



Evaluating the Role of Artificial Intelligence as A Decision Support Tool for Renewable Energy Design Integration in Healthcare Educational Buildings

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ABSTRACT

The demand for sustainable and resilient energy systems in healthcare educational environments has intensified interest in data informed design approaches. In Nigeria, persistent grid instability and rising operational costs sabotage institutional reliability. Renewable energy systems provide viable alternatives, but their success depends on informed early stage design decisions. Artificial Intelligence (AI) offers a decision support tool capable of synthesising environmental, energy, and operational data to guide architectural planning. This study evaluates AI as a decision support tool for renewable energy driven design in healthcare educational environments, using Nigerian institutions and Caleb University as contextual considerations. A qualitative approach was utilised, including documentary review, analysis of international and local precedents, and assessment of AI-supported design workflows. The study focuses on how AI informed insights can enhance professional judgement rather than replace it. Findings indicate that, although awareness of AI and renewable technologies is increasing, their implementation remains fragmented and reactive. Renewable systems are typically introduced after major architectural decisions, limiting optimisation. The study concludes that the key barrier is not the availability of technology, but rather the absence of structured frameworks that embed AI into early design and institutional planning. Strategic integration of AI at the conceptual stage is therefore essential to improve sustainability, resilience, and long term energy performance in healthcare educational environments.

Keywords: Artificial Intelligence (AI), Renewable Energy, Sustainable Design, Healthcare Educational Environment, and Energy Optimisation

INTRODUCTION

The growing demand for sustainable and resilient building systems has intensified global interest in renewable energy driven design, particularly within institutional environments that demand a persistent and dependable energy supply (International Energy Agency [IEA], 2023). Healthcare educational facilities are among the most energy intensive building types due to their extended operational hours, specialised equipment, and critical functional requirements (World Health Organisation [WHO], 2022). In developing countries such as Nigeria, these demands are further complicated by persistent grid instability, rising energy costs, and heavy dependence on fossil fuel based backup systems (Energy Commission of Nigeria, 2021). As a result, architects and planners face increasing pressure to adopt design approaches that integrate renewable energy solutions more effectively at the early stages of building development (United Nations Environment Programme [UNEP], 2021).

Renewable energy technologies, including solar photovoltaic systems and hybrid energy solutions, offer viable alternatives for enhancing energy reliability and reducing environmental impact in healthcare educational environments (IRENA, 2022). However, the success of these systems is highly dependent on informed design decisions related to building orientation, spatial configuration, system sizing, and operational planning (Attia, S. 2018). This practice highlights a critical disconnect between architectural design strategies and energy performance considerations.

Artificial Intelligence has emerged as a favourable tool for addressing this disconnect by enabling data driven decision making during the design process. Within the built environment, AI is increasingly applied to analyse environmental data, simulate energy performance scenarios, and evaluate design choices (Deb, Lee & Santamouris, 2022). Rather than functioning as an autonomous design generator, AI

operates most effectively as a decision support tool that enhances professional judgement by translating complicated datasets into actionable insights (Attia, S. 2018). Despite its growing application in building performance analysis, the systematic use of AI to support renewable energy driven architectural design remains limited within healthcare educational contexts in Nigeria (Adebayo & Oke, 2019).

This study, therefore, aims to evaluate Artificial Intelligence as a decision support tool for renewable energy driven architectural design in healthcare educational environments, within the context of Nigerian institutional settings and with Caleb University as a guiding reference. To achieve this aim, the research identifies how AI-supported analysis can inform early stage design decisions related to renewable energy integration, identify the effectiveness of an AI-assisted approach compared to conventional methods, and estimate how AI-informed insights can be interpreted to guide sustainable design strategies. Through this integrated approach, the study seeks to contribute to a better informed, resilient, and energy efficient architectural outcomes for healthcare education facilities.

REVIEW OF RELEVANT LITERATURE

The integration of Artificial Intelligence into renewable energy driven architectural design has gained increasing attention as institutions seek more sustainable and resilient energy solutions (Attia, 2018; Zhou, Li & Park, 2023). Healthcare educational environments present different challenges due to their high energy demand, functional sensitivity, and essential for an uninterrupted power supply, specifically within developing contexts where energy infrastructure remains irregular (Cain & Reynolds, 2020; Watson, 2014). Addressing these challenges requires design approaches that move beyond conventional energy planning toward data informed decision making frameworks (Nguyen & Altan, 2020).

Existing literature identifies Artificial Intelligence as an effective decision support tool for analysing environmental, climatic, and operational data within the built environment (Ahmad & Chen, 2021; Russell & Norvig, 2021). However, AI applications are frequently confined to post design performance optimisation, specifying their influence on early architectural decisions such as spatial configuration, orientation, and renewable energy integration (Zhang & Zhao, 2019; Li, Wang & Liu, 2020). Although renewable energy driven design literature consistently emphasises early stage integration for improved performance outcomes (IRENA, 2021; Deb, Lee & Santamouris, 2022), institutional buildings often adopt renewable systems as supplementary rather than formative design elements. This chapter, therefore, reviews existing scholarship on Artificial Intelligence, renewable energy driven design, and healthcare educational architecture to identify conceptual and contextual gaps that inform the direction of the present study.

Artificial Intelligence in the Built Environment

Artificial Intelligence has increasingly been applied within the built environment to support data analysis, performance prediction, and scenario evaluation. Rather than replacing human designers, Artificial Intelligence functions primarily as a decision support mechanism, assisting professionals in interpreting large datasets related to climate, energy demand, occupancy patterns, and building performance (Russell & Norvig, 2021; Ahmad & Chen, 2021). In the context of developing countries, recent Nigerian built environment research highlights the growing relevance of data driven tools for addressing energy inefficiency and infrastructure constraints, reinforcing the need for adaptive decision support systems in architectural practice (Ibitoye, 2020; Olaoye, 2021).

Studies indicate that Artificial Intelligence applications in architecture commonly include machine learning models for energy prediction, optimisation algorithms for system sizing, and simulation based decision tools (Amasyali & El Gohary, 2018; Zhou, Li & Park, 2023). These systems enable designers to compare multiple design scenarios before committing to specified architectural forms. However, literature also highlights that Artificial Intelligence is often deployed after key design decisions have been made, limiting its influence on spatial configuration and renewable energy optimisation (Zhang & Zhao, 2019; Li, Wang & Liu, 2020). Similar concerns have been identified in Nigerian institutional projects, where analytical tools are underutilised at early design stages due to limited integration within standard practice workflows (Ibitoye, 2020).

From a critical perspective, several authors caution that Artificial Intelligence depends on data quality, interdisciplinary collaboration, and institutional readiness (Lu, Wang & Zhang, 2020; Khan & Javaid, 2022). In developing contexts, limited data infrastructure, professional capacity gaps, and institutional

inertia further constrain Artificial Intelligence adoption (Olatunji & Aje, 2021). Supporting Nigerian studies emphasise that these constraints are particularly prominent in public and educational institutions, where sustainability strategies are often reactive instead of strategically embedded (Olaoye, 2021).

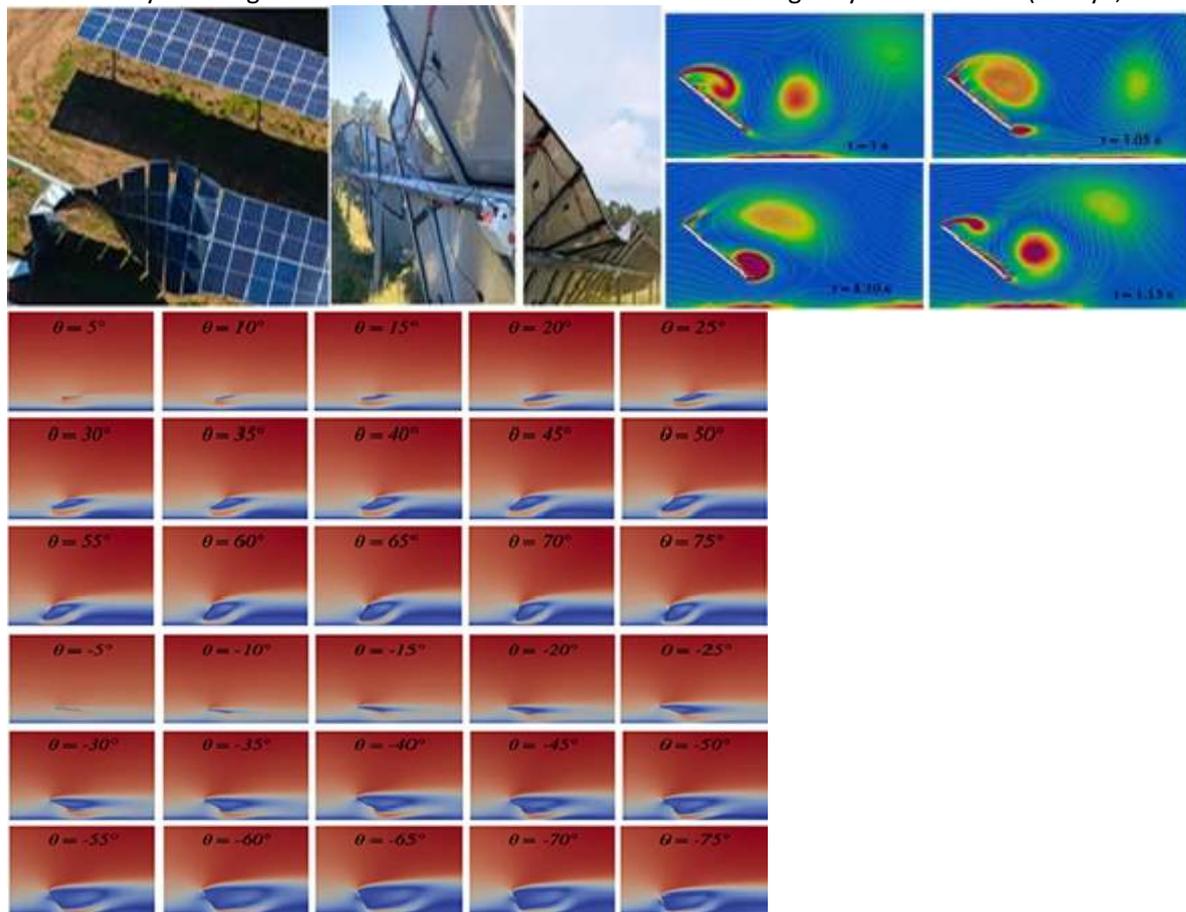


Figure 2.1: Artificial Intelligence Applications in the Built Environment
Source: <https://doi.org/10.1016/j.scs.2023.104529>

Description: A diagram illustrating Artificial Intelligence inputs such as: climate data, occupancy data, and energy demand processed through Artificial Intelligence analysis tools to inform architectural design decisions such as orientation, energy systems, and spatial layout.

Renewable Energy Driven Architectural Design

Renewable energy-driven design refers to an approach in which energy generation and efficiency concerns actively shape architectural form and planning outcomes from the earliest stages (Attia, S., 2018; Nguyen & Altan, 2020). This approach contrasts with conventional practices where renewable systems are appended after the building form has been finalised. Nigerian sustainability studies also argue that the late introduction of energy systems reduces long term efficiency and undermines environmental performance in institutional buildings (Ibitoye, 2020).

Solar photovoltaic systems, hybrid renewable formats, and campus scale energy networks are widely identified as feasible solutions for institutional buildings, particularly in regions with high solar potential (Boyle, 2012; IRENA, 2021). Research demonstrates that early stage integration enhances system performance, reduces lifecycle costs, and enhances spatial efficiency (Deb, Lee & Santamouris, 2022; Yilmaz & Korkmaz, 2022). Nigerian based studies reinforce this position, noting that early integration is especially vital in contexts where energy reliability is uncertain (Olaoye, 2021).

Despite these benefits, barriers persist. Nugent and Sovacool (2014) and Watson (2014) identify policy limitations, financial limitations, and institutional inertia as significant deterrents to the adoption of renewable energy in higher education facilities. In Nigeria, reliance on diesel generators remains prevailing

due to grid unreliability and limited enforcement of sustainable building regulations, resulting in continued environmental and economic costs (Olatunji & Aje, 2021; Ibitoye, 2020).

Suggested Table 2.1: Renewable Energy Strategies in Institutional Buildings

| S/N | Strategy | Design Stage | Benefits | Limitations |
|-----|--------------------------------|----------------|--|------------------------------|
| 1. | Solar photovoltaic integration | Early design | High efficiency and spatial optimization | Requires orientation control |
| 2. | Hybrid systems | Planning stage | Improved energy reliability | Higher capital cost |
| 3. | Post design retrofit | Late stage | Ease of implementation | Reduced performance |

This table reinforces the argument for early stage integration by clearly contrasting design stage impacts.

2.3 Artificial Intelligence as a Decision Support Tool for Renewable Energy Integration

Decision support systems bridge the gap between complicated datasets and functional design choices. In renewable energy driven architecture, Artificial Intelligence supported decision tools assist in assessing energy scenarios, system performance, and trade offs between cost, space, and reliability (Deb, Lee & Santamouris, 2022; Khan, Javaid & Almogren, 2020). Nigerian contextual studies further emphasise the possibility of such tools to support more rational energy planning within institutional environments, where findings are often constrained by uncertainty and limited technical capacity (Olaoye, 2021).

Fong et al. (2019) indicate that Artificial Intelligence based predictive models can optimise energy consumption in educational buildings when integrated into planning workflows. Similarly, Kong, Dong, & Jia, (2022) show that Artificial Intelligence supported renewable energy design improves resilience in healthcare facilities. However, these studies often prioritise performance results over architectural decision making processes. Nigerian literature echoes this limitation, noting the absence of structured frameworks that join analytical outputs directly to design logic (Ibitoye, 2020).

A periodic limitation identified across the literature is the fragmentation of Artificial Intelligence use, where tools are applied in isolation rather than embedded within holistic design frameworks (Zhang & Zhao, 2019; Li, Wang & Liu, 2020). This fortifies the need for structured decision support models that operate alongside architectural judgement rather than independently.

2.4 Healthcare Educational Environments and Energy Demand

Healthcare educational environments incorporate the operational intensity of healthcare facilities with the spatial complexity of educational institutions. These buildings require an uninterrupted power supply to help laboratories, simulation suites, teaching spaces, and clinical training environments (Cain & Reynolds, 2020; Smith & Lord, 2022). Nigerian studies further highlight that power disruptions within such environments negatively affect training quality and institutional efficiency (Olaoye, 2021).

Research highlights that energy failures in healthcare education facilities can disrupt training continuity and compromise institutional stability (Rehermann, Hartmann & Simons, 2020). Consequently, renewable energy systems are increasingly viewed as strategic infrastructure rather than optional sustainability features. However, literature reveals limited inquiry into how Artificial Intelligence supported decision making can inform the architectural design of healthcare educational facilities, particularly in developing countries, where energy planning is often treated as an operational concern rather than a spatial determinant (Watson, 2014; Ibitoye, 2020).

International and Local Contextual Studies

International studies highlight the integration of Artificial Intelligence supported renewable energy systems in university campuses across Europe and Asia, including the Technical University of Munich (TUM) and RWTH Aachen University in Germany, Delft University of Technology (TU Delft) in the Netherlands, Middle East Technical University (METU) in Turkey, and Tsinghua University and Tongji University in China (Rehermann, Hartmann & Simons, 2020; Yilmaz & Korkmaz, 2022). These institutions display varying degrees of integration between Artificial Intelligence tools and renewable energy planning frameworks, particularly in predictive modelling, energy forecasting, and campus-scale optimisation. These cases often benefit from robust policy frameworks, advanced data infrastructure, and institutional capacity. Within the

Nigerian context, Ibitoye, Oyewole, Abiola, and Adegunle, Babamboni (2023) examine sustainability and material technologies in housing estates, emphasising performance considerations and community adoption. Similarly, Tolulope Afolabi, Obafemi Adeniyi Ibitoye, Kalu C. Grace, and Gabriel Olaoye (2025) analyse green facade systems for urban heat mitigation in Lagos, supporting the importance of environmental performance integration in architectural design decision making. Although these Nigerian studies do not focus exclusively on Artificial Intelligence, they highlight contextual actualities of energy performance, environmental responsiveness, and institutional constraints within which AI-supported renewable strategies must function, thereby grounding the present study in established Nigerian architectural scholarship.

Conceptual Framework

DATA INPUT → AI DECISION SUPPORT → DESIGN INTEGRATION → OUTCOMES

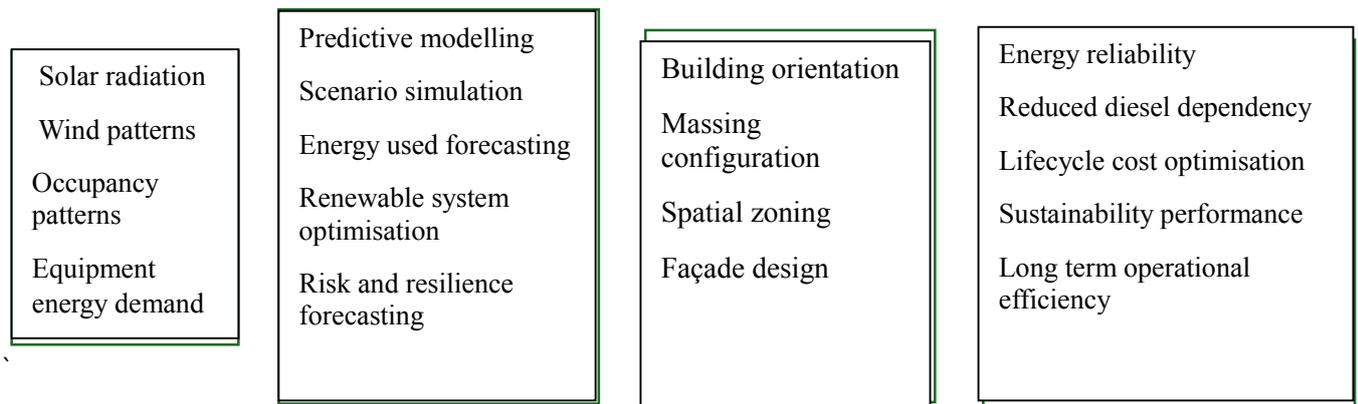


Figure 2.3: Conceptual Framework for Artificial Intelligence Supported Renewable Energy Driven Design

Intelligence

Description: The framework illustrates how environmental, climatic, and operational data are processed through an Artificial Intelligence decision support layer to inform architectural design strategies, renewable energy integration, and institutional resilience outcomes. Caleb University is positioned as the applied context for examining these interactions.

Research Gap

Despite extensive literature on Artificial Intelligence in building performance analysis and renewable energy technologies, limited research examines Artificial Intelligence as a structured decision support tool for renewable energy driven architectural design in healthcare educational environments, notably within developing contexts. Existing studies focus on technical optimisation or policy adoption, with minimal attention to early stage architectural decision making. This gap is especially prominent in Nigerian institutions, where energy insecurity persists despite growing access to Artificial Intelligence and renewable technologies. The present study addresses this gap by assessing Artificial Intelligence-supported decision-making as an integrated design strategy, using Caleb University as a guiding reference.

RESEARCH METHOD

Research Approach

This study adopts a qualitative research method to investigate how Artificial Intelligence can function as a decision support tool within renewable energy driven architectural design, particularly in healthcare educational environments. The focus of the study is not on producing numerical energy simulations, but on understanding how professionals interpret, apply, and employ data informed tools within real design processes.

A qualitative approach is therefore appropriate because the study seeks to examine professional judgement, institutional structures, and contextual constraints that shape decision making. Rather than treating Artificial Intelligence as a purely technical system, the study positions it as an analytical coating that supports architectural reasoning. This aligns with the conceptual framework established in this study.

Research Design

A multiple case study design was employed to permit for in depth examination of renewable energy planning and Artificial Intelligence understanding within institutional environments. Case study methodology enables the examination of contemporary approaches within their real world context, where design decisions are influenced by organisational culture, policy requirements, and resource availability.

Caleb University serves as the primary applied reference, particularly in relation to the proposed dentistry department. Further institutional contexts were studied to provide comparative understanding into renewable energy integration strategies and Artificial Intelligence adoption patterns. This comparative perspective intensifies the study by identifying shared challenges and structural patterns across institutions.

Study Context: Caleb University

Caleb University illustrates a relevant institutional context for exploring renewable energy driven design supported by Artificial Intelligence. Like many Nigerian higher education institutions, the university functions within an environment portrayed by energy instability and reliance on alternative power sources. The study focused on Nigerian institutional environments, with Caleb University acting as the primary contextual reference for evaluating the application of AI-supported renewable energy strategies within a proposed dentistry department. Additional institutional cases were reviewed to provide comparative insight into current practices.

Documentary Review

Institutional documents, including campus growth plans, sustainability reports, and renewable energy recommendations, were reviewed. This enabled us to establish how energy planning is currently formulated within institutional strategy and whether data informed decision processes are formally embedded. The documentary review also enabled comparison between stated sustainability goals and practical implementation.

Observational Review

Observational analysis of specified institutional facilities was undertaken to understand how renewable energy systems are presently incorporated spatially and operationally. Attention was given to system placement, spatial constraints, and evidence of coordinated planning between energy systems and architectural form. These observations supported and contextualised conclusions from interviews and documentary analysis.

Ethical Considerations

Ethical standards were upheld throughout the study. Participants were notified of the research purpose, provided voluntary consent, and assured confidentiality. Data were securely stored and used precisely for academic purposes. Triangulation across interviews, documents, and observations strengthened the credibility and reliability of the findings. Institutional confidentiality was maintained, and individual identifiers were pulled out during transcription and analysis.

RESULT AND DISCUSSION

Method of Analysis

Data collected through interviews, documentary review, and observational analysis were investigated using thematic analysis. This method allows systematic identification of patterns within qualitative datasets and supports rendition in relation to theoretical constructs commonly applied in built environment research (Attia, 2018). Interview transcripts were coded to determine themes relating to Artificial Intelligence awareness, renewable energy planning procedures, institutional readiness, and decision making structures. Documentary materials were analysed to determine how renewable energy and data informed planning frameworks are positioned within institutional strategies. Observational results confirmed alignment between stated sustainability objectives and physical implementation, particularly within energy infrastructure (Rehermann, F., Hartmann, T., & Simons, F., 2020). Themes were interpreted in relation to the conceptual framework, ensuring that findings remained aligned with the positioning of Artificial Intelligence as a decision support layer rather than a standalone optimisation system (Lu, X., Wang, J., & Zhang, H.; Russell & Norvig, 2021).

Case Study on Artificial Intelligence as a Decision Support Tool in Practice

International experience indicates increasing integration of Artificial Intelligence within institutional renewable energy planning. However, the depth of integration varies according to policy alignment, data infrastructure, and governance structures.

Germany

German university campuses such as the Technical University of Munich (TUM) and RWTH Aachen University have implemented Artificial Intelligence supported energy optimisation systems at campus scale. These institutions utilise predictive modelling platforms that integrate climatic data, occupancy profiles, and load forecasting to inform renewable energy sizing and storage planning (Rehermann, F., Hartmann, T., & Simons, F., 2020). These strategies support scenario evaluation before implementation. Artificial Intelligence is embedded within institutional energy management strategies. However, the broader German context identified, integration remains stronger within facilities management and infrastructure planning than within early stage architectural workflows. This indicates partial integration, where AI influences energy procedures but has a limited impact on conceptual architectural design. (Li, Wang & Liu, 2020).

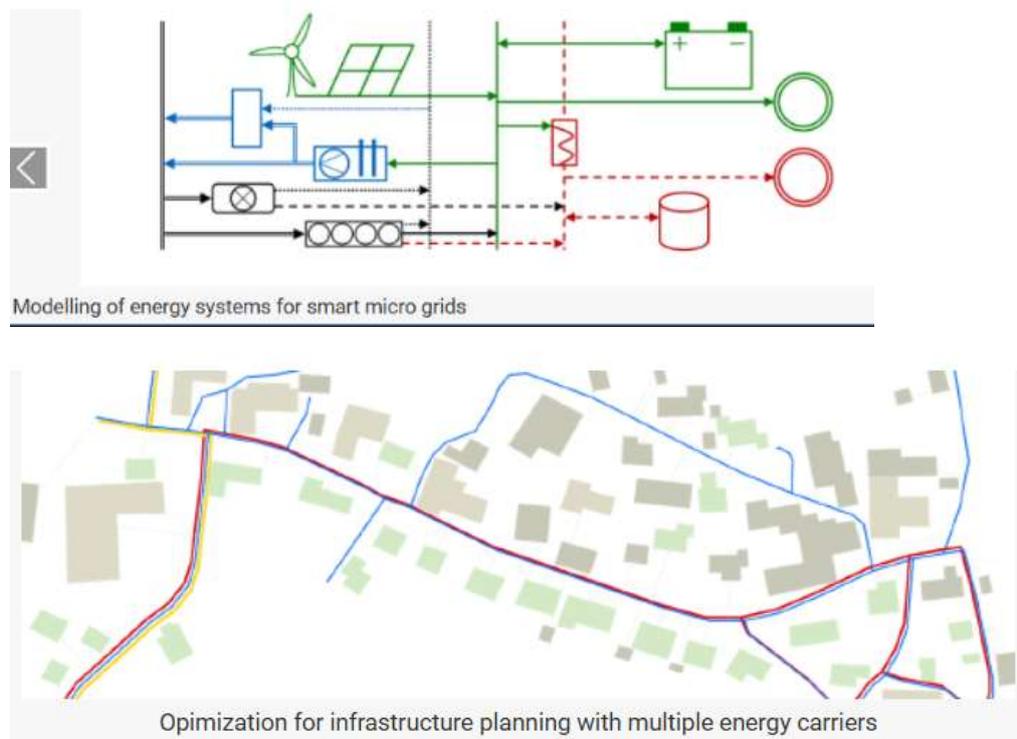
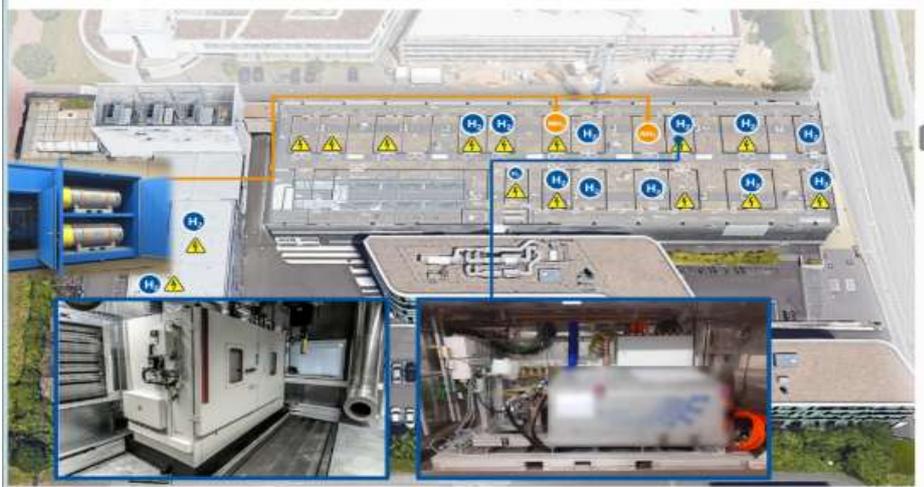
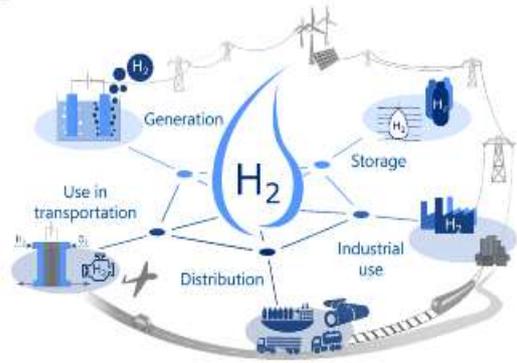


Fig.4.2.1 Campus research activity at the Technical University of Munich's Chair of Renewable and Sustainable Energy Systems, showing project visuals related to smart microgrid research and renewable energy system modelling at TUM. The image highlights modelling of energy systems and optimisation of smart microgrids at an interdisciplinary research centre

Source: <https://www.tudelft.nl/en/energy/research/energy-systems-integration>



Overview of Hydrogen and Ammonia research infrastructure.
 Left: Image of Climate Chamber. Right: Image depicting a Fuel Cell System tested in the Climate Chamber

Fig. 4.2.1.2 Diagrammatic representation of RWTH Aachen University’s energy performance data showing energy consumption trends and sustainability efforts. The image visually conveys RWTH’s campus hydraulic energy system, including infrastructure managed to enhance energy efficiency and reduce emissions
 Source: [Inside RWTH Aachen University’s Center for Sustainable Hydrogen Systems \(CSHS\)](#)

The Netherlands

Dutch campus, Delft University of Technology (TU Delft) utilises predictive analytics to back solar exposure modelling, demand forecasting, and grid interaction planning. Using Artificial Intelligence, TU Delft has implemented decentralised energy systems, rooftop photovoltaic optimisation, and demand forecasting tools aligned with national sustainability frameworks, informing long-term infrastructure decisions, specifically for decentralised energy and storage systems (IRENA, 2021).

Strong digital infrastructure and policy alignment support adoption; however, tools remain focused within energy engineering departments instead of architectural design teams (Zhou, Li & Park, 2023).





Fig. 4.2.2 showing the Delft Energy Initiative at TU Delft, a university hub for energy research and innovation where renewable and resilient energy systems (including solar, wind integration studies and sustainable energy solutions) are investigated by interdisciplinary research teams.

Source: [TU Delft Wind Energy Institute \(DUWIND\)](#), [Peter Palensky new chair TU Delft Energy Initiative](#), [Solar Energy: Integration of Photovoltaic Systems in Microgrids - TU Delft OCW](#).

Turkey

Studies from Turkey in Middle East Technical University (METU) illustrate the use of machine learning models to optimise photovoltaic (inverter power system) placement based on solar radiation and building envelope analysis (Yilmaz & Korkmaz, 2022). These tools impact façade orientation and roof design decisions but are naturally led by technical specialists rather than architectural planners, reflecting disciplinary fragmentation. Early stage architectural decision making strategies are not fully integrated with predictive modelling workflows, suggesting partial interdisciplinary coordination.



Fig.4.2.3 showing the Middle East Technical University (METU), sectored land where renewable and resilient energy solar systems powers the campus

Sources: [Waste Heat Solar Thermal Power Generation](#), [Technical Tour to the METU NCC Solar Farm | METU Northern Cyprus Campus](#)

China

In China, institutions such as Tsinghua University and Tongji University have implemented Artificial Intelligence supported renewable forecasting and load offsetting within large institutional complexes. These campuses utilise hybrid modelling systems that inform energy storage planning, renewable generation balancing, and infrastructure coordination (Khan, M. W., Javaid, N., & Almogren, A., 2020; Deb, C., Lee, S. E., & Santamouris, M., 2022). Hybrid modelling procedures inform storage and distribution planning. Healthcare facilities have embraced optimisation tools to enhance stability under peak demand circumstances (Kon, W., Dong, Z., & Jia, Y., 2022). While more assertive integration is evident at the infrastructure level, architectural influence remains variable.



Fig.4.2.4 Research visuals from the Institute of Energy, Environment and Economy at Tsinghua University, showing clean energy technologies and activity areas where renewable energy systems are studied and developed.

Source: [Renewable Energy Based Distributed Generation System - Engineering Institute of Technology](#)
:Engineering Institute of Technology.

Comparative Insight

Across these case studies, several consistent patterns emerge:

- Artificial Intelligence is most often used for predictive modelling and interpretation forecasting
- Integration is stronger at the energy systems level than at the architectural design level
- Institutional policy alignment and data infrastructure greatly influence adoption
- Early stage architectural integration remains limited even in developed contexts

Awareness and Perception of Artificial Intelligence in Design Decision Making

Findings indicate a moderate understanding of Artificial Intelligence among built environment professionals. Participants acknowledged its capacity for predictive modelling and scenario evaluation, consistent with literature on building performance analysis (Amasyali & El Gohary, 2018; Zhou, Li & Park, 2023).

Application remains mostly confined to technical verification stages. Tools are oriented after spatial configuration decisions, limiting influence on orientation, massing, and renewable placement. This reflects broader patterns in building energy research (Zhang & Zhao, 2019; Li, Wang & Liu, 2020).

Institutional constraints, including limited data infrastructure, absence of structured workflows, and restricted training, were recognised as barriers. Similar limitations are reported in developing contexts (Olatunji & Aje, 2021).

Relevance and Use of Data in Renewable Energy Planning

Environmental and operational data are consulted but not systematically ingrained within early design processes. Solar exposure and demand estimations are conducted; however, they rarely shape spatial planning decisions. Literature highlights that early integration enhances lifecycle performance and efficiency (Nguyen & Altan, 2020; Deb, Lee & Santamouris, M., 2022). Findings indicate that renewable systems are often appended post design, reducing optimisation potential, consistent with institutional adoption studies (Watson, Reherrmann, Hartmann & Simons, 2020). Participants recognised the value of predictive modelling; however, structured translation of analytical results into spatial logic remains restricted, reinforcing the gap identified in existing research (Lu, Wang & Zhang, 2020).

Renewable Energy Integration in Healthcare Educational Environments

Healthcare educational environments indicate high energy demand due to laboratories, simulation facilities, diagnostic equipment, and extended operating hours (Cain & Reynolds, 2020; Smith & Lord, 2022). Renewable integration, hence, requires alignment between spatial planning, load forecasting, and infrastructure design.

International integration strategies include:

- Planning the building's orientation early to maximise solar energy capture
- Integrating solar power with the national grid to create hybrid energy systems
- Using battery storage systems to balance energy demand and reduce extreme loads
- Implementing smart energy management platforms to monitor and optimise energy use
- Developing campus wide microgrid systems to enhance energy reliability and resilience

Early stage integration improves efficiency and lifecycle performance (Nguyen & Altan, 2020; Deb, Lee, & Santamouris, 2022). European institutional case studies establish that coordinated planning between architects and engineers enhances stability (IRENA, 2021).

Within Nigerian contexts, integration remains largely reactive. Renewable systems are installed in response to instability rather than implanted within spatial logic. Diesel generators remain prevailing, with renewables functioning as supplementary systems (Olatunji & Aje, 2021). Fragmented coordination decreases optimisation potential.

Documented Challenges of Artificial Intelligence Integration within Architectural Planning and Design

Several recurring problems were identified, aligning with global research on Artificial Intelligence adoption (Zhang & Zhao, 2019; Li, Wang & Liu, 2020):

- Fragmented workflow integration
- Limited institutional information infrastructure
- Professional skill gaps
- Absence of policy frameworks requiring data informed design
- Financial constraints restricting early analytical investment
- Organisational resistance to procedural change

Situations involving reliability and contextual adaptability were defined, notably where environmental datasets are incomplete. Artificial Intelligence performance remains dependent on data quality and institutional readiness (Lu, Wang & Zhang, 2020).

Separated decision authority between administrative and technical sections further strains interdisciplinary coordination, limiting Artificial Intelligence to an accessory analytical function.

Management Challenges

Management systems greatly shape Artificial Intelligence and renewable integration. Decision making processes are hierarchical, with limited partnership between architects, engineers, and administrators. Budget models prioritise immediate financial expenditure over long term performance, discouraging early integration of data supported techniques. Institutional energy planning is therefore shaped by governance and financial systems as much as technical feasibility. Research confirms that leadership alignment and policy frameworks are critical determinants of renewable adoption (Nugent & Sovacool, 2014; Rehmann, Hartmann, & Simons, 2020). Technological availability alone is inadequate. Effective integration requires corresponding governance, structured workflows, interdisciplinary engagement, and institutional commitment.

Management Strategies

Effective integration of Artificial Intelligence in architectural planning relies primarily on institutional governance rather than technological availability. Evidence from international and institutional publications reveals that structured management mechanisms significantly influence adoption outcomes (Li, Wang, & Liu, 2020; Rehmann, Hartmann, & Simons, 2020).

Institutions exhibiting stronger integration implemented the following strategies:

1. **Strategic policy alignment**, implementing renewable energy objectives within long term development plans and tying Artificial Intelligence outputs to measurable performance indicators (IRENA, 2021; Nugent & Sovacool, 2014).
2. **Early stage design mandates**, demanding scenario modelling and environmental analysis before architectural form is finalised to enhance renewable optimisation (Deb, Lee & Santamouris, M., 2022; Nguyen & Altan, 2020).
3. **Interdisciplinary coordination frameworks**, encouraging teamwork between architects, engineers, facilities managers, and data specialists to reduce workflow fragmentation (Lu, Wang & Zhang, 2020; Zhou, Li & Park, 2023).
4. **Capacity building and professional training**, reinforcing Artificial Intelligence literacy and institutional competence in data informed decision making (Olatunji & Aje, 2021).
5. **Data governance and infrastructure development**, concentrating on environmental and operational datasets to improve predictive modelling reliability (Ahmad & Chen, 2021; Khan & Javaid, 2022).
6. **Financial and procurement reform**, including lifecycle performance benchmarks rather than prioritising lowest initial cost (Rehmann, Hartmann & Simons, 2020; IRENA, 2021).

Discussion

The findings show that Artificial Intelligence retains a strong prospect as a decision support mechanism in renewable energy driven architectural design, yet its application remains fragmented. Across the cases, Artificial Intelligence was primarily used for performance verification and predictive modelling rather than shaping early architectural decisions such as orientation, massing, and zoning. This supports existing research that identifies late stage optimisation as the predominant mode of Artificial Intelligence deployment in building systems (Zhang & Zhao, 2019; Li, Wang & Liu, 2020).

Renewable energy integration in healthcare educational environments was also mostly reactive. Systems were introduced to address energy instability rather than embedded within conceptual plan frameworks, reducing optimisation potential and lifecycle efficiency (Nguyen & Altan, 2020; Rehmann, F., Hartmann & Simons, 2020). Institutional governance, rather than technological availability, emerged as the critical determinant of integration. Artificial Intelligence effectiveness depends on structured workflows, policy alignment, and data infrastructure (Ahmad & Chen, 2021; Lu, Wang & Zhang, 2020). Within Nigerian institutions, including Caleb University, the principal barrier is therefore structural rather than technical. The examination in Chapter Four demonstrates that the primary constraint is not technological absence but institutional structure. Artificial Intelligence tools for predictive modelling, scenario simulation, load forecasting, and renewable optimisation already exist. What is lacking is a framework that ingrains these tools into early stage architectural reasoning.

Within the context of Caleb University, this finding is particularly significant. The University is in the process of expanding into healthcare education, beginning with the Nursing Department and progressing toward a broader Faculty of Medicine. This expansion offers a rare opportunity: renewable energy systems and Artificial Intelligence support tools can be embedded from the ideational stage rather than retrofitted later.

If renewable energy integration is treated as an infrastructural afterthought, the Faculty of Medicine risks inheriting the same structural inefficiencies observed in other institutional contexts: heavy diesel dependence, fragmented planning, and reactive energy management. However, if Artificial Intelligence is positioned as a decision support layer from the start, it can guide orientation, zoning, system sizing, and campus level infrastructure planning.

Implementation Framework for Caleb University

Based on the findings of this study, the following phased implementation approach is proposed for Caleb University's assumed emerging Faculty of Medicine.

Phase 1: Early-Stage AI-Supported Conceptual Modelling

Before finalising architectural form for the Nursing Department, Artificial Intelligence should be used to:

- Simulate solar exposure and orientation scenarios
- Forecast energy demand based on foreseen equipment load and occupancy patterns
- Approximate renewable system sizing alternatives
- Model hybrid solar grid storage configurations
- Conduct risk and resilience forecasting

This assures that building orientation, massing, façade presentation, and spatial zoning respond directly to energy logic.

Phase 2: Integration Within Institutional Master Planning

Renewable energy goals must be implemented within Caleb University's broader campus development plan. Artificial Intelligence outcomes should inform:

- Microgrid feasibility for the assumed Faculty of Medicine cluster
- Distributed photovoltaic placement across rooftops
- Battery storage infrastructure planning
- Load balancing techniques between departments

Rather than creating each building independently, the Faculty of Medicine should be treated as an integrated energy ecosystem.

Phase 3: Interdisciplinary Governance Structure

Effective implementation requires collaboration between:

- Architects
- Mechanical and electrical engineers
- Energy consultants
- Facilities management
- Institutional administrators

Artificial Intelligence results must be formally examined within interdisciplinary design meetings before spatial decisions are concluded. This prevents fragmentation and assures renewable systems influence architectural logic rather than simply technical detailing.

Phase 4: Data Infrastructure and Governance

Caleb University must develop:

- Centralised environmental data repositories
- Energy demand monitoring systems
- Predictive modelling protocols
- Lifecycle performance tracking systems

Without reliable data infrastructure, Artificial Intelligence remains underutilised.

Phase 5: Lifecycle-Oriented Procurement

Procurement models should prioritise long term energy performance rather than the lowest initial cost. AI-based lifecycle cost analysis can back informed financial decision making, ensuring renewable investments align with long term institutional resilience.

CONCLUSION

Artificial Intelligence can significantly improve renewable energy driven design when embedded within early architectural sense and guided by coordinated governance. For Nigerian healthcare educational environments, sustainable adaptation depends more on institutional reform than on technological acquisition.

RECOMMENDATIONS

Effective integration requires:

1. Using Artificial Intelligence early in the design process to test various planning and energy scenarios.
2. Including renewable energy goals from the start within the institution's overall development plans.
3. Assuring collaboration between architects, engineers, energy specialists, and decision-makers.
4. Establishing organised systems for collecting, managing, and using reliable data.
5. Choosing procurement and investment models that focus on long term performance and cost efficiency, not just initial construction costs.

Contribution and Future Research

This study contributes a qualitative framework positioning Artificial Intelligence as an integrated decision support tool within renewable energy driven architectural planning.

Future research should:

- Conduct quantitative energy simulations for the proposed Dentistry Department
- Develop campus scale AI energy models for the Faculty of Medicine
- Undertake post occupancy performance evaluation
- Explore policy frameworks supporting AI-mandated early stage modelling

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