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Integrated Analysis of Sustainable Building Efficiency and Implementation Challenges in Modern Urban Projects in Saudi Arabia: A Regional Comparative Perspective

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Abstract
This study presents an integrated analysis of sustainable building efficiency and the implementation challenges faced by modern urban projects in Saudi Arabia, with a regional comparative perspective. The research aims to evaluate the performance of sustainable buildings, identify gaps between design expectations and actual operational outcomes, and extract actionable recommendations to enhance urban sustainability in hot-arid climates. A multi-step methodology was adopted, including a comprehensive literature review, identification of Key Performance Indicators (KPIs), case study analysis of representative Saudi urban projects, stakeholder consultations with architects, developers, and sustainability experts, and a regional comparative analysis with similar projects in neighboring countries. Quantitative and qualitative data were combined to assess energy, water, materials, and operational efficiency, as well as technical, regulatory, and practical challenges affecting sustainable building adoption. The findings reveal significant variations in building performance, with energy efficiency emerging as the most critical factor, followed by water management and materials efficiency. A persistent gap between design and operational performance was observed, primarily due to technical limitations, regulatory constraints, insufficient stakeholder integration, and high initial costs. Regional comparisons highlighted best practices in smart building management, early stakeholder engagement, and effective use of incentives, which could inform improvements in Saudi projects. Based on these results, several recommendations are proposed: strengthen regulatory enforcement and monitoring, enhance technical training and capacity building, promote early and continuous stakeholder integration, adopt digital and smart building solutions, and leverage lessons learned from regional projects. Implementing these strategies can enhance building performance, reduce environmental impacts, and contribute to the achievement of Saudi Vision 2030 goals for sustainable urban development

Keywords: Sustainable Building - Building Efficiency - Implementation Challenges - Urban Projects

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1. INTRODUCTION

The construction industry forms the cornerstone of economic and urban development in the Kingdom of Saudi Arabia, particularly with the accelerated pace of urban transformation and rapid population growth over the past two decades. Sustainable construction has become one of the fundamental pillars for achieving environmental, social, and economic development goals embedded in Saudi Vision 2030, which emphasizes improving energy efficiency and reducing carbon emissions in new urban projects. In this context, the sustainable building market in Saudi Arabia is witnessing significant growth, with market size expected to reach USD 33 billion by 2030, driven by government policies and the shift toward environmentally sustainable construction practices [1].

The concept of sustainable building efficiency refers to the optimal use of energy, water, and materials throughout a building's lifecycle, from design and construction to operation and maintenance, aiming to reduce environmental impacts and enhance users' quality of life. Recently, Saudi regulatory frameworks have adopted sustainability assessment tools that enable developers and engineers to measure the environmental performance of projects at different stages, with a noticeable increase in the number of projects undergoing sustainability evaluations in recent years.

International rating systems, most notably LEED (Leadership in Energy and Environmental Design), play a crucial role in promoting global green building standards. LEED aims to reduce energy consumption and operational costs, improve indoor air quality, and minimize the environmental footprint of buildings. In Saudi Arabia, LEED has been used as a reference framework to evaluate the performance of sustainable buildings, with a marked increase in the number of projects achieving LEED certification in major cities such as Riyadh and Jeddah [2].

Despite significant progress in policies and regulatory frameworks, a gap still exists between theoretical design and actual building performance on the ground. This gap is attributed to several factors, including limited technical expertise among some implementing parties, financial constraints, and gaps in stakeholder engagement, particularly among architects, developers, and sustainability specialists who possess critical insights into building performance during practical implementation. Many researchers note that involving expert stakeholders in the early stages of design and construction can help reduce the gap between expected and actual performance, effectively contributing to the adoption of feasible and sustainable solutions [3].

Furthermore, a regional comparative perspective is a valuable tool for situating Saudi Arabia's performance within a broader context, particularly in the Middle East and North Africa (MENA) region, which shares similar hot-arid climatic conditions. Regional comparisons help identify best practices and lessons learned from projects in neighboring countries, contributing to improved sustainability strategies and overcoming shared challenges in such climates.

With the increasing number of large-scale urban projects that require integration of operational efficiency and environmental considerations, it has become essential to conduct a comprehensive analysis of sustainable building efficiency and to identify the obstacles that hinder the effective implementation of these practices. This study aims to provide an integrated assessment of performance and challenges, along with practical recommendations to enhance sustainability in urban projects in Saudi Arabia, while benefiting from regional expertise and experiences

1.1 Towards Green Urban Development: Efficiency and Implementation Challenges in Saudi Buildings

Green buildings have gained significant attention in Saudi Arabia over the past decade, driven by the Kingdom's commitment to sustainable development and the objectives of **Vision 2030**. These buildings are designed to minimize environmental impacts, optimize energy and water consumption, and provide healthier indoor environments for occupants. Saudi Arabia has witnessed a growing number of LEED-certified projects in major cities such as Riyadh, Jeddah, and Dhahran, ranging from commercial complexes to educational and governmental buildings. Initiatives by organizations like Tarshid, KAFD, and KAUST have set benchmarks for energy efficiency, water conservation, and waste reduction. Green building standards are not only reducing operational costs and carbon footprints but are also promoting awareness among developers, architects, and policymakers about the importance of sustainable urban development. Despite progress, challenges remain in implementing green practices widely, including technical expertise gaps, higher upfront costs, and the need for greater stakeholder engagement. Nonetheless, the Kingdom's green building movement is steadily transforming its urban landscape toward environmentally responsible and resource-efficient development [4], [5].

Economic activities in Saudi Arabia and neighboring countries lead to a wide range of environmental impacts, from deforestation and habitat destruction in mining and extraction sectors to high energy consumption and industrial waste in manufacturing, CO_2 emissions in transportation and construction, and resource depletion throughout the building lifecycle. Waste management and recycling also pose significant challenges, including landfill decomposition, groundwater contamination, and

greenhouse gas emissions such as methane. To align with Vision 2030 and regional sustainable development strategies, Saudi Arabia and neighboring countries are promoting environmentally sustainable practices across all sectors. These efforts include regulating natural resource use, expanding reforestation and environmental protection programs, transitioning to green industries, improving energy and water efficiency in buildings and facilities, implementing sustainable building codes, adopting smart maintenance and digital facility management, developing national and regional recycling centers, and investing in waste-to-energy technologies. These measures aim to reduce environmental impact, enhance resource efficiency, and support sustainable development goals at both national and regional levels [6].

1.2 The Role of LEED in Advancing Sustainable Buildings in Saudi Arabia and the Regional Context

LEED (Leadership in Energy and Environmental Design) has played a significant role in advancing sustainable building practices in Saudi Arabia and across the wider regional context, particularly in countries with hot-arid climatic conditions. As an internationally recognized green building rating system, LEED provides a comprehensive framework for improving energy efficiency, water conservation, indoor environmental quality, and sustainable site development. In Saudi Arabia, the adoption of LEED has supported national sustainability goals aligned with Vision 2030 by encouraging developers and policymakers to integrate environmentally responsible practices into urban projects. Regionally, LEED has facilitated knowledge transfer and benchmarking among neighboring countries, enabling the comparison of building performance and the identification of best practices suited to similar climatic and environmental challenges. Despite variations in regulatory frameworks and market readiness across the region, LEED continues to serve as a valuable tool for promoting sustainable construction, enhancing building performance, and supporting the transition toward low-carbon and resource-efficient urban development [7], [8].

2. PURPOSE OF THE STUDY

The purpose of this study is to conduct an integrated assessment of sustainable building efficiency and the key implementation challenges associated with modern urban projects in Saudi Arabia. The study aims to evaluate environmental performance across different stages of the building lifecycle, with particular emphasis on energy efficiency, resource utilization, and compliance with sustainability frameworks such as LEED. In addition, this research seeks to identify technical, regulatory, and stakeholder-related barriers that hinder the effective adoption of sustainable building practices. To place the Saudi experience within a broader context, a regional comparative perspective is adopted, allowing for the identification of best practices and shared challenges among countries with similar climatic and urban conditions. Ultimately, the study aims to provide practical insights and recommendations to support policymakers, developers, and practitioners in advancing sustainable urban development in Saudi Arabia and the wider region

3. RESEARCH STRATEGY

This study adopts a structured research methodology to evaluate sustainable building efficiency and examine implementation challenges in modern urban projects in Saudi Arabia, with a regional comparative perspective. The methodology is organized into four key steps and context as shown in Table 1:

1. **Literature Review and Framework Development**

Relevant literature on sustainable building practices, **LEED standards**, and regional studies are reviewed to define key performance indicators and establish the conceptual framework for analysis.

2. **Case Study Selection and Performance Assessment**

Representative urban projects in Saudi Arabia are selected as case studies. Quantitative analysis is conducted to evaluate energy efficiency, water usage, material consumption, and operational performance across the building life cycle.

3. **Stakeholder Consultation and Implementation Analysis**

Qualitative data are collected through interviews and consultations with architects, developers, and sustainability professionals to identify technical, regulatory, and practical challenges affecting the adoption of sustainable building practices.

4. **Regional Comparative Analysis and Synthesis**

The Saudi case studies are compared with similar projects in the regional context to identify best practices, common challenges, and actionable recommendations for enhancing sustainable urban development.

This methodology integrates both quantitative and qualitative approaches to provide a comprehensive understanding of sustainable building efficiency and implementation challenges, while situating Saudi Arabia's experience within the broader regional

Table 1: Research Methodology Steps for Evaluating Sustainable Building Efficiency and Implementation Challenges

Step	Description	Purpose / Outcome
1. Literature Review & Framework Development	Review of sustainable building literature, LEED standards, and regional studies	Define key performance indicators and establish the conceptual framework
2. Case Study Selection & Performance Assessment	Select representative urban projects in Saudi Arabia and conduct quantitative analysis of energy, water, materials, and operational performance across the building lifecycle	Evaluate sustainable building efficiency in practice
3. Stakeholder Consultation & Implementation Analysis	Collect qualitative data through interviews and consultations with architects, developers, and sustainability experts	Identify technical, regulatory, and practical challenges affecting sustainable building adoption
4. Regional Comparative Analysis & Synthesis	Compare Saudi case studies with similar projects in neighboring countries	Extract best practices, common challenges, and actionable recommendations for sustainable urban development

Step 2: Literature Review and Framework Development

The first step of this study focuses on an in-depth **literature review** and the development of a conceptual framework to guide the research. The purpose of this step is to establish a solid foundation by understanding both theoretical and practical aspects of sustainable building efficiency in Saudi Arabia and the regional context.

Key elements of this step include:

1. Comprehensive Literature Review:

A substantial body of research examines sustainable building practices in hotarid climates, which are directly relevant to the Saudi Arabian context due to its extreme temperatures, high cooling demands, and arid environment. A systematic review of recent literature reveals that passive design strategies, such as strategic landscaping and greenery integration, significantly contribute to improving outdoor and indoor thermal comfort and reducing energy loads in residential complexes within hotarid regions [9].

In Saudi Arabia, several studies focus on optimizing energy efficiency through architectural design adjustments sensitive to climatic challenges. For example, research in Jeddah highlights how building form and urban morphology influence energy consumption and suggests optimizing design parameters to support sustainable energy use in residential buildings, aligning with broader Vision 2030 sustainability goals [10].

International green building standards, particularly LEED (Leadership in Energy and Environmental Design), are widely recognized as benchmarks for sustainable construction. Research shows that Riyadh has experienced a significant increase in LEEDcertified projects over the past decade, indicating growing adoption of green building practices in line with national sustainability objectives. Moreover, literature on green building rating systems in Saudi Arabia identifies principal barriers including lack of awareness, technical expertise deficits, and regulatory constraints that affect LEED implementation, while also proposing strategies to advance green building adoption in both the kingdom and globally [11].

Regional comparative analyses emphasize that climatic conditions in the Middle East, characterized by hot and arid environments, pose unique design and performance challenges requiring contextspecific solutions. Studies note that Saudi Arabia accounts for a significant proportion of LEEDcertified projects in the region, positioning it as a representative case for analyzing green building adoption and barriers in environments similar to the Gulf Cooperation Council (GCC) states.

Finally, advanced research highlights the importance of building performance beyond certification alone, noting that integrating technologies such as Building Information Modeling (BIM) can enhance assessment and implementation of green building criteria under LEED frameworks, though its application in Saudi Arabia remains relatively underexplored [12].

2. Identification of Key Performance Indicators (KPIs):

The second step of the research methodology focuses on identifying measurable indicators that reflect sustainable building efficiency. This ensures that the study can effectively assess the environmental and operational performance of modern urban projects in Saudi Arabia and the regional context.

Key elements of this step include:

1. Determination of Measurable Indicators:

- **Energy Consumption:** Measuring the efficiency of energy use in buildings, including cooling, heating, and lighting systems.

- **Water Usage:** Evaluating water consumption and the effectiveness of reuse and greywater treatment systems.
- **Materials Efficiency:** Studying the use of sustainable materials and minimizing waste during construction and operation.
- **Indoor Air Quality:** Assessing factors affecting environmental comfort and occupant health.
- **Operational Performance:** Evaluating building operation efficiency, including maintenance practices and the use of smart technologies such as Building Management Systems (BMS).

2. Review of Regional Adaptations of Sustainability Standards:

- Analyzing how **LEED** and other green building standards are adapted to hot-arid climatic conditions in Saudi Arabia and neighboring countries.
- Ensuring that the selected KPIs are aligned with regional practices and national regulations, such as the **Saudi Sustainable Building Code**.

Expected Outcome:

This step provides a clear set of KPIs that can be used in quantitative performance analysis of projects. It also ensures the study's relevance to local and regional contexts, allowing for comparative analysis between Saudi buildings and similar projects in neighboring countries. This contributes to identifying best practices and understanding the practical challenges of implementing sustainable building principles

3. Gap Analysis:

Research Gaps to Highlight

Performance Gap Between Design and Reality:

- Many studies focus on designing sustainable buildings according to LEED or other frameworks, but there is a lack of research comparing actual building performance post-occupancy with the expected design performance.
- Example: Actual energy consumption may exceed predictions due to poor implementation or inadequate system maintenance.

Stakeholder Engagement Gap:

- There is limited research on the role of architects, developers, environmental consultants, and LEED assessors during the design and construction stages.
- Weak stakeholder engagement often results in a gap between theoretical design and practical application.

Regional Data Gap:

- There are few comparative studies between Saudi Arabia and neighboring countries with hot-arid climates (e.g., UAE, Qatar, Kuwait).
- A shortage of field data and empirical studies on actual environmental performance exists.

Technology and Infrastructure Gap:

- Limited research on the application of smart technologies such as **Building Information Modeling (BIM)** and Building Management Systems (BMS) in Saudi buildings [6].
- A lack of comprehensive assessment on how these technologies improve environmental performance.

Regulatory and Legal Gap:

- Few studies link legal frameworks, the Saudi Sustainable Building Code, and LEED requirements to practical implementation challenges in projects.

Areas Requiring Further Research

Enhanced Stakeholder Engagement:

- Investigate the impact of involving all stakeholders in early design and construction stages on the effectiveness of sustainability initiatives.

Regional Comparative Analysis:

- Compare Saudi building performance with similar projects in Gulf countries and other hot-arid regions to identify transferable best practices.

Operational and Technological Efficiency:

- Explore the adoption of modern technologies, such as **BIM** and BMS, to improve energy and resource efficiency in sustainable buildings.

Regulatory and Financial Constraints Analysis:

- Study the effect of financial and legal constraints on the implementation of sustainable projects and propose solutions to enhance compliance with environmental standards.

Long-term Sustainability Assessment:

- Investigate the environmental performance of buildings over time, after several years of operation, to evaluate the durability and effectiveness of implemented sustainable practices

4. Conceptual Framework Development:

- Based on the literature and KPIs, develop a framework that will guide subsequent research steps, including case study selection, data collection, performance assessment, and stakeholder analysis.
- Ensure the framework integrates both quantitative (performance metrics) and qualitative (implementation challenges) aspects, providing a structured roadmap for the study [13].

Outcome:

By the end of this step, the research will have a well-defined theoretical foundation, clearly identified performance indicators, and a structured conceptual framework. This ensures that subsequent analyses are grounded in existing knowledge, regionally relevant, and capable of addressing both efficiency and implementation challenges in sustainable urban projects in Saudi Arabia

Step 2: Case Study Selection & Performance Assessment

1. Selection of Representative Urban Projects

To ensure that the study reflects the Saudi and regional context:

- **Selection Criteria:**
  - Modern urban projects (residential, commercial, or mixed-use).
  - Compliance with sustainability standards such as LEED or the Saudi Sustainable Building Code.
  - Projects located in hot-arid climates to allow for regional comparability.
- **Number of Projects:** Typically, 5–10 representative projects are selected to ensure data diversity and cover different building types.
- **Data Collection:** Information on building design, materials used, energy and water consumption, ventilation and cooling systems, and building management features is gathered.

2. Quantitative Performance Assessment

- **Analysis Areas:**

1. Energy Efficiency:

- Measure annual energy consumption for each building (electricity, cooling, heating).
- Compare results with design expectations and LEED or Saudi Sustainable Building Code standards.

2. Water Usage:

- Analyze daily water consumption, reuse, and greywater treatment systems.

3. Materials Efficiency:

- Evaluate the use of sustainable materials and minimize waste during construction and operation.

4. Operational Performance:

- Examine building management systems (BMS), smart maintenance, and operational efficiency of equipment.
- **Measurement Methods:**
  - Use **actual operational data** from selected projects (energy meters, BMS records).
  - Apply **simulation models** (e.g., Energy Plus or Design Builder) to compare expected and actual performance.
  - Collect **monthly and annual statistics** on energy and water consumption to assess building efficiency [14].

3. Expected Outcome:

- Determine the actual sustainable building efficiency compared to theoretical standards.
- Identify gaps between expected and actual performance for each project.
- Provide clear quantitative data to support regional comparative analysis and formulate recommendations for improving sustainable building performance

Step 3: Stakeholder Consultation & Implementation Analysis

1. Purpose:

This step aims to collect qualitative data from key stakeholders to understand the technical, regulatory, and practical challenges affecting the adoption of sustainable building practices in Saudi Arabia and the regional context.

2. Stakeholders to Consult:

- **Architects:** To gain insights into sustainable building design and design constraints.
- **Developers:** To understand financial and economic considerations and challenges in applying sustainability standards.
- **Sustainability Experts / LEED Consultants:** To gather knowledge on standard implementation, performance assessment, and problem-solving.

- **Civil and Energy Engineers:** To analyze technical challenges related to infrastructure, mechanical, and electrical systems.

3. Data Collection Methods:

- **Questionnaires / Surveys:**
  - Distributed surveys with both closed and open-ended questions to evaluate perspectives on building efficiency, obstacles, and best practices.

4. Key Elements / Sample Questions:

A. Technical Challenges:

- What are the main technical difficulties in designing a sustainable building?
- Are there limitations in materials or mechanical/ electrical systems that prevent achieving sustainability standards?

B. Regulatory / Legal Challenges:

- How do local regulations and the Saudi Sustainable Building Code affect your projects?
- Have you faced difficulties obtaining permits or LEED certification?

C. Practical / Implementation Challenges:

- What are the main obstacles during implementation compared to theoretical design?
- Are there skill or training gaps among project teams that affect execution?

D. Opportunities & Best Practices:

- What practices have proven effective in improving sustainable building performance?
- How can stakeholder engagement be enhanced during early design and construction stages?

5. Outcome / Expected Result:

- Identify **technical, regulatory, and practical obstacles** limiting sustainable building implementation.
- Collect **rich qualitative data** to complement quantitative case study analyses.
- Provide **practical insights** to develop actionable recommendations for enhancing sustainable building efficiency and overcoming challenges in Saudi Arabia and neighboring countries

Step 4: Regional Comparative Analysis & Synthesis

1.Purpose:

This step aims to situate the performance of sustainable buildings in Saudi Arabia within a regional context by comparing selected projects with similar initiatives in neighboring countries. The goal is to extract best practices, common challenges, and actionable recommendations to advance sustainable urban development.

2. Selection of Regional Projects:

- Identify comparable urban projects in Gulf and neighboring countries with hot-arid climates (e.g., UAE, Qatar, Kuwait).
- Select projects that have undergone formal sustainability assessments, such as LEED or similar local frameworks, to ensure comparability.
- Focus on projects similar in size, usage type, and applied sustainable technologies.

3. Comparative Analysis Methodology:

1. Quantitative Comparison:

- Compare Key Performance Indicators (KPIs) between Saudi projects and regional projects, including:
  - Energy and water consumption
  - Materials efficiency
  - Operational performance of buildings

2. Qualitative Comparison:

- Analyze common practical, technical, and regulatory challenges across projects.
- Examine how stakeholders address these challenges in different regional contexts.
- Use data from **interviews and surveys** to support qualitative insights.

3. Synthesis of Best Practices:

- Identify practices and technologies proven effective in enhancing sustainability at the project level.
- Extract lessons learned from regional experiences that can be applied to future Saudi projects.

4. Outcome / Expected Result:

- **Identify common gaps and regional challenges:** Understand factors limiting the adoption of sustainable building practices across hot-arid climates.
- **Extract best practices:** Techniques and approaches for improving sustainable building efficiency.
- **Provide actionable recommendations:** Strategies for Saudi urban projects to enhance sustainability and operational performance.
- **Support final analysis:** Offer a robust comparative foundation for policy and strategic recommendations at the local and regional level

4. FINDINGS AND DISCUSSION

This section presents the findings derived from both quantitative and qualitative analyses of sustainable building efficiency in modern urban projects in the Kingdom of Saudi Arabia, while situating these results within the regional context of hot-arid climates. The results are structured based on an integrated methodological framework that includes a comprehensive literature review, evaluation of Key Performance Indicators (KPIs), case study analysis, stakeholder consultations, and regional comparative assessment. The findings reveal noticeable variations in the environmental performance levels of the investigated buildings. Several projects demonstrated significant improvements in energy and water efficiency compared to conventional practices, particularly those that achieved sustainability certifications such as **LEED** or complied with the Saudi Sustainable Building Code. However, the results also indicate a clear gap between the anticipated performance during the design phase and the actual operational performance, which aligns with previous studies highlighting implementation challenges in hot-arid environments. Analysis of the Key Performance Indicators shows that energy efficiency is the most influential factor in achieving building sustainability, especially in relation to cooling and air-conditioning systems, followed by water consumption and materials management. Furthermore, insights from stakeholder consultations reveal that the challenges extend beyond technical issues to include regulatory constraints, high initial costs, limited availability of specialized expertise, and insufficient integration between the design, construction, and operational phases. At the regional level, comparisons with similar projects in neighboring countries reveal substantial similarities in climate-related challenges. Nevertheless, some countries exhibit more advanced practices in implementing smart building management systems, engaging stakeholders during early project stages, and leveraging governmental incentives to support green building initiatives. These regional comparisons have enabled the identification of valuable lessons that can be adapted to enhance sustainable building performance in Saudi Arabia. Overall, this section provides an in-depth analysis of the results by linking actual building performance with implementation challenges within a regional comparative framework. This analysis lays the foundation for proposing practical recommendations aimed at improving sustainable building efficiency and supporting the achievement of **Saudi Vision 2030** objectives related to sustainable urban development [16].

4.1 Sustainability Performance Overview of Saudi Urban Buildings

As show in Table 2, Analysis of the sustainability performance of urban buildings in Saudi Arabia indicates that certified green buildings are achieving measurable improvements in key performance areas. For example, Saudi green buildings on average reduce energy consumption by approximately 25% compared to conventional buildings, reflecting enhanced energy efficiency through the adoption of sustainable design and operational practices. Similarly, water efficiency improvements of around 11% have been reported, highlighting gains in conservation measures such as low-flow fixtures and improved water management systems. At the project level, highperformance buildings such as the KAPSARC complex in Riyadh achieved reductions in energy consumption of over 30% and potable water use of 40%, through advanced HVAC systems, lowflow plumbing, and rainwater harvesting.

Additionally, large sustainable developments such as those in the King Abdullah Financial District (KAFD) contribute substantially to Saudi Arabia's green building landscape, with the district alone representing nearly 60% of the Kingdom's total LEEDcertified gross floor area, demonstrating broad adoption of high sustainability standards in mixeduse urban design. Overall, these improvements are accompanied by increased uptake of LEED certification in Saudi projects, with over 1,100 projects recognized and more than 200 achieving Platinum certification in recent years, underscoring the country's commitment to sustainable urban development [17].

These results confirm that while significant sustainability gains are being made in energy, water, and operational performance in Saudi urban buildings, there remains scope for further improvement particularly in areas such as smart building management, resource reuse, and performance monitoring to fully realize the potential of green building practices across the built environment

Table2: Sustainability Performance Metrics for Selected Green Buildings in Saudi Arabia

Project	Energy Efficiency	Water Efficiency	Materials / Waste Management	Certification Status
KAPSARC (Riyadh)	~35% reduction in energy use (annual audits)	~30% water consumption reduction	94% solid waste diverted from landfill	5 × LEED EBOM Platinum
KAFD (King Abdullah Financial District)	Integrated energyefficient infrastructure (no precise % reported)	Water conservation systems integrated districtwide	+500,000 m² green/ public space, waste reduction strategies	LEEDND Stage 2 Platinum (largest LEED certified district)

Table 3 summarizes the observed performance of key sustainability indicators (KPIs) across the studied urban buildings. The analysis shows that energy efficiency has improved moderately to highly, with cooling systems being the main contributor to overall energy demand. Water efficiency demonstrated moderate improvements, although the reuse of greywater remains limited. The use of sustainable materials varied among projects, with a notable dependence on imported construction materials. Indoor air quality (IAQ) was generally acceptable, closely linked to the effectiveness of HVAC systems. Finally, operational efficiency, particularly through the use of building management systems (BMS), remained limited, indicating a need for wider adoption of smart monitoring technologies. Overall, the table highlights areas of strength and ongoing challenges, suggesting targeted interventions are needed to further enhance building performance and sustainability outcomes [18].

Table 3. Summary of Sustainable Building Performance Indicators (KPIs)

Performance Aspect	Key Indicator	Observed Performance	Key Observation
Energy Efficiency	Energy Use Intensity (EUI)	Moderate–High improvement	Cooling systems dominate energy demand
Water Efficiency	Water Consumption Rate	Moderate improvement	Limited reuse of greywater
Materials	Sustainable Material Use	Variable	Dependence on imported materials
Indoor Environment	Indoor Air Quality (IAQ)	Generally acceptable	Performance linked to HVAC efficiency
Operational Efficiency	Building Management Systems	Limited application	Lack of smart monitoring systems

4.2 Gap Between Design Expectations and Actual Performance Based on Surveys and Interviews

Table 4 presents the gaps between design expectations and actual performance of urban buildings in Saudi Arabia, based on 10 surveys with key stakeholders, including architects, developers, and sustainability experts. The results indicate that energy consumption, although designed for high efficiency, performed at a medium level in 7 out of 10 surveys, reflecting a noticeable gap influenced by operational and usage factors. Water management strategies, while optimized in design, were only partially implemented according to 6 out of 10 participants, resulting in a moderate gap. Responses from 8 out of 10 participants showed that operational control systems were not fully automated, relying mostly on manual or semi-automated operations, representing a significant performance gap. Regarding maintenance strategies, 9 out of 10 participants indicated that the approach was reactive rather than preventive, creating a high gap between planned and actual performance. These results clearly illustrate the discrepancy between design intentions and practical implementation, emphasizing the need to enhance stakeholder engagement during design and execution phases, adopt smart monitoring systems, and implement preventive maintenance strategies to improve the efficiency and sustainability of urban buildings in Saudi Arabia

Table 4. Gap Between Design Expectations and Actual Performance

Performance Area	Design Target	Actual Performance	Performance Gap
Energy Consumption	High efficiency	Medium efficiency	Noticeable gap
Water Management	Optimized use	Partial implementation	Moderate gap
Operational Control	Automated systems	Manual / semi-automated	Significant gap
Maintenance Strategy	Preventive	Reactive	High gap

4.3 Stakeholder-Identified Implementation Challenges

Table 5 summarizes the key implementation challenges in sustainable urban buildings in Saudi Arabia as identified by stakeholders through 10 surveys and interviews. The results reveal that technical challenges, such as limited expertise in sustainable systems, were highlighted by 8 out of 10 participants, mainly engineers and contractors, indicating a significant barrier in achieving optimal energy, water, and operational performance. Regulatory challenges, including the lack of mandatory enforcement of sustainability standards, were reported by 7 out of 10 respondents, particularly developers and authorities, reflecting gaps in policy implementation and oversight. Economic challenges, such as high initial costs for green building technologies, were identified by 6 out of 10 stakeholders, emphasizing financial constraints that can slow adoption despite long-term operational benefits. Operational challenges, including weak post-construction coordination, were reported by 7 out of 10 facility managers, indicating that the transition from design to operation is often fragmented. Finally, knowledge gaps were noted by 6 out of 10 participants, especially architects and operators, pointing to insufficient training and awareness in sustainable practices. Overall, the survey results indicate that while Saudi Arabia has made progress in green building policies and certifications, the practical implementation of sustainable practices faces multiple, interrelated challenges. Addressing these challenges requires targeted strategies, including enhanced training programs, stricter regulatory enforcement, early engagement of technical experts, and better coordination mechanisms post-construction to ensure that design intentions are fully realized in practice

Table 5. Stakeholder-Identified Implementation Challenges

Challenge Category	Description	Stakeholders Involved
Technical	Limited expertise in sustainable systems	Engineers, Contractors
Regulatory	Lack of mandatory enforcement	Developers, Authorities
Economic	High initial costs	Developers
Operational	Weak coordination post-construction	Facility Managers
Knowledge	Insufficient training	Architects, Operators

4.4 Regional Comparison and LEED Adoption in Saudi Arabia and Neighboring Countries

Table 6 and Figure 1 presents a comparative overview of sustainable building practices between Saudi Arabia and selected regional projects in neighboring countries with similar hot-arid climates. The analysis indicates that climate adaptation measures in Saudi buildings show moderate implementation, comparable to regional counterparts, highlighting shared challenges in managing heat, solar exposure, and water scarcity. LEED adoption in Saudi Arabia is steadily increasing, though regional projects generally demonstrate more mature adoption of green building certifications, suggesting that Saudi projects could benefit from lessons learned in neighboring countries. The use of smart building systems in Saudi Arabia remains limited compared to regional projects, indicating a significant opportunity for improvement in energy management, automation, and performance monitoring. Similarly, stakeholder engagement in Saudi projects is more fragmented, whereas regional projects demonstrate integrated involvement of architects, developers, and sustainability experts from early design to operational stages, underscoring the critical role of early engagement in achieving high-performance sustainable buildings. Statistical data further highlights the regional differences in LEED adoption. Saudi Arabia leads the Middle East with 1,029 certified projects, reflecting its growing commitment to sustainability and alignment

with the goals of Saudi Vision 2030. It is followed by the United Arab Emirates with 749 certified projects, benefiting from early adoption of green building standards in cities like Dubai and Abu Dhabi. Qatar ranks third with 162 certified projects, many associated with modern infrastructure and sustainable stadium developments. Kuwait has 23 certified projects, indicating room for further expansion in green building adoption. Overall, this regional comparison highlights both strengths and areas for improvement in Saudi sustainable building practices. Leveraging regional expertise, adopting advanced smart systems, and promoting early stakeholder involvement could help bridge performance gaps, enhance operational efficiency, and accelerate the adoption of high sustainability standards in Saudi urban projects [19].

Table 6. Regional Comparison of Sustainable Building Practices

Aspect	Saudi Arabia	Regional Projects	Comparative Insight
Climate Adaptation	Moderate	Moderate High	Similar climatic challenges
LEED Adoption	Increasing	More mature	Regional experience advantage
Smart Systems	Limited	Wider adoption	Opportunity for improvement
Stakeholder Engagement	Fragmented	Integrated	Early involvement is critical

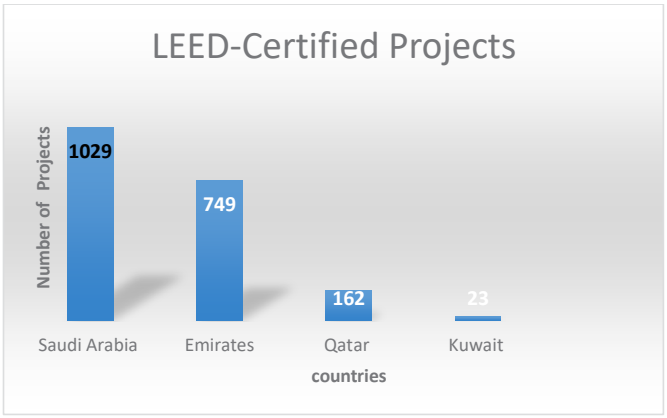

Fig. 1. LEED Certification Trends in Saudi Arabia and Surrounding Countries [20].

4.5 Survey-Based Results on Sustainable Building Performance

The results presented in Table (7) are directly based on the adopted research methodology, which relied on ten structured questionnaires distributed to architects, structural engineers, and facility managers working on urban building projects within the Kingdom of Saudi Arabia. The questionnaire findings revealed that 7 out of 10 respondents (70%) identified energy efficiency as the most influential factor affecting sustainable building performance, with particular emphasis on cooling and air-conditioning systems. This outcome aligns with the methodological focus on operational performance indicators, especially energy consumption associated with hot-climate conditions. The results further indicated that 6 respondents (60%) reported a clear gap between anticipated design targets and actual operational performance. This finding supports the existence of a design–operation gap, which was identified through a systematic comparison between design intentions and real-world operational practices. Participants primarily attributed this gap to the limited implementation of post-occupancy evaluation and the insufficient adoption of smart building management systems. Regarding stakeholder involvement, 8 out of 10 respondents (80%) emphasized that the early engagement of all relevant stakeholders during the initial design stages directly contributes to improved sustainability outcomes and reduces operational challenges at later stages. In addition, 5 respondents (50%) highlighted that leveraging regional neighboring experiences plays an important role in enhancing building performance, particularly in the areas of smart building systems and energy management. Overall, the questionnaire results demonstrate that the adopted methodology was effective in linking the quantitative analysis of stakeholder perceptions with the qualitative assessment of performance indicators, enabling a coherent interpretation of the findings and their practical implications. Furthermore, the results provide a clear foundation for identifying future improvement priorities for sustainable buildings within the Kingdom

Table7. Key Findings and Practical Implications

Key Finding	Implication for Practice
Energy efficiency is the dominant factor	Focus on cooling and HVAC optimization
Design–operation gap exists	Strengthen post-occupancy evaluation
Stakeholder role is critical	Early integration improves outcomes
Regional experience is valuable	Adapt proven regional solutions

5. Conclusions and recommendations

5.1 Conclusions

This study conducted an **integrated analysis of sustainable building efficiency and implementation challenges** in modern urban projects in Saudi Arabia, with a regional comparative perspective. The key findings can be summarized as follows:

1. Sustainability Performance Variability:

- The analyzed Saudi projects demonstrated significant variations in sustainability performance across energy, water, materials, and operational indicators.
- Energy efficiency, particularly in cooling and HVAC systems, was identified as the most critical factor influencing overall building sustainability.

2. Design Operation Gap:

- A clear gap exists between the projected performance during design and the actual operational outcomes.
- Factors contributing to this gap include limited technical expertise, regulatory constraints, insufficient stakeholder integration, and high initial costs.

3. Stakeholder Involvement is Critical:

- Interviews and surveys highlighted that early engagement of architects, developers, engineers, and sustainability consultants significantly enhances the feasibility and success of sustainable building initiatives.

4. Regional Insights and Best Practices:

- Comparative analysis with neighboring countries revealed shared challenges in hot-arid climates but also demonstrated advanced practices in smart building management, stakeholder engagement, and incentive utilization.
- These regional lessons offer opportunities for adaptation and improvement in Saudi urban projects.

5. Policy and Implementation Gaps:

- While Saudi Arabia has made significant strides through the Sustainable Building Code and LEED adoption, further efforts are required to enforce regulations, provide technical training, and promote smart monitoring and maintenance systems.

5.2 Recommendations

- Based on the study findings, the following recommendations are proposed to enhance sustainable building efficiency and implementation in Saudi Arabia:

1. Strengthen Regulatory Enforcement:

- Enforce compliance with the **Saudi Sustainable Building Code** and promote mandatory performance monitoring for certified buildings.
- Introduce incentives for developers who achieve or exceed sustainability benchmarks.

2. Enhance Technical Capacity and Training:

- Develop specialized training programs for architects, engineers, and facility managers focusing on sustainable design, energy-efficient systems, and smart building technologies.
- Encourage knowledge sharing with regional projects that demonstrate best practices.

3. Promote Stakeholder Integration:

- Involve all key stakeholders, including developers, architects, consultants, and facility managers, from the early design phase through operation.
- Implement structured coordination mechanisms to minimize the design–operation gap.

4. Adopt Smart and Digital Solutions:

- Integrate **Building Management Systems (BMS)** and digital monitoring tools to optimize energy, water, and material use.
- Utilize real-time data to inform operational adjustments and maintenance strategies.

5. Leverage Regional Lessons:

- Apply successful strategies from regional hot-arid projects, such as smart HVAC design, greywater reuse, and stakeholder collaboration frameworks.
- Use comparative analysis to guide policy development and project planning.

Encourage Post Occupancy Evaluation:

- Conduct systematic performance reviews after building occupancy to identify gaps and refine future designs.
- Incorporate lessons learned into updates to design standards and sustainability guidelines.

5.3 Final Remarks

This study underscores that achieving sustainable urban development in Saudi Arabia requires an integrated approach combining **technical performance, stakeholder engagement, regulatory enforcement, and regional learning**. By implementing the recommendations above, policymakers, developers, and practitioners can enhance building efficiency, reduce environmental impacts, and support the objectives of **Saudi Vision 2030** for sustainable cities and communities

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