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The Impact of IT Product Management, Digital Supply Chain Optimization, Energy Efficiency, and Environmental Design on Sustainable Building Performance

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Abstract

This study investigates the impact of IT product management, digital supply chain optimization, energy efficiency, and environmental design on sustainable building performance. The purpose of this research is to understand how these four key factors contribute to achieving sustainability in building performance, a critical aspect for businesses aiming to reduce their environmental footprint. A quantitative research design was employed, using a survey questionnaire to collect data from professionals in the building and construction industry in Saudi Arabia. The data was analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) to assess the relationships between the variables. The findings reveal that energy efficiency has the most significant positive impact on sustainable building performance, followed closely by digital supply chain optimization and environmental design. IT product management, while important, demonstrated a comparatively lower effect but was found to be essential for supporting other sustainability-related processes. The results suggest that organizations aiming to improve their sustainable performance should prioritize energy-efficient practices, optimize their supply chains through digital solutions, and integrate environmental considerations into their building

designs. The study concludes with recommendations for businesses and policymakers to foster a more sustainable approach to building performance, emphasizing the need for an integrated strategy combining technology, efficiency, and environmental design.

Introduction:

The increased attention on sustainability, climate change, and resource usage that the global industry is currently looking at has necessitated the need for new solutions that will help decreasing the footprint while increasing the efficiency. Built environment plays a large part and one sector that has been greatly affected is the building and construction industry that has a large percentage of global energy consumption and carbon emissions. With increased demand for sustainable buildings, as the result of environmental regulations and market forces as well as consumer awareness, organizations are inevitably pushed to deploy advanced technologies and management practices that improve the performance of the buildings, as well as reducing the ecological footprint. All these bring the role of IT product management, digital supply chain optimization, energy efficiency and environmental design into the picture. These factors together make up the total that defines the concept of sustainable building performance; that is, the amount by which a building is able to achieve both operational efficiency and environmental sustainability goals. The definition of sustainable buildings is that they reduce energy usage and waste, make optimum use of resources, and helps in delivering the healthier living and working environment, additionally they contribute to broader sustainability goals.

IT product management involves creating and managing technology based solutions that meet the strategic goals of sustainability in building performance. A strong IT product management is imperative in building smart building technologies, IoT devices, and energy management systems due to the fast advancements in these areas. While, digital supply chain optimization implies leveraging digital technologies to manage operations and supply chain processes including the selection or sourcing of sustainable materials, reduction of waste in construction and operations. Optimization of supply chains through the use of data analytics, automation, and block chain technologies can help reduce the environmental impact and improve operational efficiency. Energy efficiency is a key element in sustainable building performance that seeks to decrease the energy demand of buildings with intelligent technologies, efficient HVAC systems and renewable energy connection. Third, environmental design of the building is focused on the role architectural, materials, and the construction methods play in decreasing the ecological footprint of a building. It also integrates green building standards and certifications like LEED or BREEAM to ensure proper design of the buildings with a focus on sustainability.

These variables are direct and interdependent between each other. Better decision making and efficient resource utilization leads to improvements in IT product management and digital supply chain optimization; which in turn leads to increased energy efficiency and environmental design. For example, good IT product management means that the technologies used within the building (e.g. smart sensors, energy management systems, etc.) are aligned with the purpose of energy efficiency and environmental sustainability. Digital supply chain optimization also means procurement and management of sustainable materials and also directly influences the environmental design and the energy performance of the building. Taken together these elements have a synergistic effect on the sustainable building performance and enhance the overall sustainable performance outcomes. However, there is a theoretical linkage between these variables to the resource based view (RBV) which suggests that organizations can obtain a competitive advantage by effectively managing and deploying their resources. IT systems, supply chain processes and energy efficient technologies are valuable resources that will be integrated strategically to improve sustainable performance in this context.

Although a body of literature is growing on sustainable building performance, there are still knowledge gaps that need investigating. However, most of existing research is done based on the individual components of sustainable building performance, like energy efficiency or environmental design but without accounting for the overall effect of IT product management and optimization of digital supply chain. Further, despite the fact that some studies assess the relationship between building performance and sustainability, they overlook the contribution of advanced technologies and management practices in improving performance. The second gap in the literature is that empirical evidence to understand how these factors interact to give an overall model of sustainable building performance is lacking. The majority of existing frameworks fail to consider the growing role of digital transformation and IT in managing products towards sustainability, with the emphasis being on the traditional building performance indicators.

This study research problem results from the identification that there is the need to develop a profound understanding of how IT product management, digital supply chain optimization, energy efficiency and environmental design collectively affect sustainable building performance. Nowadays, industries are attempting to fulfill the tighter environmental rules and consumer needs of sustainable practice, hence the need to search how these factors can be strategically integrated to optimize building performance. Yet, organizations are unable to make full utilization of potential sustainable buildings due to the lack of holistic models considering technology management, supply chain processes, energy consumption, and design aspects. However, no study has focused on the combined effect of these key variables and their interrelationships to sustainable building performance.

This study is of significance because it can contribute to the academic literature as well as the industry practices. From a research point, the contribution of the research will be: to extend the existing theories on sustainable building performance by incorporating the role of IT product management and digital supply chain optimization. This will be accomplished by studying these factors in relation to traditional measures of building sustainability, like energy efficiency and environmental design, so that a more holistic view of what goes into sustainability of a building can be developed. These will fill the existing gaps within the literature and will also serve as a foundation to be used for future research looking at the integration of digital technologies with sustainability practices within the construction, as well as building, management sectors. Based upon these findings, this study will provide practitioners with practical insights from an industry viewpoint to architects, engineers, IT managers and supply chain professionals to optimize sustainable building performance. The potential to inform decision making processes within the design, construction and operation of sustainable buildings, so as to enable organizations to meet regulatory requirements, minimize environmental impact and increase operational efficiencies.

Therefore, for such a growing emphasis on sustainability in building and construction industry, it is just right to consider more comprehensive sustainability in building performance. In the past, energy efficiency and environmental design have always been in the limelight when discussing sustainability, but IT product management and the digital supply chain optimization are now taking centre stage when it comes to sustainability. Organizations can align these factors to improve sustainability outcomes of buildings, decrease energy consumption and minimize the environmental footprint. Specifically, this study aims to bridge the gap in the current literature by studying the synergistic effects of IT product management, digital supply chain optimization, energy efficiency and environment design on sustainable building performance. The results will advance new material for both academic knowledge and for practice, and offer some key learning's on how sustainable buildings will evolve in a digital age.

2.0 Literature Review

Theoretical Background

Fields of sustainable practices and climate change control are getting ever more apparent internationally – as is industry's demand for innovative solutions towards reducing its environmental footprint, minimizing carbon footprint and energy costs while staying efficient. This is more relevant in building and construction industry, where the sector has a large share of global energy consumption and carbon emissions. With greater emphasis on sustainable buildings caused by environmental regulations, market pressure and now the demands of consumers, organizations have to deploy advanced technologies and management practices that not only optimize the performance of buildings, but also bring down its ecological footprint. All these bring the role of IT product management, digital supply chain optimization, energy efficiency and environmental design into the picture. These factors together make up the total that defines the concept of sustainable building performance; that is, the amount by which a building is able to achieve both operational efficiency and environmental sustainability goals. Sustainable buildings are designed for reducing energy consumption, minimizing waste, maximizing resource use, and creating healthier living and working environments and also enhance the ability to meet both its purpose and broader sustainability goals.

IT product management involves creating and managing technology based solutions that meet the strategic goals of sustainability in building performance. A strong IT product management is imperative in building smart building technologies, IoT devices, and energy management systems due to the fast advancements in these areas. Digital supply chain optimization on the contrary means using digital technologies to reduce supply chain processes from the point of procurement of sustainable materials to the reduction of waste during construction and operations through an app. With the use of data analytics, automation and block chain technologies, supply chains can be optimized to be more environmentally friendly and operationally efficient. Energy efficiency is a key element in sustainable building performance that seeks to decrease the energy demand of buildings with intelligent technologies, efficient HVAC systems and renewable energy connection. Finally, in environmental design, architecture, materials and construction methods are addressed in order to minimize the ecological footprint of buildings. It also integrates green building standards and certifications like LEED or BREEAM to ensure proper design of the buildings with a focus on sustainability.

These variables are direct and interdependent between each other. Digital supply chain optimization and IT product management lead to better decision making and efficient resource utilization, which ultimately causes more efficient use of energy and better environmental design. For example, good IT product management means that the technologies used within the building (e.g. smart sensors, energy management systems, etc.) are aligned with the purpose of energy efficiency and environmental sustainability. Digital supply chain optimization can also help procurement and management of sustainable materials that influence the environmental design and energy performance of the building. Taken together these elements have a synergistic effect on the sustainable building performance and enhance the overall sustainable performance outcomes. However, there is a theoretical linkage between these variables to the resource based view (RBV) which suggests that organizations can obtain a competitive advantage by effectively managing and deploying their resources. IT systems, supply chain processes and energy efficient technologies are valuable resources that will be integrated strategically to improve sustainable performance in this context.

Although much literature exists on the sustainability of building performance, more research into this area is necessary to fill remaining gaps. Most of the current research pertains to the energy efficiency or environmental design of individual components of sustainable building performance, without consideration for the holistic effect of IT product management and digital

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supply chain optimization. Further, despite the fact that some studies assess the relationship between building performance and sustainability, they overlook the contribution of advanced technologies and management practices in improving performance. The second gap in the literature is that empirical evidence to understand how these factors interact to give an overall model of sustainable building performance is lacking. The majority of existing frameworks fail to consider the growing role of digital transformation and IT in managing products towards sustainability, with the emphasis being on the traditional building performance indicators.

This study research problem results from the identification that there is the need to develop a profound understanding of how IT product management, digital supply chain optimization, energy efficiency and environmental design collectively affect sustainable building performance. Given the industries' effort to meet the increasingly stringent environmental regulations and the consumers' raised expectation for sustainable practices, it becomes increasingly important to examine how these factors can be incorporated into one strategically to enhance the building performance. Currently, the lack of holistic models that capture the feedback between technology management, supply chain processes, energy consumption and design limits organizational realization of fully sustainable buildings. The gap is filled within this study through investigating the relationships between these key variables and provides empirical evidence on the combined impact that these variables have on sustainable building performance.

H1: IT product management has a positive impact on sustainable building performance.

H2: Digital supply chain optimization positively influences sustainable building performance.

H3: Energy efficiency significantly contributes to sustainable building performance.

H4: Environmental design has a positive effect on sustainable building performance.

H5: The combined impact of IT product management, digital supply chain optimization, energy efficiency, and environmental design leads to enhanced sustainable building performance

This study is of significance because it can contribute to the academic literature as well as the industry practices. From a research point, the contribution of the research will be: to extend the existing theories on sustainable building performance by incorporating the role of IT product management and digital supply chain optimization. Through the analysis of these parameters along with the conventional measures of sustainability (energy efficiency and environmental design), this study will supply a more balanced comprehension of how numerous parts add to the general sustainability of the buildings. This will enable to fill the existing gaps in the literature and serve as a starting point for further research aimed at the development of digital technologies and sustainability practices integration in the construction and building management areas. Based upon these findings, this study will provide practitioners with practical insights from an industry viewpoint to architects, engineers, IT managers and supply chain professionals to optimize sustainable building performance. The potential to inform decision making processes within the design, construction and operation of sustainable buildings, so as to enable organizations to meet regulatory requirements, minimize environmental impact and increase operational efficiencies.

Methodology

The methodology employed in this study was designed to enable a complete understanding of the effect of IT product management, digital supply chain optimizing, energy efficiency, and environmental design in sustainable building performance. The study was based on quantitative research design and it fitted positivist philosophy. The positivist approach was used because it accepts empirical data and statistical analysis in testing predetermined hypotheses and for objective observation and generalization. By this philosophical stance, the research was able to concentrate on such observable facts, relationships, and measurable outcomes as necessary for knowing the quantitative effects of the variables being investigated.

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The target population of this study is professionals working in the construction and building management sectors in Saudi Arabia. Because sustainable building performance was the topic of focus it was important to identify those who are involved with the IT product management, supply chain operations, energy efficiency and environmental design decision making and implementation. The population of engineers, architects, project managers, IT managers, and sustainability officers had practiced in sustainable building practice. The sample was made up of professionals from different environments (public and private sectors) as well as from projects that have some (or all) of the degrees of sustainability certifications such as LEED and BREEAM to make sure the representation of the sample is diversified.

For selecting participants who had sufficient expertise and experience in sustainable building performance, the non-probability sampling strategy was adopted, namely the purposive sampling. The researcher chose this sampling method because it enabled him to study persons capable of giving knowledgeable insights founded on their practical experience in the industry. The response was 300 professionals from Saudi Arabia who vary in their expertise with sustainable building initiatives. The participants had adequate knowledge and experience, therefore supporting the reliability of the data collected, through the purposive sampling strategy.

A survey questionnaire was developed based on those validated scales in previous studies and used to collect data. In this respect, the questionnaire was divided into sections according to the key variables studied, namely IT product management, digital supply chain optimization, energy efficiency, environmental design, and sustainable building performance. The content validity of the items for each section was established by adapting them from well-established measures. The Likert scale questionnaire used 5 points from 1 (Strongly Disagree) to 5 (Strongly Agree) to get respondents' perception of the variables under our study. A standardized measure for comparing across the sample was made possible by using a Likert scale in the quantitative analysis of attitudes and behaviors.

Partial Least Squares Structural Equation Modeling (PLS-SEM) was used to test the relationships of the variables for data analysis. The choice of PLS-SEM was appropriate since it is fit for complex models with multiple latent variables and small to medium sample sizes. By utilizing this method, it was possible to analyze the direct and indirect relationships between IT product management, digital supply chain optimization, energy efficiency, environmental design, and sustainable building performance at the same time. Along with this, PLS-SEM is highly suitable for explorative research where the aim is to generate theoretical models and then test their validity. This method gave a robust insight in the interaction effects of the variables on sustainable building performance.

Ethical concerns of the study were carefully taken care of so as to make sure that the research was in line with ethical considerations. The participants were informed about the purpose of this study and the participation was voluntary. The collection of data was preceded by obtaining of an informed consent from the subjects, and hence all participants were fully aware of the nature of this research and their rights to withdraw at any time. The identities of the participants were protected by anonym zing the participant responses and maintaining confidentiality throughout the study. Moreover, the data were kept securely and used for research only. According to the research, all ethical guidelines of institutional review board and all other regulations that are relevant to human subjects' research were followed.

Thus, the research design was a quantitative approach based on positivism philosophy and purposive sampling was applied to sample the participants from construction and building management sectors in Saudi Arabia. A structured survey questionnaire was used in collecting the data, which were analyzed through PLS-SEM technique to determine relationships between variables. All the study's ethical considerations were prioritized, with the protection and privacy of all the participants protected.

Results:

4.1: Reliability Analysis (Cornbrash's Alpha and Composite Reliability)

Construct	Cornbrash's Alpha	Composite Reliability (CR)
IT Product Management	0.84	0.89
Digital Supply Chain Optimization	0.87	0.91
Energy Efficiency	0.85	0.90
Environmental Design	0.82	0.88
Sustainable Building Performance	0.89	0.93

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Interpretation: The results show that all constructs have Cornbrash's Alpha values above 0.7, indicating acceptable internal consistency and reliability. The Composite Reliability (CR) values for all constructs are also greater than 0.7, demonstrating that the constructs are reliable in measuring the intended latent variables. High CR values indicate that the measures are consistent and reliable for the constructs being tested in the model.

4.2: Validity Analysis (HTMT Ratio)

Construct 1	Construct 2	HTMT Ratio
IT Product Management	Digital Supply Chain Optimization	0.72
IT Product Management	Energy Efficiency	0.64
IT Product Management	Environmental Design	0.69
IT Product Management	Sustainable Building Performance	0.58
Digital Supply Chain Optimization	Energy Efficiency	0.61
Digital Supply Chain Optimization	Environmental Design	0.67
Digital Supply Chain Optimization	Sustainable Building Performance	0.73
Energy Efficiency	Environmental Design	0.59
Energy Efficiency	Sustainable Building Performance	0.63
Environmental Design	Sustainable Building Performance	0.65

Interpretation: The HTMT ratio values are all below the threshold of 0.85, indicating that there are no issues of discriminant validity between the constructs. This suggests that the constructs are distinct and measure different aspects of the theoretical framework. The HTMT values demonstrate that each construct is adequately differentiated from the others, providing evidence of discriminant validity in the model.

4.3: Variance Inflation Factor (VIF)

Construct	VIF Value
IT Product Management	1.58
Digital Supply Chain Optimization	1.65
Energy Efficiency	1.45

Construct	VIF Value
Environmental Design	1.53

Interpretation: The VIF values for all constructs are below the threshold of 5, indicating that Multicollinearity is not a concern in the model. Multicollinearity occurs when there is a high correlation between independent variables, but the low VIF values suggest that the constructs are independent of one another. The absence of Multicollinearity ensures the robustness of the regression coefficients in the structural model.

4: Model Fitness (SRMR, NFI, R^2)

Model Fit Indicator	Value	Threshold
SRMR (Standardized Root Mean Square Residual)	0.057	< 0.08
NFI (Normed Fit Index)	0.92	> 0.90
R^2 for Sustainable Building Performance	0.58	-

Interpretation: The SRMR value of 0.057 is below the threshold of 0.08, indicating a good model fit. The NFI value of 0.92 exceeds the threshold of 0.90, further supporting the adequacy of the model fit. Additionally, the R^2 value for Sustainable Building Performance is 0.58, which means that 58% of the variance in Sustainable Building Performance can be explained by the independent variables (IT Product Management, Digital Supply Chain Optimization, Energy Efficiency, and Environmental Design). This demonstrates a moderate to strong explanatory power of the model.

Table 5: Structural Equation Model (Path Coefficients)

Path	Beta Coefficient	t-Value	p-Value
IT Product Management → Sustainable Building Performance	0.25	2.85	0.004
Digital Supply Chain Optimization → Sustainable Building Performance	0.29	3.12	0.002
Energy Efficiency → Sustainable Building Performance	0.33	3.45	0.001
Environmental Design → Sustainable Building Performance	0.28	2.98	0.003

Interpretation: The path coefficients indicate the strength of the relationships between the independent variables and the dependent variable (Sustainable Building Performance). All paths are statistically significant, with p-values below 0.05, suggesting strong relationships between IT Product Management ($\beta = 0.25$), Digital Supply Chain Optimization ($\beta = 0.29$), Energy Efficiency ($\beta = 0.33$), and Environmental Design ($\beta = 0.28$) and Sustainable Building Performance. The t-values also confirm the significance of these paths. The results suggest that all four factors play a significant role in enhancing sustainable building performance, with Energy Efficiency having the strongest impact.

Discussion & Conclusion:

The findings of this study underscore the significant role that IT product management, digital supply chain optimization, energy efficiency, and environmental design play in influencing sustainable building performance. The results from the PLS-SEM analysis demonstrate that each of these factors contributes positively to the overall sustainability of building performance, with energy efficiency emerging as the most influential predictor. This suggests that companies focusing on sustainability initiatives should prioritize energy-efficient technologies and practices as a primary driver for enhancing building performance outcomes.

IT product management showed a significant yet slightly weaker relationship compared to the other factors. This suggests that while IT systems and their effective management are crucial, they may not independently drive sustainable outcomes to the same extent as energy efficiency. However, IT product management provides critical infrastructure that supports other activities, such as digital supply chain optimization, making it an indispensable component in the overall strategy for sustainable performance.

The influence of digital supply chain optimization on sustainable building performance was found to be substantial. This finding aligns with the increasing focus on digitizing supply chains to reduce waste, enhance transparency, and improve operational efficiency in a sustainable manner. The results suggest that by implementing digital solutions in their supply chains, organizations can significantly impact their overall sustainability efforts. Furthermore, environmental design emerged as another key factor, indicating that the physical design of buildings, incorporating environmental considerations, has a strong positive effect on their performance. Sustainable architectural and environmental designs that focus on reducing energy consumption and waste, as well as incorporating renewable materials, directly enhance the sustainability metrics of buildings.

In terms of conclusions, this study reveals that the integrated approach to managing IT products, optimizing supply chains, focusing on energy efficiency, and incorporating environmental design elements leads to better sustainable outcomes in building performance. These four factors, when managed effectively, can create a synergistic effect that amplifies the sustainability and long-term viability of building projects.

From a practical standpoint, these findings offer several important recommendations. First, organizations should invest more in energy efficiency technologies and practices, as this is shown to have the most significant impact on sustainable building performance. Second, businesses should continue to enhance their digital supply chains to streamline operations and reduce environmental impact. In doing so, companies can optimize their procurement, logistics, and overall resource management, which directly contributes to sustainable outcomes. IT product management remains crucial for supporting these digital initiatives and should be viewed as an enabler rather than an isolated factor. Lastly, incorporating environmental design into construction and retrofitting projects will ensure that the building’s sustainability goals are met over its entire lifecycle.

The implications of these findings extend to both business and policy levels. Businesses need to reassess their operational strategies to incorporate sustainable practices across all facets, especially focusing on technological integration and energy efficiency. Furthermore, policymakers can use these insights to encourage regulations and incentives that promote sustainable building practices, such as tax breaks for energy-efficient buildings and green certifications that focus on environmental design standards.

Overall, the research provides strong evidence for a holistic approach to sustainable building performance, wherein multiple factors, including technology, supply chain optimization, and environmental considerations, need to be aligned. Future research could explore the interplay between these factors in different industries and regions to expand the understanding of sustainable practices and performance outcomes.

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