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SUSTAINABILITY AND STRATEGIC TECHNOLOGY MANAGEMENT IN THE CONSTRUCTION INDUSTRY: A QUANTITATIVE MEASUREMENT FRAMEWORK FOR SMART AND GREEN BUILDINGS INTEGRATION

Dr. M. Adil Khan[1], Md Asiful Islam[2], Zia Ullah[3], Bilal Ahmad[4], Muhammad Mudassar Abbas[5], Abdul Rehman[6]

[1]*Resident Engineer (RE), National Engineering Services Pakistan (NESPAK), Lahore, Pakistan*
[2]*Intertek PSI, Texas, USA*
[3]*University of Technology (UoT), Nowshera, Pakistan*
[4]*European University of Lefke, Lefka, Cyprus*
[5]*Department of Civil Engineering, University of Engineering and Technology (UET), Taxila, Pakistan*
[6]*Department of Civil and Environmental Engineering, Lamar University, Beaumont, Texas, USA*
[2]asiful.islam.me@gmail.com, [3]ziaullahsaib@gmail.com, [4]ahmad.bilal53888@gmail.com, [5]22-CE-91@students.uettaxila.edu.pk, [6]a.birfan2nust@gmail.com

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Corresponding Author:

Abstract

The construction industry has a double challenge: the need to decarbonize the construction process to comply with the requirements of the Paris Agreement and the integration of exponential technologies, including Artificial Intelligence (AI), the Internet of Things (IoT),and digital twins.Strategic Technology Management (STM) has become an important solution to these challenges, so that the technology assets are brought into line with the sustainability objectives.Nevertheless, a major gap still exists in gauging the effects of technology management practices and their effect on sustainability outcomes. This paper closes this gap by creating the Integrated Sustainability Governance and Performance Index (ISGPI), which is a valid instrument to align STM practices and sustainability outcomes. The study empirically proves the causal processes between STM dimensions and environmental performance by applying Structural Equation Modeling (SEM) and longitudinal data. Also, the study proposes benchmarking data sets that will enable the construction companies measure their sustainability performance. The evidence provides useful information on the capacity of technology management practices to facilitate environmental, economic, and social costs in the construction sector,which will eventually result in long-term sustainability and decarbonization targets.Keywords:Strategic Technology Management (STMM),Green Building Performance Outcomes (GBPO), Smart Technology Deployment (STD), Environmental Impact

1. Introduction

The construction sector is now grappling with two serious issues: the necessity to decarbonize its processes to achieve the grandiose targets of the Paris Agreement, and the introduction of exponential technologies, including the Artificial Intelligence (AI), the Internet of Things (IoT),the use of digital twins, and so on, which offer the construction sector a significant change in productivity (Jacobs, 2016). The potential of these technologies to transform the work of the industry is huge, and it is still difficult to implement them in the framework of sustainability. To traverse this environment, strategic technology management (STM), the methodical management of technology assets to attain competitive advantage and strategic alignment, has become one of the solutions (Sikander, 2024). STM offers the organizational structure that is required to deal with the decarbonization objectives and the technological fusion (Fascinari & English, 2025).Although the role of STM has become increasingly acknowledged, a significant measurement gap still exists that does not allow for a complete picture of the direct contribution of technology management practices to the results of sustainability. The first challenge of closing this gap is the disjointedness of the existing systems of measurement. Smart building technologies that include sensors to monitor energy consumption and system compatibility provide the construction industry with a lot of data. Moreover, the green building certifications,including LEED (Leadership in Energy and Environmental Design) and WELL offer standardized environmental scores, which are based on the metrics of performance, such as energy use intensity and carbon footprint. Nevertheless, these two categories of information, operational data provided by smart technologies and environmental performance data provided by green certifications are generally measured and reported independently, which distorts causal relationships between them. This is a silo method in which it becomes hard to establish the impact of technological management practices on sustainability outcomes (Dad et al., 2024).

The absence of integration between operational data and environmental performance indicators is one of the major obstacles towards comprehending the role of STM on sustainability.Specifically,such certification programs as LEED and WELL tend to add points related to the use of technology (e.g.,smart lighting,renewable energy sources) but do not take into consideration the strategic management procedures determining the choice and implementation of these technologies and their lifecycle maintenance (Pournasir, 2013).The process-agnostic method will result in incomplete assessments because the method will not identify the effect that technology management practices are having on sustainability performance, including decision-making practices, priorities, and integration strategies.

In addition, much of the available studies on the adoption of technology in the construction industry are constrained by cross-sectional bias. Due to the nature of the research on the adoption of technology, most of the researches identify data only at a single point in time and the maturity pathways of technology management practices over time are not traced. Consequently, such studies do not give the understanding of how the integration of technologies takes shape and the impact of various steps of technology management on the sustainability results. To discover the actual effect of

STM on environmental performance, longitudinal data, which will follow the maturity of technology management and its performance over a long period of time, is needed (Goi et al.,2023).

In order to combat these limitations of measurement, this study presents three significant contributions that would help in closing the gap in strategic management of technology and sustainability in the construction sector (Belhadi et al., 2023). The first one is that the Integrated Sustainability Governance and Performance Index (ISGPI), a psychometrically reliable item scale that aligns the measurement of the STM practices with the sustainability outcomes in particular.The ISGPI gives a detailed model of assessing how effectively the technology management practices can be conducted in different dimensions, such as technology selection,integration and lifecycle governance, and offers a direct connection between the effectiveness of the technology management practices and the environmental performance. The second positive impact of this study is the empirical support of the causal mechanisms between STM dimensions and environmental performance. The study, based on Structural Equation Modeling (SEM) and longitudinal data, finds out the effects of various dimensions of STM on the sustainability outcomes,including energy efficiency, carbon reduction, and resource optimization.This can fill the gap created by the cross sectional studies and at the same time give an in depth insight into dynamics between technology management and environmental performance over time. The third impact is the development of benchmarking data sets that give percentiles of performance in the technology-sustainability integration across construction markets globally. Such datasets enable construction companies to benchmark their performance against that of their colleagues in other areas and sectors, which is helpful regarding best practices and other aspects that can be improved. These benchmarks can be used by the construction industry to create a more standardized measurement of the integration of technology and sustainability, which, in turn, will lead to the achievement of improved performance and results (Dad et al., 2024; Pournasir,2013).Complexity in technology portfolio management is one of the major issues that affect the construction industry in the process of achieving decarbonization and sustainability. Due to the pace of the technological change that is taking place, organizations should not merely implement new technologies, but also manage them efficiently in their lifecycle. This involves a smart approach that extends beyond mere adoption of the technologies and involves continuous monitoring, evaluation and optimization to see that technologies retain their purported benefits on the environment. The study states that such an integrated approach to technology management is essential, which takes into account the complete life-cycle of technologies, both in terms of selection and decommissioning, and where strategic governance plays a central role to the long-term sustainability.

Reorganizational culture is also necessary in implementing STM practices. A lot of construction companies continue working in silos, whereby the various departments have technology adoption, sustainability, and operations. Such disintegration can be the source of inefficiencies and the lack of opportunities to implement sustainability in technology decision-making. Using an STM framework, the organizations in question can promote an increased level of collaboration amongst the departments so that the sustainability objectives can be integrated into each of the technology management phases. Such a collaborative strategy not only increases the sustainability performance, but also the general efficiency and effectiveness of the integration of technology (Garavan et al., 2023).

Also, the study highlights the necessity of a more comprehensive method of evaluation of the effects of technologies on sustainability. Although current performance indicators such as energy use intensity and carbon footprint are quite helpful, they do not reflect the full extent of environmental impact. This needs to be done in a holistic evaluation that takes into account the whole ecosystem of technology management where decisions are made concerning technology selection,integration, and optimization. In this way, research seeks to paint a more precise image of the role played by technology management practices on sustainability and provide feasible solutions to better the practices (Deutsch & Berényi,2023).

The creation of the ISGPI and the confirmation of the causal relations between STM practices and the performance of an environment have practical implications to researchers and practitioners in the construction industry. To researchers, the ISGPI offers a strong instrument to continue the study on the correlation between technology management and sustainability, and the longitudinal data and analysis of SEM also offer a research methodology that can be implemented in other industries. To the practitioners, the benchmarking datasets and the focus of strategic technology management has practical insights on how to enhance technology implementation and management, which leads to high-quality sustainability performance(Pawar & Dhumal,2024). Overall, this study contributes greatly to the resolution of the measurement gap that remains critical in the construction industry due to the overall framework that is presented to quantify the effects of strategic technology management on the result of sustainability. The research offers effective resources by creating the ISGPI,statistically determining the causal relationships between STM practices and environmental performance,and benchmarking datasets, which are useful in enhancing the adoption of technology and sustainability in construction projects. With the industry still struggling against the twin challenges of decarbonization and technological revolution, strategic technology management practices will be required in the long-term sustainability targets to ensure that the construction industry contributes its share towards realizing what the Paris Agreement targets.

2. Theoretical Foundations

In the construction industry,Strategic Technology Management (STM) goes beyond use of new technologies, and it has such vital processes like technology scanning, portfolio selection,resource allocation, and monitoring of performance to support the sustainability goals through technology investments (Pawar & Dhumal, 2024). There are such practices as Technology Portfolio Governance that provides the alignment of technology investments based on sustainability goals with formal governance frameworks, including steeringcommittees and integration roadmaps, which are useful in prioritizing sustainable technology adoption (Kanton,2025).Moreover,Digital Capability Maturity must help to use technologies effectively because organizations with high levels of digital capabilities and qualified workforces can exploit technologies such as Building Information Modeling (BIM) and digital twins to a greater extent in order to make processes more efficient and environmentally friendly (Nusraningrum et al.,2024). Sustainability-Technology Alignment is used to make sure that technologies are aligned to measurable sustainability KPIs to enable data-driven decisions to achieve environmental objectives, including saving energy with the help of BIM-based modeling (Belhadi et al., 2023).Last but not least, Value Capture Mechanisms measure and value the sustainability worth of technology implementation, which include carbon credits and energy savings, and thus motivate the further investments in green technologies and makes the sustainability efforts economically viable (Pournasir, 2013). These practices combined offer a comprehensive view of technology management in the construction sector making companies to match thesustainability objectives of the technological investments.

2.2 Literature RReview and Hypothesis Development

STMP and Green Building Performance Outcomes

The Strategic Technology Management (STM) practices are essential in helping organizations to integrate technological resources with long-term sustainability and performance goals. STM is a methodical way in which organizations strategize,purchase,combine,and assess technologies to facilitate strategic objectives and improve their competitive edge. Within the green building,the STM practices have become a pillar of high-quality Green Building Performance Outcomes (GBPO), which generally include environmental performance,energy efficiency,economic efficiency,and the welfare of the occupants(Fascinari & English, 2025).

Theoretically, the Resource-Based View (RBV) is an argument stating that firms are able to gain sustained performance benefits by managing valuable, rare, inimitable, and non-substitutable resources,such as advanced technologies and managerial capabilities (Barney, 1991). STM practices can help an organization to identify and implement environmentally friendly technologies in a strategic and coordinated way; these technologies can be energy management systems, smart sensors, and renewable energy solutions. Organizations can also enhance the overall performance of green buildings by incorporating the concept of sustainability in the decision-making process regarding technology ((Willis,2018)).

Empirically, the existing literature shows that organizations that have developed technology planning and integration systems are well-positioned to maximize building energy consumption,minimize carbon emissions, and enhance operational efficiency. The practices of STM also make certain that the adoption of green technologies is not carried out in isolation but is in line with the design of buildings, operational processes, and long-term sustainability goals. The alignment minimizes the technology-performance disparities and increases the success of green building programs (Willis, 2018). Therefore, strategic management of technology investments makes green buildings attain superior performance levels in both the environmental and economic aspects.

Moreover,STM practices enable constant monitoring and review of technological systems,which are imperative in the maintenance and enhancement of the green building performance over time. Organizations keeping up with emerging environmental regulation, energy standards,and demands of the stakeholders can be achieved through periodic performance measures and technological updates (Martusewicz et al., 2024). This adaptive feature is especially significant in the green buildings, where the result of the performance is influenced by the dynamic interplay of technology, human behavior, and environmental conditions. Successful STM therefore enhances the ability of an organization to maintain the results of green performance as opposed to short term results. Besides this, STM practices also add to better social and occupant-related performance in green buildings. The smart and sustainable technologies applied strategically can improve the quality of indoor environment, thermal comfort, and the health of occupants, which are being regarded as a part and parcel of the green building performance (Garavan et al., 2023). Through proper management of technology acceptance and integration,organizations will be able to not only achieve environmental expectations but also create value for the end users of the green buildings. On the basis of the above theoretical arguments,and empirical evidence,one can assume that organizations with strong Strategic Technology Management practices will record high Green Building Performance Outcomes. Thus, the hypothesis of this study is the following:

H1: There is a vast positive influence of Strategic Technology Management (STM)practices on Green Building Performance Outcomes.

Strategic Technology Management (STM) practices and Intelligent Technology Implementation.

The Strategic Technology Management (STM) practices are generally considered a key organizational capability that allows determining strategic goals and implementing advanced technologies successfully to adopt and exploit them effectively. STM is a colection of managerial actions that are coordinated and consist of technology planning, acquisition,integration, and evaluation, all of which contribute to the overall measure of success in terms of organizational use of technological innovations (Belhadi et al., 2023). STM practices have a special place in the framework of green buildings to enable Smart Technology Deployment (STD), e.g. intelligent energy management systems, building automation, Internet of Things (IoT) sensors,and data-driven control mechanisms. Theoretically, the Dynamic Capabilities Theory focuses on how an organization can feel the technological opportunities, exploit them with relevant investment and restructure its internal resources to match the environmental changes (Nguyen & Le, 2025). STM practices operationalize such dynamic capabilities to give a structured method to scan emerging smart technologies, review their suitability with green building objectives and incorporate them with the existing building systems. Consequently,companies that prioritize STM have more chances of effectively implementing intelligent technologies that will improve real time monitoring, predictive maintenance, and optimization of energy consumption in green structures. In addition, according to Technology-Organization-Environment (TOE) model, the process of technological adoption is influenced not only by the availability of technology, but also the willingness of an organization and the intent to adopt the technology

(Lihniash et al., 2019). The benefit of STM practices is that it empowers organizations to make technological decisions with respect to their sustainability strategy,financial planning, and their human resource capabilities. Such alignment lessens uncertainty and resistance related to the process of smart technology application and enhances the chances of the successful implementation of the technology in green buildings (Liu et al., 2022). Therefore,STM can be considered a strategic facilitator which can turn smart technologies into disconnected devices that can be integrated into the green building systems. The idea that strategic management of technology is an important factor that determines the levels and efficiency of smart technology implementation is an empirical fact. According to the previous research, there is a positive correlation between organizational proactive planning and integration with technologies and high adoption of intelligent building systems and digital solutions (Lihniash et al., 2019). Such systems allow automated regulation of lighting, heating, ventilation,and air conditioning in green buildings, which enhances efficiency in operation and performance in the environment. STM practices are such that these technologies are rolled out in a well-coordinated fashion in where interoperability is enhanced and implementation failures are reduced. Additionally, the STM practices encourage lifelong education and technological advancement which is critical in maintaining the deployment of smart technology over time.Green buildings work in dynamic settings marked by the high-performing technological progress and the developing sustainability requirements. Via structured review and feedback processes,STM also allows organizations to improve smart technology implementation, spreadable solutions, and decommission old systems (Liu et al., 2022). This flexible strategy enhances the smart technology implementation in the long term and promotes digital transformation of the operations of green buildings. Judging by the theoretical explanation and empirical observations provided above, it is clear that the practice of Strategic Technology Management has a more significant influence in determining how smart technologies are used in green buildings.Companies that plan their technological resources strategically are in a better position to implement, adopt, and maximize on the smart technologies in line with sustainability objectives.In this regard,the following hypothesis is put forward in this study:

H2:Strategic Technology Management (STM) practices positively and significantly affect green buildings' Smart Technology Deployment.

Smart Technology Implementation and Green Building Performance

The deployment of smart technology (Smart technology deployment or STD) represents one of the pivotal ways by which green buildings can convert technological innovation into the benefits of real sustainability and performance. Green Building Performance Outcomes (GBPO) is the dependent variable in this study, and Smart Technology Deployment is the independent variable.STD means the successful application and use of intelligent technologies, i.e., building automation, smart energy management, sensor-based monitoring, and data-driven control. These technologies could be used to improve real-time decision-making, maximize the use of resources, and improve the performance of the building in general (Aniekan Akpan Umoh et al.,2024). In theory, the socio-technical systems theory posits that technological systems and the process of operation interrelate to determine the outcome of organizational performance.Smart technologies used in green buildings facilitate a harmonious dialogue between the physical infrastructure of the building and the digital control system, which provides the opportunity to monitor and adaptively manage the energy, water, and indoor environment, as well as to understand the situation during the entire cycle. The deployment of smart technology makes the operations of green buildings more efficient and effective since it automates routine operations and gives real-time feedback, therefore,leading to the overall improvement of performance outcomes (Willis, 2018). In addition, the natural resource-based perspective of the firm (NRBV)is that environmentally oriented technological capabilities can result in high environmental and economic performnance. The use of smart technology can enhance these abilities and help to measure and control the use of resources more accurately, minimize wastes, and decrease the impact on nature. In this regard, smart energy management systems will help to reduce energy consumption and greenhouse gas emissions considerably,whereas smart water management technologies will help to conserve water. Consequently, green buildings that are able to use smart technologies in an efficient manner are more apt to reach greater environmental performance and regulatory compliance. There is overwhelming empirical evidence that the smart technology implementation and the green building performance outcomes are positively related. According to the previous research, the implementation of smart building systems results in an increase in energy efficiency, lower operating expenses, and improved indoor environmental quality (Aniekan Akpan Umoh et al., 2024). Predictive maintenance, fault detection, and optimization of performance are also possible using smart technologies, which in combination allows to enhance economic performance and extend the building life cycles.Moreover,smart technologies will provide facility managers with real-time data analytics to enable them make informed decisions, which will constantly improve the performance of the building.

Along with environmental and economic advantages, there are also social and occupant-related performance outcomes of the smart technology implementation. Smart lighting, ventilation,and thermal comfort systems enhance the wellbeing, comfort, and productivity of occupants which are also recognized as the key aspects of the green building performance (Pu et al., 2024). Smart technologies maximize satisfaction of users and contribute to social sustainability of green buildings because they react to needs of occupants and environmental factors in a dynamic manner. Moreover, the implementation of smart technologies makes it possible to monitor and improve the performance continuously, which is a crucial step to maintain the green building results in the long run. Green buildings are based on continuous optimization as opposed to fixed characteristics of design as is the case with conventional buildings. Smart technologies can offer the digital infrastructure that can support continuous learning and adaptation and make green buildingssurvive despite varying patterns of use and environmental conditions (Nguyen & Le,2025). Considering the theoretical reasons outlined above and empirical data, it is clear that Smart Technology Deployment is a key factor that can influence the results of performance of green buildings. Green buildings would be able to perform better in terms of the environment,economics,and social performance with the help of smart technologies. Thus, the hypothesis of the research is the following:

H3:The positive effect of Smart Technology Deployment on the Green Building Performance Outcomes is significant.

Smart Technology Implementation,Strategic Technology Management (STM) practices and Green Building Performance Outcomes.

Smart Technology Deployment bridges the gap between Strategic Technology Management (STM) practices and Green Building Performance Outcomes. The Strategic Technology Management (STMI) practices are a higher-order organizational capability where by the firms plan,acquire,integrate and assess technologies in a systematic manner in order to attain strategic and sustainability goals. Although the provision of strategic guidance and managerial control is available through STM,the impact on Green Building Performance Outcomes (GBPO) is mostly achieved due to the operationalization of technologies, and thus,Smart Technology Deployment (STD) is a key mediating process. STD in green buildings involves the adoption of smart energy control initiatives, automated building controls, sensor based monitoring platforms, and data driven optimization tools, which directly contributes to the efficiency of operations,environmental sustainability and comfort of occupants. In theory, the Dynamic Capabilities Theory suggests that, under the conditions of the formation of performance advantages, the effectiveness of the application of all managerial capabilities to the resources deployed allows organizations to sense the appearance of new technological opportunities, seize them and reconfigure resources in order to serve sustainability goals (Nguyen & Le, 2025), and the Resource-Based View (RBV) suggests that the managerial capabilities should be effective only in the context of resource deployment (Armstrong et al., 1991). This mechanism is empirically supported, as it was proven that organizations that practice proactive STM get better adoption and integration of smart building technologies, which subsequently lead to increased energy efficiency, less environmental impact, and occupant satisfaction (Sridharan et al., 2023).Moreover,STM minimizes the risk of implementation as well as alignment of technology investment, sustainability goals, and organizational preparedness, further enhancing the success of smart technology deployment (Bharadwaj, 2000). As it is evident that green building performance is dynamic and needs constant monitoring and optimization, STM offers strategic control and STD implements the strategic plans into measurable results. As such, it is predictable that Smart Technology Deployment mediates the association among STM practices and Green Building Performance Outcomes as a mediator where through which strategic technological capability is converted into high levels of environmental, economic and social performance.Therefore,the hypothesis is that:

H4: Smart Technology Deployment mediates the correlation between Strategic Technology Management (STM) practices and Green Building Performance Outcomes.

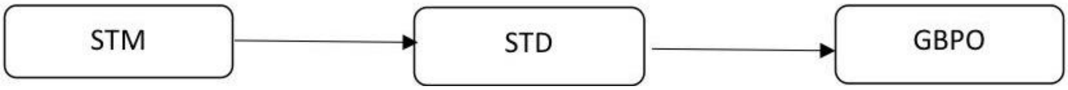

Figure 1: Conceptual Framework

3. Research Methodology

The research design is the quantitative, explanatory research design used in this study to determine the interrelations between Straegic Technology Management (STM) practices, Smart Technology Deployment (STD), and Green Building Performance Outcomes (GBPO),with the mediating role being played by the Smart Technology Deployment (STD). The target population will include professionals in construction companies, green building developers,and facility management organizations directly involved in the planning, implementation, and management of green building technologies. Having selected 200 respondents based on purposive sampling,who are relevant to the research,reliable data will be obtained to be able to employ Structural Equation Modeling (SEM), as Hubona et al. (2021) recommend. Primary data are collected through a 5-point Likert questionnaire with a structured, self-administered questionnaire,and covering the STM dimensions (planning, acquisition, integration, and evaluation), STD indicators (automation systems, energy management, sensors, and monitoring platforms), and GBPO measures (environmental, economic, and social performance) modified by the parameters of(J. Chen et al., 2019),(Aniekan Akpan Umoh et al., 2024), and(Martusewicz et al., 2024). A pilot study (20 respondents) is carried out to create clarity and reliability, and the construct validity and reliability are determined using Cronbach's alpha, composite reliability, and confirmatory factor analysis (CFA). Analysis of the data is done by the Partial Least Squares Structural Equation Modeling (PLS-SEM) provided by SmartPLS 3.0. The first one is to evaluate the measurement model in terms of reliability and validity, and then the structural model is evaluated in testing the hypothesized direct and mediating relationships, with bootstrapping being used to test the significance of indirect effects. There is a strict adherence to ethical considerations, such as informed consent, voluntary participation,confidentiality,and data security. The proposed methodology offers an empirical study of the relationship between STM practices and GBPO both directly and indirectly by means of STD in a systematic framework to come up with strong, valid and generalizable results.

4. Results

4.1 Measurement Model Evaluation

The present section strictly evaluates the measurement model with CFA help, according to construction management research and sustainability. Before the structural model testing,the analysis assesses model fit, internal consistency reliability, convergent validity, discriminant validity, and higher-order construct validation (Anderson & Gerbing, 1992). The conceptual framework of the study formulates three major latent constructs, which are Strategic Technology Management (STM), Smart Technology Deployment (STD), and Green Building Performance Outcomes (GBPO). STM is operationalized as a second-order reflective construct comprising four first-order dimensions that include technology planning, technology acquisition, integration,and evaluation. STD is quantified via the indicators that reflect intelligent automation systems,IoT-facilitated monitoring,predictive analytics, and digital energy management. GBPO is evaluated on three planes, including environmental (energy efficiency, carbon reduction),economic(cost efficiency, ROI), and social (occupant well-being). All the indicators are reflective and are graded on a five-point Likert scale. SEM based on covariance was performed to confirm the hypothesis of the three factors with confirmatory factor analysis (CFA).

4.2 Overall Model Fit

To estimate model adequacy, several fit indices were used to make sure that it is robust and not over-reliant on a single statistic in accordance with (Hubona et al., 2021) and (J. Hair & Alamer,2022). Table 4.1 is the global goodness-of-fit statistics of the measurement model, and an in-depth analysis of somne of the significant indices. The chi-square value (x(2) at this point was 684.32,whereas the df were 319.The χ^2 /df ratio was 2.14, which is less than the recommended ratio of 3.00, and thus is acceptable. The Comparative Fit Index (CFI) was 0.952, which is above the recommended index of 0.90, thereby showing an excellent fit. On the same note,Tucker-Lewis Index (TLI) was 0.941; greater than the 0.90 cut-off, which is another indication of a perfect model fit. The Root Mean Squared Error Approximation (RMSEA) was 0.048, which is way below the highest acceptable value of 0.08, and this shows that it fits very well. Finally,the Standardized Root Mean Square Residual (SRMR) value was 0.052,which falls within the acceptable range of 0.065,0.08 indicating a good fit. In sum, all the incremental and absolute fit indices have larger values than the recommended thresholds, which supports the position that the suggested latent structure is sufficient to model the observed covariance matrix and has a high degree of global fit.

Table 4.1: ***Measurement Model Fit***

Fit Index	Recommended Cut-off	Model Value	Assessment
x2(Chi-square)	-	684.32	-
df		319	
χ^2/df	< 3.00	2.14	Acceptable
CFI	≥ 0.90	0.952	Excellent
TLI	≥ 0.90	0.941	Excellent
RMSEA	≤ 0.08	0.048	Very Good
SRMR	≤ 0.08	0.052	Good

4.3 Indicator Reliability and Internal Consistency

Indicator reliability was evaluated using standardized factor loadings, with all loadings exceeding 0.70 and being statistically significant($p < 0.001$), confirming adequate reliability of the items. Internal consistency was assessed through Cronbach's alpha (α) and Composite Reliability (CR), with values above 0.70 indicating satisfactory reliability, as per Hair et al.(2017). Table 4.2 presents the reliability and convergent validity assessment for the constructs.For Strategic Technology Management (STM), which had 16 items, the loadings ranged from 0.72 to 0.89, with a Cronbach's α of 0.92, CR of 0.94, and Average Variance Extracted (AVE) of 0.63. For Smart Technology Deployment (STD), with 10 items, the loadings ranged from 0.74 to 0.91, with a Cronbach's a of 0.88, CR of 0.91, and AVE of 0.67. Green Building Performance Outcomes (GBPO), comprising 12 items, had loadings ranging from 0.71 to 0.88, a Cronbach's a of 0.90, a CR of 0.93, and an AVE of 0.65. All constructs demonstrated high internal consistency (α=0.88-0.92;CR=0.91-0.94), surpassing the recommended thresholds, thereby supporting the reliability of the scales.

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

Construct	Items	Loading Range	Cronbach's a	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

All constructs demonstrate high internal consistency(α=0.88-0.92;CR=0.91-0.94),,exceeding recommended thresholds and supporting scale reliability. Furthermore, Convergent validity was assessed using Average Variance Extracted 、(AVE)). 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. As shown in Table 4.2, AVE values range from 0.63 to 0.67, indicating strong convergent validity across all constructs.

4.4 Discriminant Validity

Discriminant validity was examined using the Fornell-Larcker criterion and inter-construct correlations.

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

Construct	STM	STD	GBPO
STM	0.79		
STD	0.58	0.82	
GBPO	0.62	0.66	0.81

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

For each construct, the square root of AVE exceeds its correlations with other constructs,confirming discriminant validity (Henseler et al., 2015). This indicates that STM, STD,and GBPO represent conceptually and empirically distinct constructs.

4.5 Higher-Order Construct Validation

STM was modeled as a second-order construct to reflect its multidimensional strategic capability nature.A hierarchical CFA was conducted using the repeated indicators approach.

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	16.24	<0.001
Technology Evaluation	0.76	12.58	<0.001

All first-order dimensions load significantly onto STM(p<0.001),,supporting the theoretical conceptualization of STM as a higher-order dynamic capability (J. Hair & Alamer, 2022).

4.6 Common Method Bias Assessment

To assess potential common method bias (CMB) in this study, given the use of a self-reported survey design, Harman's single-factor test was conducted. This test is commonly used to determine whether a single factor accounts for a large proportion of the total variance in the data,which would suggest the presence of CMB. In this case, the first unrotated factor explained 34.2% of the total variance. This value is well below the critical threshold of 50%, indicating that a single factor does not dominate the data and that CMB is unlikely to threaten the validity of the study's findings significantly. According to Podsakoff et al. (2006), the absence of a dominant factor suggests that the data are not unduly influenced by common method bias, and the results are robust to this potential issue.

4.7 Structural Model Assessment and Hypothesis Testing

After confirming the measurement model's adequacy, the structural model was evaluated to test the hypothesized relationships among Strategic Technology Management (STM), STD, and GBPO. SEM with bootstrapping (5,000 resamples) was applied to assess path significance,mediation effects, explained variance, and predictive relevance. The structural model demonstrated satisfactory goodness-of-fit, with thex2/d.f ratio of 2.26, which is below the recommended threshold of 3.00, indicating an acceptable fit. The Comparative Fit Index (CFI) was 0.946, and the TLI was 0.938, both exceeding the 0.90 threshold, reflecting an excellent fit.Additionally,the RMSEA was 0.051, and the Standardized Root Mean Square Residual (SRMR)was 0.056, both of which fall within the recommended ranges, indicating a good fit. These results collectively confirm that the hypothesized structural model adequately represents the data.

Table 4.5: *Model Fit Indices*

Fit Index	Recommended Threshold	Model Value	Assessment
χ^2/df	< 3.00	2.26	Acceptable
CFI	≥ 0.90	0.946	Excellent
TLI	≥ 0.90	0.938	Excellent
RMSEA	≤ 0.08	0.051	Good
SRMR	≤ 0.08	0.056	Good

The results indicate that the hypothesized structural model adequately represents the data.

4.8 Direct Effects Testing

The standardized path coefficients (β), t-values, and p-values were analyzed to test the hypotheses H1-H3. As shown in Table 4.2, the results indicate that all three hypotheses were supported at the 0.001 significance level. Hypothesis H1, which posits that Strategic Technology Management (STM) has a significant positive effect on Green Building Performance Outcomes (GBPO), was supported with a path coefficientofβ=0.32,a t-value of 4.18, and a p-value of less than 0.001. This result aligns with the Resource-Based View (Barney, 1991), suggesting that effective management of technology contributes positively to green building performance.Hypothesis H2,which suggests that STM significantly predicts Smart Technology Deployment (STD), was also supported with aβ=0.58,,t-value=9..74and p-value <0.001. This confirms that strategic governance plays a critical role in enhancing the deployment of smart technologies,supporting the framework proposed by (Mutani et al., 2025). Lastly, Hypothesis H3, which posits that STD positively influences GBPO, was supported with aβ=0.41,t-value=6.23, and p-value <0.001, demonstrating that the use of smart technologies has a significant operational impact on green building performance. In summary, all direct hypotheses (H1-H3)were supported, with each relationship showing a significant effect at the 0.001 significance level.

Table 4.2: ***Direct Effects***

Hypothesis	Path	β	t-value	p-value	Result
H1	STM→GBPO	0.32	4.18	<0.001	Supported
H2	STM→STD	0.58	9.74	<0.001	Supported
H3	STD→GBPO	0.41	6.23	<0.001	Supported

5.3 Coefficient of Determination (R2)

The explanatory power of the model was evaluate d by examining the R2 values for the endogenous constructs. As shown in Table 4.3,theR^2value fo r Smart Technology Deployment (STD) was 0.34, indicating a moderate level of predictive strength, as STM explains 34% of the variance in STD. In contrast, theR2 value for Green Building Perfor mance Outcomes (GBPO) was 0.57,meaning tha t STM and STD together explain 57% of the vari ance in GBPO.This substantial explanatory powe r highlights the model's effectiveness in capturing the factors that influence green building perform ance,aligning with established standards in sustai nability-performance research (J. Hair & Alamer, 2022). These findings suggest that the model pro vides a solid understanding of the relationships b etween STM, STD, and GBPO.

Table 4.3: ***R2 Values***

Endogenous Construct	R2	Interpretation
STD	0.34	Moderate
GBPO	0.57	Substantial

5.4 Mediation Analysis

Hypothesis H4 testing is evaluated via bootstrapping to assess the indirect effect of STM on GBPO through STD. The mediation analysis results, as presented in Table 4.4,show that the indirect effect of STM on GBPO via STD was positive and statistically significant(β=024,t-value=5.87,95%CI=[0.17,0.32]).The p-value is less than 0.001,indicating a robust and statistically significant mediation effect. Since both the direct effect of STM on GBPO and the indirect effect through STD remain significant, the results suggest partial mediation, in line with the framework proposed by (J. F. Hair et al., 2017). Therefore,Hypothesis H4 is supported,confirming that Smart Technology Deployment partially mediates the relationship between Strategic Technology Management and Green Building Performance Outcomes.

Table 4.4: ***Mediation Analysis (Bootstrapping Results)***

Path	Indirect Effect(β)	t-value	95% CI	Result
STM→STD→GBPO	0.24	5.87	[0.17,0.32]	Significant

5.5 Effect Size (f2)

The effect size was calculated to evaluate the substantive impact of the exogenous constructs in the model. As shown in Table 4.5, the effect size (f2) for the path from STM to STD was 0.51,which is considered large, indicating that STM has a substantial influence on the deployment of smart technologies and highlighting its strategic importance. The effect size for the path from STD to Green Building Performance Outcomes (GBPO) was 0.28, which is medium, suggesting a moderate impact of smart technology deployment on green building performance. Similarly,the effect size for the direct path from STM to GBPO was 0.16, also medium, indicating a moderate effect of STM on green building outcomes. These results provide further insights into the relative strength of the relationships in the model.

Table 4.5: ***Effect Size (f2) Assessment***

Path	f2	Interpretation
STM→STD	0.51	Large
STD→GBPO	0.28	Medium
STM→GBPO	0.16	Medium

5.6 Predictive Relevance (Q2)

Predictive relevance was assessed using the blindfolding procedure, and the results are presented in the table below. For Smart Technology Deployment (STD), the Q2 value was 0.23,indicating moderate predictive relevance, suggesting that the model has a reasonable capacity to predict this construct. For Green Building Performance Outcomes (GBPO), the Q2 value was 0.39,reflecting strong predictive relevance, meaning that the model demonstrates a robust ability to predict this construct. PositiveQ2 values for both constructs indicate that the model possesses adequate predictive capability, supporting its overall predictive relevance.

Construct	Q	Interpretation
STD	0.23	Predictive relevance
GBPO	0.39	Strong predictive relevance

Overall,the structural model provides strong empirical support for all hypothesized relationships. Furthermore, Positive Q2 values indicate that the model has adequate predictive capability. It demonstrates that Strategic Technology Management (STM) significantly enhances Smart Technology Deployment (STD), confirming that strategic governance plays a crucial role in enabling smart technology initiatives. Additionally, the model shows that smart technology deployment significantly improves Green Building Performance Outcomes (GBPO),highlighting the operational impact of advanced technologies on sustainability. STM not only directly influences GBPO but also indirectly affects it through STD, confirming both direct and indirect pathways. Furthermore, STD partially mediates the relationship between STM and GBPO,indicating that the impact of STM on green building performance is, in part, channeled through the deployment of smart technologies. The model exhibits substantial explanatory power,with anR2 value of 0.57, demonstrating its ability to explain the variance in GBPO.These findings align with Dynamic Capabilities Theory (Dubey et al., 2023) and the Natural Resource-Based View (Hart,1995),confirming that strategic governance of technology leads to measurable sustainability outcomes through effective smart technology deployment.

5. Discussion

This paper set out to analyze the structural relationships between STM,STD,and GBPO in the construction industry. The results are very solid empirical evidence of the hypothesized model,and the findings are included in the accumulating research on the digital transformation and sustainability performance. First, the fact that STM is significantly and positively related to GBPO provides evidence that strategic governance of technology is an important determinant of green building performance. This result is in line with the Resource-Based View (Barney,1991)that posits that organizational capabilities and not specific technological resources can be the sources of sustained competitive advantage. The finding is in line with the existing empirical literature showing that formal technology planning and integration promote better environmental and operational results in construction projects (Saravana Balaji et al., 2020). As opposed to the previous studies, which focused on the degree of technology adoption, the current results indicate that strategic management, lifecycle management and sustainability alignment also carry the same weight. This supports statements of (Sridharan et al., 2023), who was of the opinion that environmental innovation that is appropriately managed is capable of enhancing both environmental and economic performance. Second, the high impact of STM on STD confirms the presence of the Dynamic Capabilities Theory that suggests that organizations that have a superior degree of strategic technology governance are in a better position to feel and capture digital opportunities.

This finding is in line with the findings of (Yuasa & Takeuchi, 2024) who have identified that organizational readiness and strategic intent have a great impact on the outcomes of technological adoption. On the same note, Jantapoon (2025) noted that companies that are proactive in digital strategies have an increased rate of smart system integration.The current research goes further to corroborate this literature by offering an empirical validation to the role of STM as an enabling process to smart building technologies in the sustainability-oriented environment. Third, the favorable and meaningful correlation between STD and GBPO attests to the idea that smart automation systems, IoT-based monitoring systems,and predictive analytics tools, have a direct and beneficial effect on the environmental, economic, and social performance of buildings. The result is in line with (Pu et al., 2024), who indicated that the smart building systems enhance energy efficiency and operational performance. It also upholds the Natural Resource-Based View of Önder & Gülay (2009) that suggests that the environmentally oriented technological capability contributes to the best sustainability effects. The current findings present objective data that smart technologies are not a symbolic sustainability device but are working processes that will leadto less energy use, greater occupant comfort, and cost-effectiveness. Notably, based on the mediation analysis, STD partially mediates the correlation between STM and GBPO. This result adds to the body of literature by explaining the process by which strategic governance is converted into quantifiable performance results. Earlier research has tended to look at strategic management and technology implementation in isolation, but the current findings prove that smart technology implementation is a channel of transmission between the top-level strategic intent and operational benefits in terms of sustainability. This is in line with (Y. Chen, 2020) who highlighted that the advantages of technology arerealizable only when incorporated in systematic management systems. On the whole, the results imply that the sustainable construction performance requires an integrated approach that involves the combination of strategic governance and operational deployment of digital facilities. These findings enhance both theoretical incorporation in RBV, Dynamic Capabilities Theory, and the Natural Resource-Based View and empirically confirm previous sustainability and smart building studies. This research complements prior knowledge on the application of technology strategy in creating observable environmental and company performance change in the construction industry by providing both direct and mediated relationships.

5.1 Theoretical Implications

This paper makes a number of significant theoretical contributions to the sustainability,construction management, and strategic technology governance literature. First, the results are the extension of the Resource-Based View (RBV) of (Barney, 1991) since the Strategic Technology Management (STM) has been empirically proven as a higher-order organizational capability that brings about sustainability-oriented performance benefits. Although RBV conventionally focuses on both tangible and intangible resources of the firm, this paper illustrates that a structured technology governance, which involves planning, acquisition, integration, and evaluation, represents a strategic capability that directly improves Green Building Performance Outcomes (GBPO). As compared to previous studies, which concentrated on the presence of technology or the degree of adoption (Sridharan et al., 2023), the current results indicate that the positive effect of performance is caused by the systematic governance systems other than the technology assets. Second, the research paper contributes to Dynamic Capabilities Theory in that it operationalizes and empirically examines the operation of sensing, seizing,and reconfiguring capabilities in the context of sustainability-based construction. The close correlation between STM and Smart Technology Deployment (STD) offers the quantitative data that the strategic governance increases the capacity of an organization to implement digital innovations successfully.Previous studies have proposed that dynamic capabilities are essential to digital transformation (Bharadwaj, 2000), but no empirical proofon the same has been done in the context of green building performance frameworks. The paper will fill that gap by combining digital capability maturity with environmental performance measurement. Third, the results extend to the Natural Resource-Based View (NRBV) (Pu et al., 2024) by finding that the environmental capabilities are anchored in technological systems and generate observable sustainability results. The high correlation between STD and GBPO verifies the position that environmentally focused technological capabilities are strategic forces of high environmental and economic results. As opposed to the information presented in studies that solely examine the level of green certification (Liu et al., 2022), the current research combines digital operational systems with the sustainability theory, providing a more comprehensive perspective on the performance generation. Fourth, the mediating role of STD explains the process that exists between strategic governance and sustainability performance. In the past, most researchers have tended to consider strategic management and smart technology implementation as a pair of similar concepts (Novikova & Samaybekova, 2024). Nevertheless, this paper proves that the adoption of smart technology is an act of transmission, the conversion of a strategic intent into operational results. The partial mediation implies that not only the decisions made at the governance level predetermine sustainability performance, but also the operational digital infrastructures. This two-way explanation goes further towards the integration of theory between RBV,Dynamic Capabilities Theory and NRBV. Lastly, the research has a methodological contribution to the area in that it confirms the use of a multidimensional measurement model to measure technology-sustainability integration. It offers a deep quantitative model that can be replicated in other sectors experiencing the process of digital sustainability by integrating higher-order CFA and structural mediation analysis.

5.2. Practical Implications

The paper also has important practical implications for construction companies,sustainability managers, digital transformation leaders, and policymakers. To begin with, the results outline the importance of the firms to change their narrow approach to technological acquisition and adopt a complex technological governance framework. The close impact of STM on STD means that the digital investments prove to be the most effective to provide returns in the form of formal planning structures, lifecycle monitoring, and KPIs aligned with sustainability. To ensure the optimal performance impact, construction organizations are encouraged to develop cross-functional technology steering committees, as well as incorporate sustainability goals within digital roadmaps. Second, the fact that STD has a positive impact on GBPO implies that the investments in smart building solutions, including IoT-based monitoring, building automation systems, predictive maintenance tools, and energy management applications, can generate quantifiable environmental and economic benefits. Nevertheless, such technologies need to be incorporated in synchronized strategic architectures. Companies that perceive smart systems as a detached instrument are likely to experience poor performance and disjointed sustainability results (Darko et al., 2017). Third, the outcome of the mediation points out the need to match the digitaI transformation strategies with sustainability agendas. The digital programs and sustainability programs in most construction companies do not go hand in hand. These observations indicate that Chief Information Officers (CIOs), sustainability officers, and operations managers should be integrated in a manner that they are able to realize all the value of smart technologies. Fourth, the policymakers and certification agencies can take into account the use of technology governance maturity indicators during the green building certification systems.The existing frameworks mostly consider technology presence instead of quality governance.The dimensions of strategic management should be included to enhance accountability and promote performance along the long-term sustainability. Lastly,the high level of explained variance in GBPO(R2=057)offers extensive support to the capital allocation on the sphere of integrated digital strategies of sustainability. These findings can assist the executives in making investment decisions and communicating evidence-based value propositions to the stakeholders.

5.3. Limitation and Future Research

Although this study has given some contributions both theoretical and practical, it has several limitations,which offer future research opportunities. First, the research implemented a cross-sectional research design, which does not provide a good opportunity to make a solid causal conclusion about the dynamic relationship between Strategic Technology Management (STM),Smart Technology Deployment (STD), and Green Building Performance Outcomes (GBPO).Even though Structural Equation Modeling (SEM) offers statistical proof of directional correlation (Hair et al., 2017),longitudinal investigations are required to determine how technology governance maturity changes with time and how long-term sustainability is affected by sustained digital transformation. This study needs to utilize panel data or time-series analysis in future studies to improve causality and performance trajectories. Second, self-reported survey tools were used to gather the data, and this can create common method bias and limitations on perceptual measurements (Podsakoff et a1., 2003). Although statistical checks indicated that common method variance was not a significant issue of concern, the use of perceptual data may not entirely portray objective environmental or financial performance outcomes. To enhance empirical soundness and minimize the possibility of bias, future research must use objective measures like energy use intensity (EUI), measures of carbon emissions, lifetime cost data or third-party green certification index. Third, the research is limited to those organizations that are operating in a particuar national and regulatory environment. The institutional settings,maturity of digital infrastructure, and regulation of sustainability are not the same across nations. Thus,the application of the findings to the developed economies or regions that have varied policy frameworks can be rather restricted. Comparative studies across countries should be done in the future to help study the relationship between technology governance and sustainability performance to be moderated by the regulatory stringency, market maturity or cultural factors.Fourth,the model fails to explicitly study possible moderating variables that can be used to determine the strength of the hypothesized relationships. The variables of organizational size,level of digital maturity, complexity of the project, the orientation of leadership, and pressure of regulatory factors might influence the conversion of STM into STD and GBPO. The moderating and control variables should be included in futurestudies to determine the boundaries within which strategic technology governance would be more or less effective. Fifth, although the study conceptualizes STM as a higher-order construct, it is not an in-depth examination of how the various dimensions of the construct (planning, acquisition, integration, and evaluation)can have a differing effect on sustainability outcomes. Further studies may break down these dimensions and see their comparative significance or nonlinear influence. Also, newer technologies like artificial intelligence, supply chains powered by blockchain, and digital twins should be explored further to learn how the next generation of digital technologies can transform sustainable construction practices. All in all,longitudinal,multi-method, and multi-country research approaches should be taken in the future to perfect the measurement frame and increase the extrapolability of the results. The enhancement of the model with moderating variables and new technologies will lead to the further development of theoretical knowledge and practical implementation of the changing environment of smart and sustainable construction.

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