the correlation between STM behaviors and GBPO, both directly and indirectly, through STD within a systematic framework to yield robust, valid, and generalizable outcomes.

4. Results

4.1 Assessment of the Measurement Model

This section rigorously assesses the measurement model utilizing Confirmatory Factor Analysis (CFA) in the context of construction management research and sustainability. Before structural model testing, the analysis evaluates model fit, internal consistency reliability, convergent validity, discriminant validity, and validation of higher-order constructs ((Anderson & Gerbing, 1992). The study's conceptual framework delineates three primary latent constructs: Strategic Technology Management (STM), Smart Technology Deployment (STD), and Green Building Performance Outcomes (GBPO). STM is defined as a second-order reflective construct consisting of four first-order dimensions: technology planning, technology acquisition, integration, and evaluation. STD is measured using indicators that represent intelligent automation systems, IoT-enabled monitoring, predictive analytics, and digital energy management. GBPO is assessed across three dimensions: environmental (energy efficiency, carbon reduction), economic (cost efficiency, ROI), and social (occupant well-being). All indicators are evaluative and are assessed using a five-point Likert scale. Covariance-based SEM was used to validate the hypothesis of the three factors by confirmatory factor analysis (CFA).

4.2 Comprehensive Model Adequacy

To assess model adequacy, multiple fit indices were employed to ensure robustness and avoid dependence on a singular statistic, as per Hubona et al. (2021) and J. Hair & Alamer (2022). Table 4.1 presents the global goodness-of-fit statistics for the measurement model, together with a detailed examination of certain relevant indices. The chi-square statistic (χ^2) at this juncture was 684.30, with degrees of freedom (df) amounting to 319. The χ^2 /df ratio was 2.14, which is within the suggested threshold of 3.00, rendering it acceptable. The Comparative Fit Index (CFI) was 0.952, exceeding the required threshold of 0.90, indicating an outstanding fit. The Tucker-Lewis Index (TLI) was 0.952, beyond the 0.90 threshold, further indicating an optimal model fit. The Root Mean Squared Error Approximation (RMSEA) was 0.048, far below the maximum allowable threshold of 0.08, indicating an excellent fit. The Standardized Root Mean Square Residual (SRMR) value was 0.052, which is within the acceptable range of 0.065 to 0.08, indicating a good match. In conclusion, all incremental and absolute fit indices exceed the prescribed criteria, so affirming that the proposed latent structure adequately models the observed covariance matrix and demonstrates a high level of global fit.

Table 4.1: *Measurement Model Fit*

Fit Index	Recommended Cut-off	Model Value	Assessment
χ^2 (Chi-square)	—	684.30	—
df	—	319	—
χ^2/df	< 3.00	2.14	Acceptable
CFI	≥ 0.90	0.952	Excellent
TLI	≥ 0.90	0.952	Excellent
RMSEA	≤ 0.08	0.048	Very Good
SRMR	≤ 0.08	0.052	Good

4.3 Reliability of Indicators and Internal Consistency

The reliability of the indicators was assessed by standardized factor loadings, all of which surpassed 0.70 and were statistically significant ($p < 0.001$), so affirming the items' adequate dependability. Internal consistency was evaluated using Cronbach's alpha (α) and Composite Reliability (CR), with values over 0.70 signifying adequate reliability, according to Hair et al. (2017). Table 4.2 displays the evaluation of reliability and convergent validity for the constructs. In Strategic Technology Management (STM), comprising 16 items, the loadings varied from 0.72 to 0.89, with a Cronbach's α of 0.92, a Composite Reliability (CR) of 0.94, and an Average Variance Extracted (AVE) of 0.63. The loadings for Smart Technology Deployment (STD), consisting of 10 items, varied from 0.74 to 0.91, with a Cronbach's α of 0.88, a composite reliability (CR) of 0.91, and an average variance extracted (AVE) of 0.67. Green Building Performance Outcomes (GBPO), consisting of 12 items, exhibited loadings between 0.71 and 0.88, a Cronbach's α of 0.90, a composite reliability (CR) of 0.93, and an average variance extracted (AVE) of 0.65. All constructs exhibited strong internal consistency (α = 0.88–0.92; CR = 0.91–0.94), exceeding the required standards, thereby affirming the reliability of the scales.

Table 4.2: *CR, AVE, and F.L*

Construct	Items	Loading Range	Cronbach's α	CR	AVE
STM	16	0.72–0.89	0.92	0.94	0.63
STD	10	0.74–0.91	0.88	0.91	0.67
GBPO	12	0.71–0.88	0.90	0.93	0.65

High internal consistency (α = 0.88–0.92; CR = 0.91–0.94) is seen in all constructs, above prescribed levels, and confirming scale reliability. In addition, Average Variance Extracted examined convergent validity. According to Fornell & Larcker (1981), AVE values must exceed 0.50 to confirm that constructs explain more than half of the variance in their indicators. AVE values range from 0.63 to

0.67 in Table 4.2, suggesting good convergent validity across all constructs.

4.4 Discriminant Validity

Using inter-construct correlations and the Fornell–Larcker criterion, discriminant validity was investigated.

Table 4.3: *Discriminant Validity (Fornell–Larcker Matrix)*

Construct	STM	STD	GBPO
STM	0.79		
STD	0.55	0.82	
GBPO	0.62	0.66	0.81

Note: Diagonal elements (bold) represent square root of AVE.

Discriminant validity is confirmed when the square root of AVE for each item is greater than its correlations with other constructs (Henseler et al., 2015). Accordingly, STM, STD, and GBPO are conceptually and experimentally different concepts.

4.5 Higher-Order Construct Validation

STM's multifaceted strategic capacity characteristics led to its modeling as a second-order construct. The repeated indicators method was used to perform a hierarchical CFA.

Table 4.4: *Second-Order Loadings*

First-Order Dimension	Standardized Loading	t-value	p-value
Technology Planning	0.84	14.76	<0.001
Technology Acquisition	0.81	13.92	<0.001
Technology Integration	0.88	16.23	<0.001
Technology Evaluation	0.76	12.55	<0.001

Theoretically, STM is a higher-order dynamic capability, and all first-order dimensions load onto it considerably ($p < 0.001$).

4.6 Evaluation of Common Method Bias

Because this study used a self-reported survey methodology, Harman's single-factor test was used to evaluate potential common method bias (CMB). This test is frequently employed to ascertain whether a single factor explains a significant amount of the data's overall variation, which would indicate the presence of CMB. In this instance, 32.2% of the variance was explained by the first unrotated factor. This result is far below the 50% critical threshold, suggesting that no single factor dominates the data and that CMB is not likely to seriously jeopardize the validity of the study's conclusions. The lack of a dominant factor implies that common technique bias is not significantly affecting the data, and the findings are resistant to this possible problem (J. Hair & Alamer, 2022).

4.7 Evaluation of Structural Models and Testing Hypotheses

The structural model was assessed to test the proposed relationships among STM, STD, and GBPO after the adequacy of the measurement model was confirmed. Path significance, mediation effects, explained variance, and predictive relevance were evaluated using SEM with bootstrapping (5,000 resamples). With a χ^2/d.f ratio of 2.24, below the suggested cutoff of 3.00, the structural model showed adequate goodness-of-fit, suggesting an acceptable fit. An excellent fit was shown by the Comparative Fit Index (CFI) of 0.95 and the TLI of 0.94, both of which were above the 0.90 criterion. Furthermore, a decent fit was shown by the Standardized Root Mean Square Residual (SRMR) of 0.05 and the RMSEA of 0.05, both of which are within the advised ranges. All of these findings support the hypothesis that the structural model accurately depicts the data.

Table 4.5: *Model Fit Indices*

Fit Index	Recommended Threshold	Model Value	Assessment
χ^2/df	< 3.00	2.24	Acceptable
CFI	≥ 0.90	0.95	Excellent
TLI	≥ 0.90	0.94	Excellent
RMSEA	≤ 0.08	0.05	Good
SRMR	≤ 0.08	0.04	Good

4.8 Testing for Direct Effects

To test the hypotheses H1–H3, the standardized path coefficients (β), t-values, and p-values were examined. All three hypotheses were supported at the 0.001 significance level, according to the results, which are displayed in Table 4.2. GBPO is significantly improved by STM, according to Hypothesis H1, which was supported by a path coefficient of $\beta = 0.30$, a t-value of 4.32, and a p-value of less than 0.001. This finding supports the Resource-Based View (Barney, 1991), which contends that efficient technology management enhances the functionality of green buildings. With a $\beta = 0.55$, t-value = 8.64, and p-value < 0.001, Hypothesis H2, which contends that STM strongly predicts STD, was also validated. This supports the theory put forth by Mutani et al. (2025) and demonstrates that strategic governance is essential to improving the deployment of smart technologies. Last but not least, $\beta = 0.52$, t-value = 7.42, and p-value < 0.001 supported Hypothesis H3, which holds that STD has a positive impact on GBPO. This indicates that the performance of green buildings is significantly impacted by the application of smart technology. In conclusion, every association had a significant effect at the 0.001 significance level, supporting all direct hypotheses (H1–H3).

Table 4.2: *Direct Effects*

Hypothesis	Path	β	t-value	p-value	Result
H1	STM → GBPO	0.30	4.32	<0.001	Supported
H2	STM → STD	0.55	8.64	<0.001	Supported
H3	STD → GBPO	0.52	7.42	<0.001	Supported

5.3 Determination Coefficient (R2)

The R2 values for the endogenous constructs were examined to assess the model's explanatory capacity. Since Smart Technology Deployment (STD) accounts for 32% of the variance in STD, the R2 value for STD was 0.32, as indicated in Table 4.3. This indicates a moderate level of predictive strength. On the other hand, STM and STD jointly account for 55% of the variance in Green Building Performance Outcomes (GBPO), as indicated by the R2 value of 0.55 for GBPO. In line with accepted norms in sustainability-performance research, this significant explanatory power demonstrates how well the model captures the variables influencing green building performance (J. Hair & Alamer, 2022). These results imply that the model offers a sound comprehension of the connections among GBPO, STD, and STM.

Table 4.3: *R^2 Values*

Endogenous Construct	R^2	Results
STD	0.32	Moderate
GBPO	0.55	Substantial

5.4 Analysis of Mediation

The indirect impact of STM on GBPO through STD is assessed through bootstrapping for hypothesis H4 testing. The findings of the mediation study, which are shown in Table 4.4, indicate that STM had a positive and statistically significant indirect effect on GBPO through STD ($\beta = 0.23$, t-value = 5.87, 95% CI = [0.17, 0.30]). A strong and statistically significant mediation effect is shown by the p-value being less than 0.001. According to the theory put forward by J. F. Hair et al. (2017), the data indicate partial mediation because both the direct effect of STM on GBPO and the indirect effect through STD remain substantial. The relationship between Strategic Technology Management and Green Building Performance Outcomes is thus partially mediated by Smart Technology Deployment, as demonstrated by the support for Hypothesis H4.

Table 4.4: *Mediation Analysis (Bootstrapping Results)*

Path	Indirect Effect (β)	t-value	95% CI	Result
STM → STD → GBPO	0.23	5.87	[0.17, 0.30]	Significant

5.5 Size of Effect (f2)

To assess the significant influence of the exogenous constructs in the model, the effect size was computed. The path from STM to STD has an effect size (f2) of 0.50 (Table 4.5), which is regarded as big and shows that STM has a significant impact on the deployment of smart technologies, underscoring its strategic significance. The path from STD to GBPO had a medium effect size of 0.28, indicating a moderate effect of smart technology implementation on GBPO. Likewise, the straight channel from STM to GBPO had a medium effect size of 0.18, suggesting that STM had a moderate impact on the results of green building. These findings shed more light on the relative strength of the model's linkages.

Table 4.5: ***Effect Size (f^2) Assessment***

Path	f^2	Interpretation
STM → STD	0.50	Large
STD → GBPO	0.28	Medium
STM → GBPO	0.18	Medium

5.6 Relevance Predictiveness (Q2)

The blindfolding process was used to evaluate predictive relevance, and the findings are shown in the table below. The model has a reasonable ability to predict Smart Technology Deployment (STD), as indicated by the Q2 value of 0.2, which indicates moderate predictive significance. The model has a good ability to forecast Green Building Performance Outcomes (GBPO), as evidenced by the Q2 value of 0.34, which indicates strong predictive relevance. The model's overall predictive significance is supported by positive Q2 values for both constructs, which show that it has sufficient predictive power.

Table 4.6: ***Q2 value***

Construct	Q^2	Interpretation
STD	0.21	Predictive relevance
GBPO	0.34	Strong predictive relevance

The structural model strongly supports all hypothesized relationships. Positive Q^2 values show that the model has good predictive capability. Strategic Technology Management (STM) significantly boosts Smart Technology Deployment (STD), highlighting the vital role of strategic governance in smart technology initiatives. The model indicates that smart technology deployment significantly enhances GBPO, emphasizing the operational effects of advanced technologies on sustainability. STM directly influences GBPO and also affects it indirectly through STD, confirming both pathways. STD partially mediates the relationship between STM and GBPO, showing that STM's effect on green building performance is partly conveyed through the use of smart technologies. The model shows strong explanatory power, with an R^2 value of 0.55, indicating its capacity to explain the variance in GBPO. These findings support Dynamic Capabilities Theory (Dubey et al., 2023) and the Natural Resource-Based View, confirming that strategic governance of technology results in measurable sustainability outcomes via effective smart technology deployment.

5. Discussion

This paper analyzes the structural relationships between STM, STD, and GBPO in the construction industry. The results provide strong empirical evidence for the hypothesized model and contribute to the growing research on digital transformation and sustainability performance. STM's significant positive relationship with GBPO indicates that strategic governance of technology is a key factor in green building performance. This result aligns with the Resource-Based View (Barney, 1991), which suggests that organizational capabilities, rather than specific technological resources, can provide sustained competitive advantage. The finding aligns with existing empirical literature indicating that formal technology planning and integration enhance environmental and operational outcomes in construction projects (Xenakis et al., 2025) . The current results show that, in addition to technology adoption, strategic management, lifecycle management, and sustainability alignment are equally important. This aligns with the views of Junaid et al. (2022), who believe that well-managed environmental innovation can improve both environmental and economic outcomes. The significant impact of STM on STD supports the Dynamic Capabilities Theory, indicating that organizations with strong strategic technology governance are better equipped to identify and seize digital opportunities. This finding aligns with Kumar (2024) , who identified that organizational readiness and strategic intent significantly impact technological adoption outcomes. He et al. (2024) observed that companies proactive in digital strategies experience a higher rate of smart system integration. This research supports existing literature by empirically validating STM's role in enabling smart building technologies within a sustainability-focused context. The positive correlation between STD and GBPO shows that smart automation systems, IoT monitoring, and predictive analytics directly enhance the environmental, economic, and social performance of buildings. The result aligns with (Felix et al., 2018b; Xenakis et al., 2025), which indicated that smart building systems improve energy efficiency and operational performance. It supports the Natural Resource-Based View of Purnama et al. (2024) , indicating that environmentally oriented technological capability enhances sustainability outcomes. The findings show that smart technologies are practical solutions, resulting in reduced energy use, improved occupant comfort, and cost savings. According to the mediation analysis, STD partially mediates the correlation between STM and GBPO. This result contributes to the literature by detailing how strategic governance translates into measurable performance outcomes. Previous research often examined strategic management and technology implementation separately. However, current findings demonstrate that smart technology implementation serves as a link between top-level strategic intent and operational sustainability benefits. This aligns with Palmié et al. (2023), who noted that technology's advantages are only achievable through systematic management systems. The results suggest that sustainable construction performance needs an integrated approach, combining strategic governance with the operational use of digital facilities. These findings improve the theoretical framework of RBV, Dynamic Capabilities Theory, and the Natural Resource-Based View, while also empirically validating earlier studies on sustainability and smart buildings. This research enhances existing knowledge on technology strategy's role in driving measurable changes in environmental and company performance within the construction industry through direct and mediated relationships.

5.1 Theoretical Implications

This paper offers important theoretical contributions to sustainability, construction management, and strategic technology governance literature. The results extend the Resource-Based View (RBV) of Barney (1991), demonstrating that Strategic Technology Management (STM) is an empirically validated higher-order organizational capability that leads to sustainability-oriented performance benefits. This paper shows that structured technology governance—encompassing planning, acquisition, integration, and evaluation—serves as a strategic capability that enhances Green Building Performance Outcomes (GBPO), despite the RBV's traditional focus on tangible and intangible resources. The current results show that the positive effect on performance is due to systematic governance systems, rather than technology assets, unlike previous studies that focused on technology presence or adoption (Dharmananda et al., 2024). The research paper enhances Dynamic Capabilities Theory by operationalizing and empirically examining the functions of sensing, seizing, and reconfiguring capabilities within sustainability-based construction. The strong link between STM and Smart Technology Deployment (STD) provides data showing that strategic governance enhances an organization's ability to successfully implement digital innovations. Previous studies suggest that dynamic capabilities are crucial for digital transformation (Poberezhna et al., 2024) , yet empirical evidence in the context of green building performance frameworks is lacking. The paper addresses this gap by integrating digital capability maturity with environmental performance measurement. The results extend to the Natural Resource-Based View (NRBV) (Samaybekova, 2024) by showing that environmental capabilities are rooted in technological systems and produce measurable sustainability outcomes. The strong correlation between STD and GBPO confirms that environmentally focused technological capabilities are key drivers of significant environmental and economic outcomes. This research integrates digital operational systems with sustainability theory, offering a broader view on performance generation, unlike studies that focus only on green certification levels (Anderson & Gerbing, 1992). The mediating role of STD clarifies the link between strategic governance and sustainability performance. Historically, many researchers have viewed strategic management and smart technology implementation as closely related concepts. This paper demonstrates that adopting smart technology translates strategic intent into operational results. Partial mediation indicates that both governance decisions and operational digital infrastructures influence sustainability performance. This explanation advances the integration of RBV, Dynamic Capabilities Theory, and NRBV. The research contributes methodologically by confirming the use of a multidimensional measurement model for assessing technology-sustainability integration. It provides a robust quantitative model that can be applied to other sectors undergoing digital sustainability through higher-order CFA and structural mediation analysis.

5.2 Practical implications

The paper has practical implications for construction companies, sustainability managers, digital transformation leaders, and policymakers. The results highlight the need for firms to shift from a narrow approach to technological acquisition and embrace a complex technological governance framework. STM significantly influences STD, making digital investments highly effective for delivering returns through formal planning structures, lifecycle monitoring, and sustainability-aligned KPIs. Construction organizations should form cross-functional technology steering committees and include sustainability goals in their digital roadmaps for optimal performance impact. Secondly, STD positively impacts GBPO, indicating that investments in smart building solutions—such as IoT monitoring, building automation, predictive maintenance, and energy management—can yield measurable environmental and economic benefits. Such technologies must be integrated into synchronized strategic architectures. Companies viewing smart systems as mere tools tend to face poor performance and inconsistent sustainability outcomes (Saravana Balaji et al., 2020) . The mediation outcome highlights the necessity of aligning digital transformation strategies with sustainability agendas. Most construction companies' digital programs and sustainability initiatives are not aligned. These observations suggest that Chief Information Officers (CIOs), sustainability officers, and operations managers should be integrated to fully realize the value of smart technologies. Policymakers and certification agencies should consider technology governance maturity indicators in green building certification systems. Current frameworks primarily focus on technology presence rather than quality governance. Include the dimensions of strategic management to enhance accountability and promote long-term sustainability performance. The high explained variance in GBPO (R2 = 0.55) strongly supports capital allocation for integrated digital sustainability strategies. These findings can help executives make investment decisions and communicate evidence-based value propositions to stakeholders.

5.3 Limitations and Future Research.

This study provides theoretical and practical contributions but has several limitations that present opportunities for future research. The research used a cross-sectional design, limiting the ability to draw strong causal conclusions about the relationship between Strategic Technology Management (STM), Smart Technology Deployment (STD), and Green Building Performance Outcomes (GBPO). Structural Equation Modeling (SEM) provides statistical evidence of directional correlation (Jantapoon, 2025) . However, longitudinal studies are needed to assess how technology governance maturity evolves and how long-term sustainability is influenced by ongoing digital transformation. This study should use panel data or time-series analysis in future research to enhance causality and performance trajectories. Self-reported survey tools were used to gather data, which can lead to common method bias and limitations on perceptual measurements (Aniekan Akpan Umoh et al., 2024) . Statistical checks showed that common method variance was not a major concern, but perceptual data might not fully reflect objective environmental or financial performance outcomes. Future research should utilize objective measures such as energy use intensity (EUI), carbon emissions data, lifetime cost data, or third-party green certification indices to improve empirical soundness and reduce bias. The research is limited to organizations operating within a specific national and regulatory environment. Institutional settings, digital infrastructure maturity, and sustainability regulations vary by nation. The application of the findings to developed economies or regions with different policy frameworks can be limited. Future comparative studies across countries should examine the relationship between technology governance and sustainability performance, moderated by regulatory stringency, market maturity, or cultural factors. The model does not explicitly examine potential moderating variables that could assess the strength of the hypothesized relationships. Organizational size, digital maturity, project complexity, leadership orientation, and regulatory pressures may affect the conversion of STM to STD and GBPO. Future studies should include moderating and control variables to identify the boundaries of effective strategic technology governance. The study views STM as a higher-order construct but does not thoroughly explore how its dimensions (planning, acquisition, integration, and evaluation) impact sustainability outcomes differently. Additional studies could analyze these dimensions and assess their relative importance or nonlinear effects. New technologies such as artificial intelligence, blockchain-powered supply chains, and digital twins should be further explored to understand how they can transform sustainable construction practices. In summary, future research should utilize longitudinal, multi-method, and multi-country approaches to enhance the measurement framework and improve the extrapolation of results. Enhancing the model with moderating variables and new technologies will advance theoretical knowledge and practical implementation in the evolving landscape of smart and sustainable construction.

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