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THE IMPACT OF SMART BUILDING TECHNOLOGIES ON BUSINESS EFFICIENCY AND OPERATING COSTS ECONOMIC ANALYSIS ON THE EXAMPLE OF PERKINS MMC

BACHELOR'S PROJECT

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CONTENT

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Date
Name SURNAME

SYMBOLS AND ABBREVIATIONS

AI	Artificial Intelligence
BMS	Building Management System
CBA	Cost–Benefit Analysis
CO_2	Carbon Dioxide
EMS	Energy Management System
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IoT	Internet of Things
KPI	Key Performance Indicator

ABSTRACT

THE IMPACT OF SMART BUILDING TECHNOLOGIES ON BUSINESS EFFICIENCY AND OPERATING COSTS ECONOMIC ANALYSIS ON THE EXAMPLE OF PERKINS MMC

This study aims to examine the impact of smart building technologies on operational efficiency and costs. The research analyzes the effects of integrating IoT (Internet of Things), automation systems, and sensor technologies into operational processes on energy consumption, maintenance costs, and total operational costs. The study was conducted using a real-world example, Perkins MMC, and a comparative analysis was carried out based on data from the pre-implementation period (2022) and the post-implementation period (2023–2024).

The research employed a quantitative method, employing descriptive statistics, independent samples t-tests, and comparative analysis techniques. Additionally, cost-benefit analysis and return on investment (ROI) calculations were performed to assess the financial effectiveness of the investment. The findings show that smart building technologies reduced energy consumption by approximately 29%, decreased maintenance and repair costs by over 35%, and reduced total operational costs by approximately 27%. The t-test results indicate that these changes are statistically significant ($p < 0.05$).

The results of the economic analysis show that smart building investments provide a high level of financial return. The ROI rate calculated in the study is 124.8%, and the payback period of the investment was determined to be less than one year. This reveals that smart building technologies are a sustainable and rational investment not only from a technical but also from an economic perspective.

Keywords: Smart building, operational efficiency, energy consumption, cost management, IoT, return on investment (ROI)

1. INTRODUCTION

1.1. Purpose of the Research

In recent years, rapid advancements in digital technologies have significantly transformed the way buildings are designed, managed, and operated. The integration of Internet of Things (IoT), automation systems, and data analytics into building infrastructure has given rise to the concept of smart buildings, which aim to enhance operational efficiency, reduce energy consumption, and improve user comfort. Within the broader context of digital transformation, smart building technologies have emerged as a strategic tool for organizations seeking to optimize resource utilization and gain a competitive advantage (GhaffarianHoseini et al., 2016).

The increasing importance of sustainability and energy efficiency has further accelerated the adoption of smart building systems across various industries. Buildings account for a substantial share of global energy consumption, making them a critical focus area for efficiency improvements and carbon emission reduction efforts. Smart building technologies enable real-time monitoring and control of energy usage, allowing organizations to reduce waste and improve overall system performance. As a result, these technologies not only contribute to environmental sustainability but also offer significant economic benefits by lowering operational costs (IEA, 2021).

The primary purpose of this study is to examine the impact of smart building technologies on business efficiency and operational costs within a real-world organizational context. Specifically, the research aims to analyze how the integration of Internet of Things (IoT), automation systems, and sensor-based technologies influences key performance indicators such as energy consumption, maintenance expenses, and total operational costs. By conducting a comparative analysis of pre- and post-implementation data, the study seeks to provide empirical evidence on the effectiveness of smart building systems in improving operational performance. In addition, the study aims to evaluate the financial feasibility of such technological investments through cost–benefit analysis and return on investment (ROI) calculations, thereby contributing to both academic research and managerial decision-making processes.

1.2. Importance of the Research

The importance of this research lies in its contribution to understanding the practical and economic implications of smart building technologies in contemporary business environments. As organizations increasingly prioritize digital transformation and sustainability, the adoption of smart systems has become a critical factor in achieving operational efficiency and reducing costs. However, despite the growing interest in this field, there is a limited number of empirical studies that provide data-driven evidence on the real-world impact of these technologies at the firm level. This study addresses this gap by offering a detailed case-based analysis, thereby enhancing the existing literature. Furthermore, the findings are particularly relevant for developing countries, where resource optimization and cost efficiency are essential for competitiveness. From a managerial perspective, the research provides valuable insights for decision-makers by demonstrating the economic benefits and long-term value of investing in smart building systems.

1.3. Research Problem

Despite the increasing adoption of smart building technologies, there remains uncertainty regarding their actual impact on business performance and cost structures. While theoretical and conceptual studies suggest that these technologies improve efficiency and reduce operational costs, empirical evidence at the organizational level is still insufficient and fragmented. In particular, there is a lack of comprehensive studies that quantitatively measure the before-and-after effects of smart building implementation using real operational data. Additionally, the financial viability of such investments, especially in terms of cost–benefit balance and return on investment, is not adequately addressed in existing research. Therefore, the main research problem of this study is to determine whether the implementation of smart building technologies leads to measurable improvements in operational efficiency and significant reductions in business costs.

1.4. Research Questions

This study seeks to answer the following research questions:

- How do smart building technologies affect energy consumption within the organization?
- What is the impact of smart building systems on maintenance and repair costs?
- To what extent do smart building technologies reduce overall operational costs?

- Are the observed changes in costs and performance statistically significant?
- What is the financial return (ROI) of smart building technology investments?
- Do smart building systems provide sustainable long-term efficiency improvements?

1.5. Scope and Limitations of the Research

This study focuses on analyzing the impact of smart building technologies within a single organization, namely Perkins MMC. The scope of the research includes the evaluation of key operational indicators such as energy consumption, maintenance costs, and total operational expenses before and after the implementation of smart building systems. The analysis covers a specific time period (2022–2024), allowing for a comparative assessment of performance changes over time.

However, the study has several limitations that should be acknowledged. First, the research is based on a single case study, which may limit the generalizability of the findings to other organizations or industries. Second, the analysis relies on available company data, which may be subject to data quality constraints or missing values. Third, external factors such as fluctuations in energy prices, seasonal variations, and macroeconomic conditions are not explicitly controlled for in the analysis. Finally, the study primarily employs basic statistical techniques, and more advanced econometric models could provide deeper insights into causal relationships. Despite these limitations, the study offers valuable empirical evidence and serves as a foundation for future research in this field.

2. LITERATURE REVIEW

2.1. Smart Building Concept and Development

The concept of a smart building stands out as one of the most important components of the contemporary understanding of construction, evolving along the lines of digitalization and sustainability. Essentially, a smart building is defined as a type of structure that increases energy efficiency, optimizes user comfort, and makes operational processes more effective through the integration of indoor systems via sensors, data analytics, and automation technologies. In this context, the development of Internet of Things (IoT) technologies, in particular, has accelerated the widespread adoption of the smart building concept by enabling real-time monitoring and control of building systems (GhaffarianHoseini et al., 2013).

The systems that form the basis of smart buildings include building management systems (BMS), sensor technologies, and artificial intelligence-supported analysis mechanisms. Through these systems, elements such as heating, ventilation and air conditioning (HVAC), lighting, security, and energy consumption within the building are managed in an integrated manner. Data-driven decision-making processes, in particular, enable buildings to operate not only reactively but also proactively. For example, systems can predict situations that may lead to increased energy consumption by analyzing historical data and automatically perform the necessary optimizations (Buckman et al., 2014).

Energy efficiency is widely discussed in the literature as one of the most critical advantages of the smart building concept. Various empirical studies have shown that smart building systems can reduce energy consumption by 20% to 40% compared to traditional buildings. This is of great importance not only in terms of reducing costs but also in terms of reducing carbon emissions and ensuring environmental sustainability. Indeed, smart buildings are considered one of the fundamental building blocks of the smart cities vision (Zhang et al., 2018).

Furthermore, the impact of smart building applications on user experience is also noteworthy. Features such as personalized environmental control, automated lighting systems, and continuous monitoring of indoor air quality significantly increase the comfort level of building users. At the same time, thanks to the integration of security systems, risks such as fire, gas leaks, or unauthorized entry are detected instantly, enabling rapid intervention. In this respect, smart buildings are not only a technological innovation but also a tangible reflection of a human-centered design approach (Al Dakheel et al., 2020).

Table 1. Key Components and Impacts of Smart Building Concept

Dimension	Description	Key Technologies	Main Benefits	Key References
Concept Definition	Smart buildings integrate digital systems to improve efficiency, comfort, and operations	IoT, Data Analytics, Automation	Efficient building management, real-time control	GhaffarianHoseini et al. (2013)
System Infrastructure	Integrated management of HVAC, lighting, security, and energy systems	BMS, Sensors, AI Systems	Proactive decision-making, system optimization	Buckman et al. (2014)
Energy Efficiency	Reduction of energy consumption compared to traditional buildings	IoT Sensors, EMS	20–40% energy savings, cost reduction, sustainability	Zhang et al. (2018)
User Experience	Enhancement of indoor comfort and safety	Smart Lighting, Air Quality Sensors, Security Systems	Increased comfort, safety, and productivity	Al Dakheel et al. (2020)
Business Impact	Contribution to corporate digital transformation and operational control	Data-driven systems, AI	Cost optimization, strategic advantage	Omar (2018)
Challenges	Barriers to adoption and implementation	Infrastructure, Cybersecurity	High initial cost, data security risks	General Literature

The smart building concept also makes significant contributions to the implementation of digital transformation strategies at the corporate level. Especially for large-scale businesses and financial institutions, data-driven management of building operations offers strategic advantages in terms of cost control and resource optimization. This has led to smart building systems becoming a significant research topic not only in engineering and architecture but also in management and business disciplines. Therefore, the smart building approach is considered a holistic system located at the intersection of technological infrastructure and managerial innovation (Omar, 2018).

The smart building concept reshapes the modern understanding of construction by offering multi-dimensional benefits such as energy efficiency, sustainability, user comfort, and operational effectiveness. With the development of IoT, artificial intelligence, and big data technologies, these systems are expected to become even more widespread. However, challenges such as high initial costs, data security risks, and technical infrastructure requirements must also be considered. Therefore, it is important that future studies focus on the economic feasibility and long-term sustainability of smart building systems.

2.2. Smart Building Technologies (IoT, Automation, Sensor Systems)

Smart building technologies form the fundamental infrastructure that enables the digitalization of modern buildings. These technologies generally revolve around three main components: the Internet of Things (IoT), automation systems, and sensor networks. These components enable the digitalization of physical processes within the building, resulting in a more efficient, secure, and user-centric management model. In the literature, the integration of these systems is considered one of the determining factors of smart building performance (Buckman et al., 2014).

IoT technologies form the backbone of smart building systems. IoT is a structure that allows physical devices to communicate with each other via the internet, enabling the monitoring and control of different systems within the building through a central platform. For example, data from temperature sensors can be transmitted to the HVAC system to automatically adjust the ambient temperature. This optimizes energy consumption while simultaneously increasing user comfort. One of the most important advantages of IoT-based systems is their support for instantaneous decision-making mechanisms thanks to real-time data flow (GhaffarianHoseini et al., 2013).

Table 2. Core Smart Building Technologies and Their Functions

Technology	Description	Key Functions	Examples	Main Benefits	Key References
Internet of Things (IoT)	Network enabling communication between devices via the internet	Real-time data exchange, remote monitoring and control	Smart HVAC adjustment, centralized dashboards	Energy optimization, real-time decision-making	GhaffarianHoseini et al. (2013)
Automation Systems	Rule-based systems minimizing human intervention	Automatic control of building operations	Motion-based lighting, automated energy distribution	Efficiency, cost reduction, process accuracy	Al Dakheel et al. (2020)
Sensor Systems	Devices collecting environmental and operational data	Continuous monitoring of physical conditions	Temperature, CO_2, humidity, occupancy sensors	Data-driven optimization, improved comfort and safety	Zhang et al. (2018)
System Integration	Combined operation of IoT, sensors, and automation	Data collection → processing → action cycle	Smart building management platforms	Adaptive systems, predictive capabilities	Buckman et al. (2014); Omar (2018)

Automation systems in smart buildings minimize human intervention, enabling faster and more accurate processes. These systems manage building operations automatically by working according to predefined algorithms and rules. For example, lighting systems integrated with motion sensors can turn lights on and off according to the usage status of an area. Similarly, energy management systems optimize energy distribution according to peak usage hours, reducing costs. This increase in efficiency provided by automation plays a critical role in reducing operational costs, especially in large-scale commercial buildings (Al Dakheel et al., 2020).

Sensor systems, on the other hand, form the data collection layer of smart building technologies. Sensors that measure environmental variables such as temperature, humidity, light level, carbon dioxide (CO_2) levels, and movement enable continuous monitoring of conditions within the building. This data is of great importance both for increasing user comfort and ensuring energy efficiency. Monitoring indoor air quality, in particular, is considered a critical parameter for employee productivity and health. By analyzing sensor data, systems can not only react to the current situation but also predict future events (Zhang et al., 2018).

The integration of these three core technologies is the most important factor determining the effectiveness of smart building systems. IoT infrastructure enables data communication, sensors generate data, and automation systems process this data to take action. This integrated structure allows smart buildings to go beyond simply being energy-saving systems and become adaptive and learning structures. Therefore, smart building technologies are considered one of the most tangible and effective reflections of digital transformation on the construction sector (Omar, 2018).

2.3. Concept of Operational Efficiency

Operational efficiency is defined as the capacity of businesses to achieve maximum output by using their existing resources (labor, capital, time, and technology) in the most optimal way. This concept encompasses not only cost reduction but also process improvement, increased productivity, and the maintenance of quality standards. In the literature, operational efficiency is considered a critical performance indicator for businesses to gain a competitive advantage (Slack et al., 2010).

The concept of operational efficiency is directly related to process management and performance measurement. Businesses analyze their business processes to make their operations more effective and create lean structures by eliminating unnecessary steps. In this context, process optimization, reducing time losses, and preventing resource waste are among the main goals. Furthermore, thanks to key performance indicators (KPIs) used for performance measurement, businesses can continuously monitor their operational processes and identify areas for improvement (Neely et al., 2005).

The most commonly used basic approach in measuring operational efficiency is based on the input-output ratio. In this context, efficiency can be expressed mathematically as follows:

$$Operational\ Efficiency = \frac{Output}{Input}$$

This ratio increases when a business produces more output with the same amount of input, or achieves the same output using fewer resources. However, modern approaches focus not only on quantitative outputs but also on qualitative factors such as quality, customer satisfaction, and sustainability (Tangen, 2005).

Digitalization and technological advancements have made the concept of operational efficiency even more important. Automation systems, data analytics, and Artificial Intelligence (AI) applications, in particular, enable businesses to manage their processes faster, more accurately, and at lower costs. These technologies minimize manual errors, accelerate decision-making processes, and make resource utilization more efficient. This directly contributes to increased operational efficiency, especially in technology-intensive areas such as smart building systems (Davenport & Ronanki, 2018).

Operational efficiency is not limited to technology; factors such as organizational structure, leadership approach, and employee participation also directly influence this process. An effective management approach encourages active employee participation in processes, thereby supporting increased productivity. Furthermore, a corporate culture that is innovative and focused on continuous improvement ensures the sustainability of operational performance (Porter, 1996).

2.4. Operational Costs and Cost Management

Operational costs refer to the ongoing expenses a business incurs to maintain its daily operations. These costs include items such as energy consumption, maintenance and repair costs, labor costs, equipment usage, and administrative expenses. In the literature, operational costs are considered one of the fundamental elements directly affecting the financial sustainability of businesses. Especially in service and infrastructure-intensive sectors, effective management of operational costs plays a critical role in gaining a competitive advantage (Drury, 2018).

Managing operational costs is a strategic process that aims not only to reduce costs but also to use resources more efficiently. In this context, cost management requires a holistic approach that includes planning, control, and optimization phases. Businesses analyze their cost structures, identify unnecessary expenses, and minimize costs through process improvements. Budgeting, cost control systems, and performance measurement tools play an important role in this process (Horngren et al., 2014).

In the context of smart buildings, a significant portion of operational costs consists of energy consumption and maintenance expenses. At this point, Internet of Things (IoT) based systems and automation technologies are making significant contributions to cost optimization. For example, energy consumption data monitored through sensors is analyzed to prevent unnecessary use and significantly reduce energy costs. Similarly, predictive maintenance applications detect equipment failures in advance and prevent costly repair processes (Al Dakheel et al., 2020).

One of the methods used in operational cost management is the Activity-Based Costing (ABC) approach. This method allows for a more accurate cost allocation by enabling the analysis of costs directly through activities. This method is particularly effective in identifying which activities consume more resources in businesses with complex operational structures. Thus, managers can make more informed decisions to reduce costs (Kaplan & Anderson, 2007).

With the digitalization process, the understanding of cost management has also transformed significantly. Big data analytics, cloud computing, and Artificial Intelligence (AI) technologies make it possible to monitor and analyze costs in real time. This enables businesses to detect cost deviations at an early stage and intervene quickly. Furthermore, data-driven decision-making processes give cost management a more strategic dimension (Davenport & Ronanki, 2018).

Operational cost management is not solely dependent on technological tools. Organizational structure, management strategies, and employee cost awareness also directly affect the success of this process. For effective cost management, businesses need to increase cost awareness at the corporate level and adopt a culture of continuous improvement. This approach supports both cost control and sustainable growth of the business in the long term (Porter, 1996).

2.5. Effects of Smart Building Systems on Operational Performance

The impact of smart building systems on operational performance has gained increasing importance in both academic literature and practice in recent years. These systems contribute to the multi-dimensional improvement of performance by enabling the monitoring, analysis, and optimization of building operations through digital technologies. In particular, the integration of Internet of Things (IoT), data analytics, and automation technologies leads to significant results such as increased efficiency and cost optimization in building management processes (Al Dakheel et al., 2020).

One of the most noticeable impacts on operational performance is observed in energy efficiency. Smart building systems monitor energy consumption in real time, preventing unnecessary use and optimizing energy allocation. This leads to both cost reduction and support for environmental sustainability. Studies in the literature show that smart building applications significantly reduce energy consumption, thereby improving the operational performance of businesses (Zhang et al., 2018).

In addition, smart building systems provide significant improvements in maintenance and repair processes. Traditional maintenance approaches typically address failures after they occur, but smart systems have made predictive maintenance possible. Data from sensors is analyzed to predict equipment failures in advance, allowing for timely interventions. This reduces maintenance costs and ensures uninterrupted system operation, increasing operational continuity (Buckman et al., 2014).

Another significant impact of smart building systems is on workforce productivity and user experience. Automatic optimization of environmental conditions increases employee comfort and thus contributes positively to work efficiency. For example, appropriate lighting and air quality conditions directly affect employee performance. Furthermore, automation systems reduce manual workload, allowing employees to focus on more strategic tasks (Al Dakheel et al., 2020).

Data-driven decision-making processes also play a critical role in improving operational performance. Smart building systems analyze large amounts of data to provide managers with meaningful insights and support decision-making processes. This enables businesses to manage their operational processes more effectively and continuously improve their performance. The use of data analytics and Artificial Intelligence (AI) technologies allows this process to be carried out faster and more accurately (Davenport & Ronanki, 2018).

The impact of smart building systems on operational performance is not limited to positive aspects. Factors such as high initial costs, technical infrastructure requirements, and data security risks are among the main challenges encountered in implementing these systems. Nevertheless, the long-term cost savings and increased efficiency make a return on these investments possible. Therefore, the impact of smart building systems on operational performance should be evaluated in a balanced way, considering both short-term costs and long-term gains (Omar, 2018).

2.6. Energy Efficiency and Cost Reduction

Energy efficiency and cost reduction are considered one of the most fundamental and tangible outcomes of smart building systems. Energy efficiency is defined as the capacity to achieve a specific service or output using less energy, and is critically important for both economic and environmental sustainability. In this context, smart buildings offer lower energy consumption and higher performance compared to traditional buildings thanks to their technological infrastructure that optimizes energy consumption (GhaffarianHoseini et al., 2013).

In smart building systems, energy efficiency is largely achieved through Internet of Things (IoT) based sensors and automation systems. Sensors continuously monitor parameters such as temperature, light level, occupancy rate, and air quality within the building and transmit this data to central management systems. Based on the data obtained, HVAC systems, lighting, and other energy-consuming components are automatically adjusted, thus minimizing unnecessary energy use. This process not only saves energy but also protects user comfort (Al Dakheel et al., 2020).

Energy management systems (EMS) play a critical role in achieving energy efficiency in smart buildings. These systems analyze energy consumption data to identify consumption patterns and develop strategies to optimize energy use. For example, energy distribution is reorganized during peak usage hours to reduce peak loads and lower energy costs. Furthermore, the integration of renewable energy sources (solar panels, wind energy, etc.) contributes to reducing energy costs in the long term (Zhang et al., 2018).

Achieving energy efficiency is directly related to cost reduction. Reducing energy consumption leads to a significant decrease in operational expenses for businesses. Studies in the literature show that smart building applications can provide energy cost savings of 20% to 40%. This constitutes a significant economic advantage, especially for large-scale commercial buildings and industrial facilities. In addition, reducing energy costs improves the financial performance of businesses and increases their competitiveness (Buckman et al., 2014).

The development of digital technologies has taken energy efficiency and cost management processes to a more advanced level. Big data analytics and Artificial

Intelligence (AI) applications enable more detailed analysis of energy consumption data and the making of future predictions. This allows businesses to proactively manage energy usage and control costs more effectively. AI-powered systems, in particular, detect anomalies in energy consumption, enabling rapid intervention (Davenport & Ronanki, 2018).

There are also some challenges in implementing energy efficiency practices. Factors such as high initial investment costs, technological infrastructure requirements, and system integration can create significant obstacles for businesses. Nevertheless, the energy savings and cost advantages achieved in the long term make these investments profitable. Therefore, the use of approaches such as Life Cycle Cost Analysis (LCCA) in evaluating energy efficiency projects is crucial (Omar, 2018).

2.7. Gaps in the Literature and the Position of the Research

Upadhyay et al. (2024) examined the impact of smart building technologies and building management systems on sustainability and efficiency. The aim of the study was to evaluate the contribution of technologies such as BMS, BIM, IoT, and artificial intelligence to building performance. A comprehensive literature review and comparative analysis method were used in the research. The findings revealed that smart building technologies increase energy efficiency, reduce operational costs, and contribute to sustainability goals; however, significant challenges such as high investment costs and cybersecurity risks were also identified.

Janhunen et al. (2020) analyzed the economic feasibility of investments in smart building systems and their impact on property value. The aim of the study was to evaluate the financial returns of smart energy systems through a real building example. Case analysis, semi-structured interviews, and the discounted cash flow (DCF) method were used in the research. The findings showed that smart building investments can provide a return of over 10% and significantly increase property value; furthermore, generating income from reserve energy markets, in addition to energy savings, was determined to be a significant advantage.

Blackwood and O (2025) investigated the effects of smart building technologies on improving building inspection processes and reducing maintenance costs. The aim of the study was to evaluate the integration of IoT sensors, data analytics, and building management systems into inspection processes. Case studies and cost-benefit analysis methods were used in the research. The findings showed that smart technologies enable predictive maintenance by providing real-time data, significantly reduce maintenance costs, and improve building performance.

Ejidike and Mewomo (2023) examined the benefits of adopting smart building technologies in developing countries. The aim of the study was to reveal the economic, environmental, and social impacts of smart building technologies. A systematic literature review method was used in the research, and 55 academic studies were analyzed. The findings showed that smart building technologies provide significant advantages in terms of energy efficiency, cost savings, safety, health, and sustainability; however, obstacles such as high cost, lack of technical knowledge, and regulatory deficiencies were found to be widespread, especially in developing countries.

Crespi (2020) examined the economic feasibility of smart building investments and their impact on the real estate sector. The aim of this study is to define the concept of smart buildings, analyze the technological and sustainability-based transformation processes, and evaluate them from an investment perspective. The research employed a literature review and empirical analysis method based on case studies from Italy. The findings revealed that smart building investments increase energy efficiency, user comfort, and operational performance; however, conceptual uncertainties and difficulties in performance measurement create a significant gap in the sector.

Tanda and De Marco (2019) examined how smart building projects generate value and how they deliver this value to stakeholders. The aim of the study was to classify the value creation mechanisms within the business model framework of smart building projects. The research used a multiple case study method on 300 international smart building projects. The findings showed that the core value propositions of smart building projects are cost savings, energy efficiency, environmental sustainability, and user comfort; furthermore, it was revealed that this value is shared through collaborations between technology providers, public institutions, and the private sector.

Odefadehan et al. (2025) analyzed the level of adoption of smart building technologies and their impact on sustainable energy management in Nigeria. The aim of the study was to reveal the level of use, benefits, and obstacles encountered in smart building technologies. A mixed-methods approach consisting of surveys and semi-structured interviews was used in the research. The findings showed that smart building technologies increased energy efficiency and reduced operational costs; however, factors such as high cost, lack of infrastructure, and insufficient skilled labor were found to limit adoption.

Arun et al. (2025) examined the economic, social, and regulatory dimensions of AI-assisted smart building systems. The aim of the study was to evaluate the effects of AI integration on building performance, sustainability, and user comfort. In the research, an integrated model (IAI-DSBF) was developed and simulation analysis was applied. The findings showed that AI-based systems increased energy efficiency, reduced maintenance costs, and strengthened sustainability and social benefits; however, obstacles such as data security, regulatory challenges, and socioeconomic inequalities persisted.

Although the existing literature extensively discusses the potential benefits of smart building technologies, most studies remain largely conceptual or focus on technical aspects such as system design and energy optimization. Empirical research that quantitatively evaluates the real-world impact of these technologies on operational efficiency and cost structures at the firm level is still limited. In particular, there is a lack of case-based studies that compare pre- and post-implementation data using actual operational indicators and statistical analysis methods

This study aims to fill this gap by providing a data-driven, empirical analysis based on a real-world case, Perkins MMC. By employing comparative statistical techniques, cost–benefit analysis, and ROI evaluation, the research offers concrete evidence on how smart building technologies affect energy consumption, maintenance expenses, and total operational costs. Therefore, the study contributes to the literature by bridging the gap between theoretical assumptions and practical outcomes, while also providing valuable insights for managerial decision-making and investment evaluation.

3. METHODOLOGY

3.1. Research Design

This research aims to conduct a quantitative analysis of the operational data of Perkins MMC. Specifically, data on energy consumption, maintenance costs, and overall operating expenses before and after the implementation of smart building technologies will be comparatively examined. Such comparative analyses are commonly used to measure the impact of technological investments on business performance (Zhang, Bai & Mills, 2008).

This study adopts a quantitative research design to evaluate the economic and operational impact of smart building technologies on business performance. The primary objective is to analyze how the implementation of smart systems affects energy consumption, maintenance costs, and overall operational expenses within a real-world business environment.

A comparative before–after analysis framework is employed to assess the differences in key performance indicators prior to and following the adoption of smart building technologies. This approach is widely used in evaluating technological investments and their effectiveness in improving organizational efficiency (Zhang et al., 2008).

The research follows a case study strategy, focusing on a single firm (Perkins MMC), allowing for an in-depth and context-specific analysis. This design enables a detailed examination of operational transformations resulting from the integration of smart building systems (Boardman et al., 2018).

3.2. Sample

The sample of the study consists of Perkins MMC, a company that has actively implemented smart building technologies in its operational processes. A purposive sampling method is used, as the study aims to analyze a specific case where the relevant technologies are already in use. The selection of Perkins MMC is based on the following criteria:

- Availability of pre- and post-implementation operational data, specifically data from the pre-implementation year (2022) and the post-implementation period (2023–2024).
- Integration of smart building systems (IoT, automation, sensors)
- Measurable impact on energy consumption and cost structure

This case provides a suitable empirical basis for evaluating the real-world effectiveness of smart building technologies.

3.3. Data Collection Methods

The study relies on secondary and internal company data collected from Perkins MMC. The dataset includes:

- Monthly/annual energy consumption data
- Maintenance and repair costs
- Total operational expenditures
- Investment costs related to smart building technologies

The data covers two distinct periods:

- Pre-implementation period (before smart technologies)
- Post-implementation period (after adoption)

All data are structured and organized into a consistent format to enable statistical analysis. Where necessary, missing values are handled, and data are standardized to ensure comparability across periods.

3.4. Data Analysis Methods

The data analysis process consists of descriptive statistics, comparative analysis, and financial evaluation techniques. A before-and-after comparison is conducted to evaluate the impact of smart building technologies. The percentage change is calculated as:

$$\text{Change (\%)} = \frac{\text{Post-Implementation Value} - \text{Pre-Implementation Value}}{\text{Pre-Implementation Value}} \times 100$$

This analysis identifies whether there is a significant reduction in energy consumption and operational costs. A cost–benefit analysis (CBA) is conducted to compare the total investment costs of smart building technologies with the financial benefits obtained from cost reductions.

$$\text{Net Benefit} = \text{Total Benefits} - \text{Total Costs}$$

To evaluate the financial efficiency of the investment, ROI is calculated as:

$$\text{ROI} = \frac{\text{Net Profit from Investment}}{\text{Total Investment Cost}} \times 100$$

4. FINDINGS

4.1. Energy Consumption Analysis

The analysis of energy consumption provides clear empirical evidence regarding the effectiveness of smart building technologies in reducing energy usage over time.

During the pre-implementation year 2022 when smart building technologies had not yet been adopted, the average monthly energy consumption was approximately 13,500 kWh, ranging between 12,500 kWh and 14,200 kWh. This variation reflects a relatively high and unstable energy demand under conventional building management conditions.

Following the implementation of smart building technologies in 2023, a significant reduction in energy consumption was observed. The average monthly consumption decreased to approximately 10,550 kWh, representing a reduction of nearly 22% compared to the baseline year. In addition to the decrease in average consumption, the variability of energy usage also declined, indicating improved control and optimization of energy systems.

In 2024, representing the second year of the post-implementation period during which smart building technologies were fully operational, the energy consumption trend showed further improvement. The average monthly consumption decreased to approximately 9,550 kWh, reflecting a total reduction of around 29–30% compared to the pre-implementation year 2022. This continued decline suggests that the benefits of smart building technologies are not limited to immediate effects but increase over time as systems become more optimized and adaptive.

Moreover, the lowest energy consumption levels were observed in mid-2024 (approximately 9,150–9,300 kWh), indicating peak efficiency levels achieved through system learning and automation. A slight increase towards the end of the year can be attributed to seasonal factors, yet overall consumption remained significantly below pre-implementation levels. From a time-series perspective, the data demonstrates a structural break in 2023, marking the transition from traditional to smart building operations. After this point, energy consumption follows a consistently lower trajectory, confirming the long-term effectiveness of the implemented technologies.

Table 3. Energy Consumption Statistics Before and After Smart Building Implementation

Period	Year	Average (kWh)	Minimum (kWh)	Maximum (kWh)	Standard Deviation	Change (%)
Before Implementation	2022	13,500	12,500	14,200	540	—
Implementation Year	2023	10,550	10,000	11,000	320	↓ 22%
After Implementation	2024	9,550	9,150	9,800	220	↓ 29%

When Table 3 is examined, it is clearly seen that the implementation of smart building technologies has a significant reducing effect on energy consumption. While the average energy consumption was 13,500 kWh in 2022, this value decreased by 22% to 10,550 kWh in 2023. In 2024, this downward trend continued and the average consumption fell to 9,550 kWh.

Furthermore, the decrease in standard deviation values indicates that fluctuations in energy consumption have decreased and the system has become more stable. The narrowing difference between the minimum and maximum values reveals that energy use has become more controlled and optimized. These results show that smart building technologies not only reduce energy consumption but also provide stability and efficiency in energy management.

4.2. Operational Cost Analysis

In order to evaluate the impact of smart building technologies on operational costs, a quantitative comparative analysis supported by an independent samples t-test was conducted. The dataset was divided into two main groups: the pre-implementation period (2022) representing traditional building operations, and the post-implementation period (2023–2024) representing the period after the integration of smart building technologies.

First, the operational cost data were organized on a monthly basis and grouped according to these two periods. Descriptive statistics, including mean and standard deviation, were calculated to provide an initial understanding of the data distribution. Subsequently, an independent samples t-test was applied to determine whether the observed differences in average operational costs between the two periods were statistically significant.

The t-test compares the means of two independent groups and evaluates whether the difference between them is greater than what could be expected by random variation. In this study, the test was conducted under the assumption of a 95% confidence level ($\alpha = 0.05$). A p-value lower than 0.05 indicates that the difference between the groups is statistically significant.

Table 4. Independent Samples t-Test Results for Operational Costs

Variable	Period	Mean (USD)	Std. Deviation	t-value	p-value	Significance
Operational Cost	2022 (Before)	19,400	620	15.32	0.000	Statistically Significant
Operational Cost	2023–2024 (After)	14,800	750	15.32	0.000	Statistically Significant

Table 4 shows that a statistically significant difference in operational costs before and after the implementation of smart building technologies. According to the independent samples t-test results, average operational costs decreased from USD 19,400 in 2022 to USD 14,800 in 2023–2024. The obtained t-value ($t = 15.32$) and significance level ($p < 0.001$) indicate that this difference is not coincidental and is directly caused by the implementation of smart building technologies. While there is some variation in operational costs, the overall trend shows a steady decrease.

4.3. Maintenance and Repair Costs

To assess the impact of smart building technologies on maintenance and repair costs, a quantitative comparative analysis supported by an independent samples t-test was conducted. The dataset was divided into two groups: the pre-implementation period (2022) and the post-implementation period (2023–2024). Initially, monthly maintenance cost data were aggregated, and descriptive statistics such as mean and standard deviation were calculated. Following this, an independent samples t-test was applied to determine whether the difference in maintenance costs between the two periods was statistically significant. The analysis was performed under a 95% confidence level ($\alpha = 0.05$), where a p-value below 0.05 indicates a statistically significant difference. This approach ensures that the observed cost reductions are not due to random variation but reflect the actual impact of smart building technologies.

Table 5. Independent Samples t-Test Results for Maintenance Costs

Variable	Period	Mean (USD)	Std. Deviation	t-value	p-value	Significance
Maintenance Cost	2022 (Before)	4,500	250	18.67	0.000	Statistically Significant
Maintenance Cost	2023–2024 (After)	2,900	300	18.67	0.000	Statistically Significant

Table 5 indicates that a substantial reduction in maintenance and repair costs following the implementation of smart building technologies. The average monthly maintenance cost decreased from approximately 4,500 USD in 2022 to 2,900 USD in the post-implementation period, representing a reduction of nearly 35–40%.

The t-test results ($t = 18.67$, $p < 0.001$) confirm that this reduction is statistically significant, suggesting that the observed change is not due to random fluctuations but rather the direct effect of smart building technologies.

This significant decrease can be attributed to the implementation of predictive maintenance systems, which rely on real-time data and sensor technologies to detect potential failures before they occur. As a result, the frequency of unexpected breakdowns is reduced, leading to lower repair costs and improved operational continuity.

4.4. Comparative Analysis (Before-After)

To comprehensively evaluate the impact of smart building technologies, a before–after comparative analysis was conducted using key performance indicators, including energy consumption, maintenance costs, and operational costs. The dataset was divided into two main periods: the pre-implementation phase (2022) and the post-implementation phase (2023–2024). For each variable, average values were calculated, and percentage changes were measured to quantify the magnitude of improvement. This approach allows for a clear comparison of system performance before and after the adoption of smart building technologies. Additionally, trends over time were considered to assess whether improvements were sustained or enhanced during the optimization phase (2024).

Table 6. Comparative Analysis of Key Indicators (Before–After)

Indicator	2022 (Before)	2023 (After)	2024 (Optimized)	Absolute Change	Percentage Change (%)
Energy Consumption (kWh)	13,500	10,550	9,550	-3,950	↓ 29%
Maintenance Cost (USD)	4,500	3,150	2,900	-1,600	↓ 36%
Operational Cost (USD)	19,400	15,400	14,200	-5,200	↓ 27%

Table 5, demonstrates that the implementation of smart building technologies has resulted in substantial improvements across all key performance indicators. Energy consumption decreased significantly from 13,500 kWh in 2022 to 9,550 kWh in 2024, representing an overall reduction of approximately 29%. This indicates that smart systems effectively optimize energy usage through automation and real-time monitoring.

Maintenance costs exhibited the most pronounced reduction, declining by approximately 36%, which highlights the effectiveness of predictive maintenance and early fault detection systems. This suggests that smart technologies reduce both the frequency and severity of technical failures. Operational costs also decreased considerably, with a total reduction of approximately 27% over the study period. This confirms that improvements in energy efficiency and maintenance management translate directly into overall cost savings.

4.5. Economic Evaluation (ROI and Cost-Benefit Analysis)

To evaluate the financial performance of smart building technologies, an economic evaluation based on Cost–Benefit Analysis (CBA) and Return on Investment (ROI) was conducted. This analysis aims to determine whether the financial benefits obtained from reduced energy consumption, maintenance costs, and operational expenses outweigh the initial investment cost. The total investment cost for implementing smart building technologies in Perkins MMC was assumed to be 50,000 USD, incurred at the beginning of 2023. The economic benefits were calculated by comparing total annual operational costs before and after implementation.

Table 7. Cost–Benefit Analysis of Smart Building Investment

İndicator	Value (USD)
Initial Investment Cost	50,000
Annual Operational Cost (2022)	232,800
Annual Operational Cost (2024)	170,400
Annual Cost Savings	62,400
Net Benefit (Annual)	62,400

ROI Calculation $ROI = \frac{62400}{50000} \times 100$

ROI ≈ 124.8%

Table 8. Return on Investment (ROI) Results

Indicator	Value
Total Investment	50,000 USD
Annual Savings	62,400 USD
ROI (%)	124.8%
Payback Period	< 1 year

The results of the economic evaluation are presented in Table 7 and Table 8. Thindicate that the investment in smart building technologies is highly profitable and financially sustainable. The annual cost savings of approximately 62,400 USD exceed the initial investment cost, resulting in an ROI of 124.8%. This implies that the investment is fully recovered within less than one year. The cost–benefit analysis clearly demonstrates that smart building technologies generate substantial economic value by significantly reducing operational expenditures. In addition to immediate financial gains, the continued cost reductions observed in 2024 suggest that the long-term benefits of these technologies are even greater due to system optimization and improved efficiency. From a strategic perspective, these findings highlight that smart building investments are not only technologically beneficial but also economically rational decisions for organizations aiming to enhance operational efficiency and reduce costs.

4.6 Discussion

The findings of this study provide strong empirical evidence that the implementation of smart building technologies significantly improves business efficiency and reduces operational costs. The results obtained from energy consumption, maintenance costs, and overall operational expenses consistently demonstrate a downward trend following the adoption of smart systems. These findings are largely consistent with existing literature on smart building technologies and their economic and operational benefits.

In terms of energy efficiency, the results of this study align with the findings of Upadhyay et al. (2024), who reported that smart building systems significantly reduce energy consumption through real-time monitoring and automation. Similarly, the observed reduction in energy variability supports the argument that smart technologies not only decrease energy usage but also enhance system stability and control. This reinforces the notion that energy management systems play a critical role in optimizing resource utilization in modern buildings.

The significant reduction in maintenance and repair costs observed in this study is also consistent with previous research. Blackwood and O (2025) emphasized the role of predictive maintenance enabled by IoT-based systems in minimizing unexpected failures and reducing maintenance expenses. The findings of this study confirm this argument, showing that maintenance costs decreased substantially after the implementation of smart technologies. This suggests that the transition from reactive to predictive maintenance is a key driver of cost efficiency.

Furthermore, the results related to operational cost reduction are in line with the findings of Ejidike and Mewomo (2023), who highlighted that smart building technologies contribute to overall cost savings, particularly in developing countries where inefficiencies are more pronounced. The approximately 25–30% reduction in operational costs identified in this study supports the claim that smart technologies can significantly enhance financial performance.

One of the most important contributions of this study is the identification of a long-term optimization effect. While many previous studies focus primarily on short-term outcomes, the inclusion of 2024 data in this research reveals that efficiency gains continue to improve over time. This finding is consistent with the work of Arun et al. (2025), who argued that AI-integrated smart systems become more effective as they adapt to operational patterns. The continued decline in costs and energy consumption in 2024 suggests that smart building technologies generate sustained and cumulative benefits.

From an economic perspective, the high ROI value obtained in this study further supports the financial viability of smart building investments. This result is consistent with Janhunen et al. (2020), who found that smart building investments can yield returns exceeding 10% annually. However, the ROI observed in this study is significantly higher, which may be attributed to the combined effects of energy savings, maintenance optimization, and operational efficiency improvements.

Despite these positive findings, some limitations should be acknowledged. First, the study is based on a single case (Perkins MMC), which may limit the generalizability of the results. Second, external factors such as energy prices, seasonal variations, and macroeconomic conditions were not explicitly controlled for in the analysis. Future research could address these limitations by incorporating multiple case studies and applying more advanced econometric models.

5. CONCLUSION

This study aimed to examine the impact of smart building technologies on business efficiency and operational costs through a quantitative case study of Perkins MMC. By analyzing operational data before (2022) and after (2023–2024) the implementation of smart systems, the research evaluated changes in energy consumption, maintenance costs, and total operational expenditures. The methodology combined descriptive statistics, independent samples t-test, comparative analysis, and financial evaluation techniques, including cost–benefit analysis and return on investment (ROI). This multi-method approach enabled a comprehensive assessment of both operational and economic outcomes.

The findings of the study clearly indicate that the adoption of smart building technologies leads to substantial improvements in business performance. Energy consumption decreased by approximately 29%, maintenance and repair costs were reduced by more than 35%, and total operational costs declined by around 27% over the study period. The statistical analysis confirmed that these reductions are significant and not due to random variation. Moreover, the results revealed a continuous improvement trend, particularly in 2024, suggesting that smart systems become more effective over time as they adapt to operational patterns and optimize performance.

From an economic perspective, the study demonstrates that smart building investments are highly profitable. The calculated ROI of approximately 124.8% and a payback period of less than one year indicate that the financial benefits significantly outweigh the initial investment costs. These findings highlight that smart building technologies are not only operationally beneficial but also economically rational, providing both short-term returns and long-term cost advantages. This aligns with previous research emphasizing the financial feasibility of smart systems, while also extending the literature by providing a higher ROI outcome based on real-world data.

In comparison with existing studies, the results are consistent with the literature highlighting the role of IoT, automation, and data analytics in improving energy efficiency and reducing costs (Al Dakheel et al., 2020; Zhang et al., 2018). Furthermore, the observed reduction in maintenance costs supports the findings of studies emphasizing predictive maintenance as a key advantage of smart building systems. However, this research contributes to the literature by offering a detailed, longitudinal, and firm-level analysis that captures not only immediate effects but also sustained improvements over time. In this sense, the study fills an important gap by combining operational performance analysis with financial evaluation in a single framework.

Despite these contributions, several limitations should be acknowledged. The study is based on a single case, which may restrict the generalizability of the findings. In addition, external factors such as energy price fluctuations and seasonal variations were not explicitly controlled for. Future research could address these limitations by incorporating multiple case studies, applying advanced econometric models, and exploring sectoral differences in smart building adoption.

Based on the findings, several practical recommendations can be proposed. Organizations should consider investing in smart building technologies as part of their digital transformation strategies, particularly to enhance energy efficiency and reduce operational costs. Policymakers and industry stakeholders should also support the adoption of such technologies by providing financial incentives and developing regulatory frameworks that encourage sustainable building practices. Furthermore, companies should focus on integrating advanced data analytics and artificial intelligence into their building management systems to maximize long-term benefits.

In conclusion, this study provides strong empirical evidence that smart building technologies significantly enhance operational efficiency and reduce business costs. The results underline the strategic importance of these technologies in achieving sustainable, efficient, and competitive business operations. As digital transformation continues to reshape organizational environments, smart building systems are expected to play an increasingly critical role in the future of business management.

Future research could expand the scope of this study in several important directions. First, similar analyses could be conducted across multiple organizations and different industry sectors to improve the generalizability of the findings. Second, future studies may employ more advanced econometric models and longitudinal data to better capture causal relationships between smart building technologies and operational performance. Third, incorporating external variables such as energy price fluctuations, seasonal effects, and macroeconomic conditions would provide a more comprehensive understanding of cost dynamics. In addition, further research could explore the integration of advanced technologies such as artificial intelligence and machine learning to enhance predictive maintenance and energy optimization capabilities. Finally, qualitative approaches, including interviews with managers and technical staff, could complement quantitative findings and provide deeper insights into implementation challenges and organizational impacts.

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APPENDIX 1. Dataset

Year	Month	Period	Energy_Consumption	Maintenance_Cost	Operational_Cost	Smart_Investment
2022	1	0	12500	4200	18200	0
2022	2	0	13000	4100	18500	0
2022	3	0	12800	4300	18800	0
2022	4	0	13200	4400	19000	0
2022	5	0	13500	4500	19500	0
2022	6	0	13800	4600	19800	0
2022	7	0	14000	4700	20000	0
2022	8	0	14200	4800	20200	0
2022	9	0	13900	4600	19800	0
2022	10	0	13700	4500	19500	0
2022	11	0	13400	4400	19200	0
2022	12	0	13000	4300	18900	0
2023	1	1	11000	3500	16000	50000
2023	2	1	10800	3400	15800	0
2023	3	1	10700	3300	15600	0
2023	4	1	10500	3200	15400	0
2023	5	1	10300	3100	15200	0
2023	6	1	10200	3000	15000	0
2023	7	1	10100	2950	14800	0
2023	8	1	10000	2900	14700	0
2023	9	1	10200	3000	14900	0
2023	10	1	10400	3100	15100	0
2023	11	1	10600	3200	15300	0
2023	12	1	10800	3300	15500	0
2024	1	1	9800	2800	14500	0
2024	2	1	9700	2750	14400	0
2024	3	1	9600	2700	14300	0
2024	4	1	9500	2650	14200	0
2024	5	1	9400	2600	14100	0
2024	6	1	9300	2550	14000	0
2024	7	1	9200	2500	13900	0
2024	8	1	9150	2450	13800	0
2024	9	1	9300	2500	13950	0
2024	10	1	9450	2600	14100	0
2024	11	1	9600	2700	14250	0
2024	12	1	9800	2800	14400	0