

GENERATIVE AI FOR CLIMATE-ADAPTIVE ARCHITECTURAL DESIGN: OPTIMIZING BUILDING ENERGY RESILIENCE IN PAKISTAN

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Abstract

The rapid development of generative artificial intelligence (GenAI) has created new opportunities for optimizing architectural design in response to climate and energy challenges. This study examined the role of GenAI-assisted architectural design in enhancing building energy resilience in Pakistan. A quantitative, cross-sectional research design was employed, and data were collected from 300 architects, engineers, academics, energy consultants, and building professionals through a structured questionnaire. The study examined four dimensions of GenAI-assisted design: AI-Assisted Passive Design Optimization, Climate-Responsive Design Generation, Building-Envelope Optimization, and AI-Enabled Climate and Energy Scenario Simulation. Architectural AI Competence was examined as a moderating variable, while Building Energy Resilience was the dependent variable. Descriptive statistics, correlation analysis, multiple regression, and moderation analysis were employed to test the proposed relationships. The findings indicated that all four GenAI-assisted design dimensions had significant positive effects on building energy resilience, with Climate-Responsive Design Generation demonstrating the strongest effect. Architectural AI Competence also significantly strengthened the relationship between GenAI-assisted architectural design and building energy resilience. The findings suggest that GenAI can support climate-adaptive architectural decision-making by facilitating rapid design exploration, passive-design optimization, envelope performance improvement, and scenario-based evaluation. The study contributes to Resilience Theory by conceptualizing AI-enabled architectural design as a proactive mechanism for strengthening building resistance, adaptability, and robustness under climatic and energy disturbances. The study recommends integrating GenAI with local climate data, building-performance simulation, professional expertise, and Pakistan's Energy Conservation Building Code to develop more resilient and energy-responsive buildings.

Introduction

Climate change is increasingly transforming the conditions under which buildings are designed,

constructed, and operated. Rising temperatures, more frequent heat extremes, changing precipitation patterns, and increasing pressure

on energy systems are making conventional approaches to building design progressively less adequate for future climatic conditions. The Intergovernmental Panel on Climate Change (IPCC, 2023) emphasizes that adaptation and mitigation responses must increasingly be integrated across infrastructure and urban systems because climate risks interact with energy demand, human health, economic activity, and the built environment. For buildings, this means that design strategies can no longer focus exclusively on present-day energy efficiency; they must also address the capacity of buildings to maintain acceptable thermal and operational performance under increasingly uncertain climatic conditions.

The challenge is particularly significant in Pakistan, where climatic vulnerability intersects with rapid urbanization, increasing cooling requirements, energy-system constraints, and substantial deficiencies in building energy efficiency. Pakistan's building sector accounts for more than 43.7% of national energy use, with the country's predominantly hot and sunny climate contributing substantially to cooling demand (World Bank Group, 2025). The problem is compounded by rapid urban growth and increasing construction activity, which are expected to increase building energy consumption and associated greenhouse-gas emissions. Recent evidence further indicates that electricity demand in Pakistan is highly sensitive to seasonal cooling requirements, creating substantial pressure on the electricity system during periods of extreme heat (World Bank Group, 2025). Thus, improving the energy performance of buildings represents not only an environmental objective but also an important energy-security and climate-resilience strategy.

Pakistan's exposure to climate risks makes this challenge more urgent. The World Bank Group (2022) identifies Pakistan as highly vulnerable to climate change and highlights the need for long-term investments in climate resilience, low-carbon development, and energy-sector transformation. The country's vulnerability is particularly relevant to the built environment because increasing temperatures can intensify cooling loads, while unreliable or constrained electricity supply can compromise the ability of mechanically conditioned buildings to maintain

thermal comfort. Consequently, climate-adaptive architectural design needs to consider both energy efficiency under normal conditions and resilience under climate and energy-system stress.

The policy environment in Pakistan has also evolved in response to these challenges. The Energy Conservation Building Code 2023 (ECBC-2023) establishes minimum requirements for energy-efficient building design, construction, and operation. The code specifically addresses building-envelope optimization, passive design, insulation, retrofitting, energy monitoring, renewable energy, and energy-management systems (National Energy Efficiency and Conservation Authority [NEECA], 2023). This development provides an important institutional foundation for moving from conventional architectural design toward performance-oriented and climate-responsive building design. However, the existence of energy codes alone does not guarantee optimal building performance. The effectiveness of such standards depends substantially on the ability of designers to evaluate alternative architectural configurations and identify solutions that simultaneously satisfy energy, comfort, cost, functional, and regulatory requirements.

Within this context, artificial intelligence (AI) has emerged as an important technological development in building design and performance optimization. AI-based approaches can process complex relationships among climatic variables, building geometry, materials, occupancy, energy systems, and performance outcomes. More recently, generative AI (GenAI) has extended this capability by enabling the generation of alternative design solutions rather than merely evaluating predetermined alternatives. The emerging literature suggests that AI-driven design optimization can support the exploration of large design spaces and accelerate the identification of high-performing building configurations (Manmatharasan et al., 2025).

The potential of generative and performance-driven design is particularly relevant during the early architectural-design stage. Decisions concerning building orientation, massing, spatial configuration, window-to-wall ratio,

shading, envelope characteristics, and material selection can substantially influence subsequent energy performance. Recent research has demonstrated the feasibility of integrating generative design with building-performance simulation and multi-objective optimization. Li et al. (2024), for example, developed a multi-objective generative design framework combining multi-task learning, code-compliance checking, and optimization to identify building solutions that simultaneously address energy consumption, life-cycle cost, and daylight performance. Similarly, Manmatharasan et al. (2025), in a systematic review, identified AI-driven optimization as an increasingly important approach for sustainable building design while highlighting continuing challenges related to data, computational requirements, generalizability, and practical implementation. More recent research has moved specifically toward generative AI and large language model-based design processes. An emerging approach integrates large language models with parametric building representations and building-performance simulation to introduce energy objectives directly into the design-generation process. Such frameworks demonstrate that generative AI can potentially move architectural performance evaluation from a predominantly post-design activity toward an iterative design-generation and optimization process. Recent empirical evidence has reported meaningful improvements in simulated energy-use intensity when generative AI is incorporated into early-stage building optimization (EnergAI study, 2025). Other research has similarly demonstrated the potential of AI-assisted spatial-layout generation and evolutionary optimization for climate-adaptive building design, including energy savings across different climatic conditions (Huang et al., 2025).

Importantly, the emerging literature is beginning to distinguish between energy-efficient design and energy-resilient design. Energy efficiency primarily concerns reducing energy consumption for a specified set of operating conditions, whereas energy resilience additionally considers the capacity of a building to maintain acceptable performance when climatic conditions become more severe or energy availability becomes constrained. Recent

performance-based generative-design research has explicitly incorporated future climate conditions and energy-resilience objectives into building optimization, demonstrating the potential of generative approaches to identify building forms that perform more effectively under climate-change scenarios (Energy-resilient performance-based generative design study, 2025). This development is particularly relevant for Pakistan, where extreme heat and electricity-system constraints can occur simultaneously.

Despite these advances, an important contextual and empirical gap remains. Existing AI-driven building-design research has predominantly been conducted in contexts with comparatively developed digital building ecosystems, extensive building-performance datasets, standardized simulation environments, and established computational design infrastructures. Moreover, much of the literature focuses on energy efficiency, carbon reduction, or individual performance indicators rather than examining building energy resilience as an integrated outcome of climate-adaptive architectural design. The applicability of these approaches to Pakistan remains insufficiently investigated, particularly with respect to local climatic conditions, architectural practices, regulatory requirements, energy-system constraints, and variations among Pakistan's climatic zones.

The research gap is therefore not simply whether AI can generate architectural designs. The more important question is whether GenAI can be systematically incorporated into climate-adaptive architectural decision-making to generate and optimize building configurations that are simultaneously energy-efficient, thermally resilient, climate-responsive, and compatible with Pakistan's regulatory environment. Addressing this question requires moving beyond the technological novelty of GenAI toward an integrated framework linking climate data, architectural parameters, building-performance simulation, energy-resilience indicators, and professional decision-making.

Accordingly, this study investigates the role of generative AI in climate-adaptive architectural design with particular emphasis on optimizing building energy resilience in Pakistan. The study conceptualizes GenAI-assisted passive design optimization, climate-responsive design

generation, building-envelope optimization, and AI-enabled climate and energy scenario simulation as potential mechanisms through which architectural design performance can be improved. In doing so, the study seeks to contribute to the emerging intersection of generative AI, sustainable architecture, climate adaptation, and building energy resilience while providing contextually relevant evidence for Pakistan.

Problem Statement

Pakistan's building sector is confronted with a complex combination of climate change, increasing urbanization, rising cooling requirements, energy insecurity, and inefficient building design. Buildings already account for more than 43.7% of Pakistan's total energy use, while increasing temperatures and growing urban demand are expected to place additional pressure on energy systems (World Bank Group, 2025). The problem is particularly acute during periods of extreme heat, when cooling demand increases substantially at precisely the time when electricity systems face heightened peak-load pressures. Consequently, inefficient building design creates a dual vulnerability: it increases energy consumption during normal operation and simultaneously reduces the capacity of buildings to remain thermally functional during periods of energy-system stress.

The conventional architectural-design process presents a significant limitation in addressing this problem. Architects typically make early decisions regarding building orientation, massing, spatial organization, façade design, glazing, shading, materials, and envelope configuration before comprehensive energy-performance assessment is undertaken. Although building-performance simulation can subsequently evaluate these decisions, the evaluation process may be computationally demanding and may occur after important design decisions have already constrained the available solution space. Recent research confirms that performance-driven generative design is increasingly being developed to address this limitation by linking parametric design, simulation, and optimization during the early stages of architectural development (Li et al., 2024; Manmatharasan et al., 2025).

Generative AI potentially provides a further transformation of this process. Instead of evaluating a small number of architect-generated alternatives, GenAI can assist in generating numerous design configurations according to predefined climatic, functional, energy, and regulatory constraints. Recent studies have demonstrated the feasibility of combining generative AI, parametric modelling, building-performance simulation, and optimization for improving energy-related design outcomes (Huang et al., 2025; Manmatharasan et al., 2025). However, the rapid emergence of this technology also creates an important research problem: the generation of a design alternative does not necessarily mean that the design is climate-adaptive, energy-efficient, technically feasible, or resilient. AI-generated outputs must therefore be evaluated against objective performance criteria and contextual constraints. A further limitation in the existing literature is its emphasis on energy efficiency rather than comprehensive energy resilience. Reducing annual energy consumption is important, but it does not necessarily guarantee that a building will remain habitable or operational during extreme heat, electricity interruptions, or other climate-related disruptions. A building may demonstrate low annual energy consumption while remaining highly dependent on mechanical cooling and therefore vulnerable during grid failures. Building energy resilience consequently requires a broader consideration of cooling demand, peak electricity requirements, thermal comfort, passive survivability, renewable-energy contribution, and the ability of the building envelope and passive systems to reduce dependence on mechanical systems.

This distinction is particularly important in Pakistan because the country's energy and climate challenges are interconnected. The World Bank Group (2022, 2025) identifies increasing cooling demand, energy-system constraints, climate vulnerability, and the need for improved building efficiency as important components of Pakistan's climate-development challenge. Although ECBC-2023 provides a national framework addressing building envelopes, passive design, insulation, renewable energy, and energy management (NEECA,

2023), there is limited empirical evidence demonstrating how emerging GenAI technologies can be used to systematically optimize architectural designs within these regulatory and climatic requirements.

Another important gap concerns contextual transferability. Existing generative-design research has produced promising findings in particular building types and climatic settings, but building-performance relationships are highly context dependent. Orientation, solar exposure, ventilation, thermal mass, insulation, glazing, shading, and cooling requirements vary across climatic zones. Therefore, an AI framework developed for one geographical or climatic context cannot automatically be assumed to provide optimal solutions for Pakistan. The absence of Pakistan-specific evidence creates uncertainty regarding how GenAI should incorporate local climatic data, construction practices, materials, energy constraints, building regulations, and architectural preferences.

There is also a professional capability gap. The effectiveness of GenAI-assisted design depends not only on the technical sophistication of AI systems but also on the ability of architects and engineers to formulate appropriate constraints, interpret simulation results, identify unrealistic outputs, and integrate AI recommendations with professional standards. Thus, AI competence may influence whether generative technologies actually contribute to improved building performance. Treating GenAI simply as an automated design generator may overlook the importance of human expertise, professional judgment, regulatory compliance, and interdisciplinary collaboration.

Therefore, the central problem addressed by this study is the lack of an empirically grounded and contextually relevant framework explaining how generative AI can be integrated into climate-adaptive architectural design to optimize building energy resilience in Pakistan. Existing research establishes the technical potential of AI-driven and generative design optimization, but insufficient attention has been given to the combined effects of AI-assisted passive design, climate-responsive generation, building-envelope optimization, and climate/energy scenario simulation on building energy

resilience within Pakistan's specific environmental and institutional context.

This research consequently addresses both a theoretical gap and a practical gap. Theoretically, it extends the emerging literature on AI-driven building-performance optimization by conceptualizing energy resilience as a broader outcome than conventional energy efficiency. Practically, it seeks to identify how architects, engineers, developers, and policymakers can use GenAI as a performance-oriented decision-support technology rather than merely as a visual or conceptual design tool. Contextually, the study responds to Pakistan's increasing need for buildings capable of reducing energy demand while maintaining thermal and operational performance under climate and energy-system stress.

Research Questions

RQ1: How does GenAI-assisted passive design optimization influence building energy resilience in Pakistan?

RQ2: What is the effect of GenAI-enabled climate-responsive design generation on building energy resilience in Pakistan?

RQ3: To what extent does GenAI-assisted building-envelope optimization contribute to building energy resilience?

RQ4: What effect does AI-enabled climate and energy scenario simulation have on building energy resilience?

RQ5: Does architectural AI competence strengthen the relationship between GenAI-assisted architectural design and building energy resilience?

RQ6: How can GenAI be integrated with climate data, building-performance simulation, and Pakistan's Energy Conservation Building Code to support climate-adaptive architectural design?

Research Objectives

The overall objective of the study is:

To examine the role of generative artificial intelligence in climate-adaptive architectural design and determine its contribution to optimizing building energy resilience in Pakistan.

The specific objectives are:

1. To examine the effect of GenAI-assisted passive design optimization on building energy resilience in Pakistan.
2. To determine the effect of GenAI-enabled climate-responsive design generation on building energy resilience.
3. To assess the contribution of GenAI-assisted building-envelope optimization to building energy resilience.
4. To evaluate the effect of AI-enabled climate and energy scenario simulation on building energy resilience.
5. To examine the moderating role of architectural AI competence in the relationship between GenAI-assisted architectural design and building energy resilience.
6. To develop an integrated framework linking generative AI, climate-responsive architectural design, building-performance simulation, and energy resilience within the Pakistani context.
7. To formulate context-specific recommendations for architects, building professionals, developers, and policymakers concerning the responsible integration of GenAI into climate-adaptive building design in Pakistan.

Significance of the Study

Theoretical Significance

The study contributes to the emerging literature at the intersection of generative artificial intelligence, architectural design, climate adaptation, and building energy performance. Existing research has largely examined AI as a mechanism for prediction, simulation, or optimization, while recent generative-design research has begun to explore automated generation of high-performance building alternatives (Li et al., 2024; Manmatharasan et al., 2025). This study extends that literature by conceptualizing building energy resilience as a multidimensional outcome encompassing energy efficiency, cooling-load reduction, peak-demand management, thermal performance, and resilience under climate and energy-system stress.

The study also contributes theoretically by positioning GenAI within a socio-technical architectural environment in which AI capabilities interact with professional expertise,

climatic information, building regulations, and engineering validation. This perspective avoids treating AI as an autonomous replacement for architectural expertise and instead conceptualizes it as a decision-support mechanism within a broader building-design system.

Practical Significance

For architects and architectural engineers, the study can provide a structured approach for incorporating GenAI into early-stage design decisions. Rather than using generative AI primarily for visualization or conceptual ideation, professionals can employ it to explore alternative orientations, massing configurations, building envelopes, shading systems, ventilation strategies, and other design variables according to measurable performance criteria.

For building developers and owners, the study can demonstrate how performance-oriented generative design may assist in identifying building configurations that reduce energy consumption, cooling requirements, peak electricity demand, and potentially long-term operating costs.

For engineering and design education, the study can provide a basis for integrating AI-assisted design, building-performance simulation, climate-responsive architecture, and energy modelling into architectural and engineering curricula. This is increasingly important as the architectural profession moves toward computational and performance-driven design environments.

Policy Significance

The study has particular relevance for Pakistan's building-energy policy. ECBC-2023 establishes requirements related to building-envelope performance, passive design, insulation, renewable energy, energy monitoring, and energy management (NEECA, 2023). The proposed research can help demonstrate how emerging GenAI technologies may complement these regulatory objectives by enabling systematic exploration of code-compliant, climate-responsive, and energy-efficient design alternatives.

For policymakers and regulatory authorities, the findings can support the development of future

guidelines for AI-assisted building-performance assessment, digital building approval systems, and performance-based compliance mechanisms. The research can also contribute to broader climate-resilience strategies by demonstrating how building design can reduce energy-system pressure while improving occupant resilience during extreme climatic conditions.

Ultimately, the study is significant because it shifts the discussion from "Can AI generate architectural designs?" toward the more consequential question of "Can AI help generate and validate architectural designs that remain energy-efficient, climate-responsive, and resilient under Pakistan's future environmental conditions?" This distinction provides the central intellectual and practical contribution of the proposed research.

Literature Review

1. Evolution of AI in Architectural and Building Design

The integration of artificial intelligence (AI) into architectural design has evolved from relatively narrow applications of computational prediction toward increasingly sophisticated systems capable of generating, evaluating, and optimizing design alternatives. Earlier AI applications in the built environment were primarily concerned with energy forecasting, load prediction, HVAC control, fault detection, and building-performance assessment. More recent developments have shifted attention toward the design stage, where AI can influence building geometry, spatial configuration, envelope characteristics, material selection, daylighting, thermal performance, and energy consumption before construction decisions become difficult or expensive to modify.

This shift is important because decisions made during early architectural design substantially constrain subsequent building performance. Manmatharasan et al. (2025), in a systematic review of AI-driven design optimization for sustainable buildings, demonstrate that AI increasingly functions as a surrogate model capable of rapidly evaluating large numbers of design alternatives. Their review of 70 studies indicates that operational energy demand remains the dominant sustainability objective,

while daylight performance and carbon emissions are also increasingly incorporated into optimization. Importantly, the authors emphasize that early-stage optimization can be more effective and economical than attempting to correct poor performance after construction. The increasing importance of AI in architectural design is further demonstrated by Jang et al. (2025), who systematically reviewed 161 journal articles concerning generative AI in architectural design. Their findings show that AI applications are heavily concentrated in the early design stage, with schematic design accounting for approximately 68.94% of applications. However, image-based data dominate current applications, while multimodal, graph-based, and performance-oriented applications remain comparatively less developed. This finding is important for the present study because it reveals a distinction between AI-assisted architectural creativity and AI-assisted performance optimization. Generating visually compelling alternatives does not necessarily produce buildings that are energy-efficient or climate-resilient.

Similarly, Li et al. (2025) reviewed generative AI models across different architectural design stages and identified applications ranging from conceptual design and spatial planning to detailed design and design evaluation. Their analysis suggests that generative AI has the potential to reduce the time required for design iteration, but the reliability of outputs remains dependent on data quality, prompt formulation, model capability, and appropriate evaluation procedures. Therefore, the architectural value of GenAI should be assessed not simply by the number or visual quality of generated alternatives but by its capacity to produce measurably superior design outcomes.

2. Generative AI and Performance-Based Architectural Design

Generative AI represents a particularly significant development because it changes the role of AI from a predictive tool into a potential **design-generation and optimization mechanism**. Traditional performance simulation normally follows a sequential logic: the architect creates a design, the engineer simulates its performance, problems are

identified, and the design is subsequently modified. Generative AI potentially enables a more iterative process in which performance requirements become design-generation constraints from the outset.

Recent research provides evidence supporting this transition. Ma and Lu (2025), through the EnergAI framework, integrated large language models with parametric building representations and ClimateStudio to introduce energy objectives directly into early-stage building-form generation. Their experimental results demonstrate that structured performance-oriented prompting can produce substantial improvements in simulated energy-use intensity compared with human-generated designs. The significance of this work lies less in the specific AI models used and more in its demonstration that natural-language generative systems can be connected to quantitative building-performance feedback.

This represents an important methodological development for sustainable architecture. Rather than treating GenAI as an independent design generator, the technology can operate within a closed-loop system:

Design generation → simulation → performance evaluation → AI refinement → improved design

Such a process enables architects to examine a substantially larger design space than would ordinarily be practical through manual iteration. However, the literature also indicates that GenAI should not be treated as an autonomous optimization mechanism. Jang et al. (2025) found that subjective comparative evaluation remains dominant in architectural GenAI research, while objective performance-based evaluation is comparatively less established. This creates a significant methodological concern for climate-adaptive architecture. A design may be aesthetically successful according to human evaluators while performing poorly in terms of thermal comfort, cooling demand, peak electricity consumption, or future climate exposure.

Accordingly, the present study conceptualizes GenAI as a decision-support and optimization technology, rather than as a replacement for professional architectural judgment. Its effectiveness should ultimately be determined

through measurable building-performance indicators.

3. AI-Driven Building Energy Optimization

The relationship between AI and building energy optimization has become increasingly established. AI-based systems can approximate complex relationships between building parameters and energy outcomes, allowing computationally intensive simulation processes to be accelerated.

Manmatharasan et al. (2025) show that surrogate modelling is particularly valuable in this respect. A conventional building-performance simulation may require substantial computational resources when thousands of combinations of orientation, glazing, insulation, geometry, HVAC parameters, and environmental conditions are evaluated. AI-based surrogate models can approximate these relationships and subsequently support optimization with substantially lower computational requirements.

More recent evidence further confirms the broad potential of AI in building-energy management. Gunasinghalge et al. (2025) conducted a systematic review and meta-analysis of 126 peer-reviewed studies and identified predictive systems, adaptive control, pattern recognition, hybrid approaches, and edge AI as major categories of AI applications in smart buildings. Their analysis also demonstrates considerable variation in performance across building types and climate zones and identifies limited real-world deployment as an important weakness in the existing literature.

This finding is highly relevant to the present research. The effectiveness of an AI system demonstrated in a controlled laboratory environment cannot automatically be generalized to Pakistan's diverse climatic and energy conditions. Climate zone, occupancy, building typology, construction materials, energy infrastructure, and user behavior can all influence the relationship between AI-based optimization and actual building performance. Consequently, there is a need to move from generic claims regarding AI's capacity to save energy toward context-specific evidence concerning which AI-enabled design strategies

improve which dimensions of building energy resilience under particular climatic conditions.

4. Generative AI and Early-Stage Energy Optimization

Early-stage architectural design represents a particularly important opportunity for GenAI because many high-impact decisions are made before detailed engineering begins. Building orientation, massing, glazing ratio, façade configuration, shading, envelope composition, and spatial organization can strongly influence solar gains, ventilation, cooling demand, and thermal comfort.

Ma and Lu (2025) provide particularly relevant evidence through the EnerGenAI framework. Their approach uses a dataset of simulated building forms and energy-performance outcomes to establish relationships between site conditions, building massing, and energy use. The framework then uses large language models to generate alternative forms and iteratively assess their energy performance.

This approach is conceptually important because it transforms the role of AI from design visualization to performance-aware design generation.

Nevertheless, early-stage energy optimization has limitations. Energy performance is only one dimension of architectural quality. A theoretically optimal design may be impractical because of structural constraints, construction costs, local materials, cultural requirements, spatial functionality, aesthetics, or building regulations. Consequently, the optimal GenAI system should use multi-objective optimization, where energy performance is evaluated alongside functional, economic, environmental, regulatory, and architectural criteria.

Manmatharasan et al. (2025) similarly identify multi-objective optimization as an important direction for AI-driven sustainable building design. Their review indicates that although operational energy remains the most frequently optimized variable, increasingly sophisticated studies are combining energy, daylight, carbon, and other sustainability objectives.

5. Climate-Responsive and Climate-Adaptive Architectural Design

Climate-responsive architecture is not a new concept. Traditional architecture has historically incorporated orientation, shading, thermal mass, natural ventilation, courtyards, local materials, and building form to respond to climatic conditions. What has changed is the increasing need to design not merely for current climatic conditions but for future climatic uncertainty.

Saifudeen and Mani (2024) emphasize that building adaptation to climate change requires a combination of passive and active mechanisms. Their review highlights the importance of orientation, form, shading, ventilation, thermal performance, and locally responsive architectural strategies.

Liyanage et al. (2024) similarly demonstrate that traditional energy-retrofit approaches may become inadequate under future climate conditions. Their review identifies overheating as an increasingly important future risk and emphasizes that passive strategies can substantially reduce overheating while climate modelling and energy simulation should be integrated into adaptation planning.

This literature creates an important connection with generative AI. If future climatic conditions are incorporated into the design objectives, GenAI could theoretically evaluate design alternatives against both current and projected weather conditions. This would static climate-responsive design to dynamic climate-adaptive design. represent a shift from static climate-responsive design to dynamic climate-adaptive design.

The distinction is fundamental:

Climate-responsive design: performs well under known climatic conditions.

Climate-adaptive design: maintains acceptable performance across changing and uncertain climatic conditions.

For Pakistan, this distinction is particularly important because climatic conditions vary considerably between regions and future climate stress is expected to increase thermal and energy-system risks.

6. Building Energy Resilience

Building energy resilience has emerged as a distinct research area because energy efficiency alone does not adequately describe building performance during disruptive events. Wei et al. (2025) argue that there is no universally accepted definition of energy resilience in the built environment and propose a multidimensional incorporating vulnerability, resistance, robustness, and recoverability. Their review identifies heat waves and system failures among the most frequently investigated disruptions and categorizes resilience indicators into occupant, grid, infrastructure, economic, and hybrid dimensions.

This conceptual development is highly relevant to the present study. A building that consumes relatively little energy under normal conditions may nevertheless be highly vulnerable during a heatwave accompanied by a power outage. Conversely, a building with effective passive cooling, thermal mass, shading, insulation, renewable energy, and energy storage may maintain acceptable indoor conditions for longer periods despite reduced grid availability. Zhang et al. (2025) reinforce this argument by demonstrating that extreme weather events can interact with power outages to destabilize indoor thermal conditions. Their review specifically emphasizes maintaining thermal stability during heat and cold waves as a core component of building energy resilience.

Peri et al. (2024) further demonstrate that the understanding of building resilience has evolved from conventional energy efficiency toward broader concepts incorporating climate adaptation, thermal performance, life-cycle carbon, renewable energy, and urban context. Their systematic review of 226 studies indicates that building resilience research is increasingly shifting toward integrated climate resilience rather than isolated energy-efficiency measures. Thus, the present study defines building energy resilience as the capacity of a building to maintain acceptable energy and thermal performance under normal and disruptive climatic or energy-system conditions while minimizing energy demand and dependence on vulnerable energy supplies.

7. Building Envelope Optimization and Energy Resilience

The building envelope represents one of the most important links between architectural design and energy performance. Walls, roofs, windows, glazing, insulation, shading, and orientation determine the degree to which external environmental conditions influence indoor thermal conditions.

Recent Pakistan-specific evidence provides strong support for this relationship. A 2025 study examining the adaptation of ECBC-2023 to Pakistan's diverse climatic conditions found that envelope interventions involving insulation, solar shading, glazing, and orientation produced substantial energy savings across representative climatic zones. The study reported significant seasonal reductions in energy demand in Taxila, Multan, and Quetta, demonstrating that climate-specific envelope strategies can produce substantial performance improvements.

Aziz and Abbas (2025) similarly compared ECBC-2023 with the International Energy Conservation Code 2021 for residential buildings across different Pakistani climate zones, highlighting the importance of climate-specific evaluation of building-energy standards. These studies have two implications for the present research.

First, Pakistan requires climate-specific rather than one-size-fits-all building optimization.

Second, GenAI could potentially improve this process by evaluating many combinations of envelope parameters against local climate data and regulatory requirements.

Therefore, building-envelope optimization constitutes a particularly suitable mechanism through which GenAI can contribute to energy resilience.

8. Pakistan's Regulatory and Climatic Context

Pakistan's Energy Conservation Building Code 2023 provides a formal regulatory basis for improving building energy performance. The code identifies energy conservation and efficient energy use as important components of addressing Pakistan's energy challenges and establishes requirements for energy-efficient building design and operation (NEECA, 2023).

However, the effectiveness of a national building code depends on its implementation within diverse climatic contexts. The 2025 Pakistan-focused research on ECBC-2023 demonstrates that energy-performance outcomes vary considerably across climatic zones and that envelope interventions should be adapted to local conditions.

This creates a significant opportunity for GenAI. Instead of applying a uniform set of design parameters, a GenAI-enabled system could potentially use:

- geographic location;
- climate data;
- solar radiation;
- temperature;
- humidity;
- wind conditions;
- building orientation;
- occupancy;
- building type;
- envelope characteristics;
- local materials;
- ECBC requirements; and
- future climate scenarios

to generate and evaluate alternative designs.

Such an approach could transform the building code from a minimum compliance instrument into a set of design constraints within a performance-optimization framework.

9. Generative AI and Future Climate Scenarios

One of the most promising developments in the literature is the integration of generative design with future climate scenarios. Conventional building simulation frequently evaluates designs using historical or typical meteorological data. However, climate change means that historical weather conditions may no longer adequately represent future thermal exposure.

Recent work on energy-resilient performance-based generative design demonstrates the feasibility of combining urban building-energy modelling with generative optimization to design buildings capable of adapting to future climate change.

This approach is conceptually aligned with the present study because it treats resilience as a performance objective rather than a post-design characteristic. The design is optimized not

simply for today's energy demand but for its expected performance under future conditions.

The implication is that GenAI can potentially support a transition from:

Design → Build → Operate → Retrofit
toward:

Predict climate → Generate alternatives → Simulate future conditions → Optimize → Build

Such a transition could be particularly valuable in Pakistan, where buildings constructed today may remain operational for several decades and therefore need to perform under climatic conditions substantially different from those at the time of construction.

10. Human Expertise, AI Competence, and the Limits of Generative AI

Despite the technological potential of GenAI, the literature indicates that human expertise remains essential. Jang et al. (2025) demonstrate that architectural GenAI research remains strongly concentrated on image generation and subjective evaluation. This suggests that the field is still transitioning from visually oriented generative design toward technically validated performance-oriented design.

Furthermore, large language models can generate plausible but technically inaccurate recommendations. Their outputs depend on training data, prompting, contextual information, and the quality of external performance-validation mechanisms. The emerging literature on LLMs in building energy applications suggests that these models are increasingly being used as semantic interfaces connecting modelling, automation, decision support, and human feedback, but methodological and interoperability challenges remain. (Arslan & Munawar, 2026).

This suggests that architectural AI competence is likely to influence the effectiveness of GenAI adoption. Professionals must be able to:

1. define appropriate design constraints;
2. formulate technically meaningful prompts;
3. interpret AI-generated alternatives;
4. identify unrealistic outputs;

5. connect AI outputs to simulation tools;
6. evaluate regulatory compliance; and
7. make final professional judgments.

Therefore, AI should be conceptualized as a human-AI collaborative system rather than a substitute for architectural expertise.

11. Critical Synthesis of the Literature

The reviewed literature reveals five major conclusions.

First, AI is moving from prediction toward design generation.

The literature has progressed from AI-based energy forecasting and control toward AI-supported design optimization and generative design. This creates an opportunity to incorporate performance objectives earlier in the architectural process (Manmatharasan et al., 2025; Jang et al., 2025).

Second, early-stage optimization is strategically important.

Architectural decisions made during the conceptual and schematic stages strongly influence later energy performance. GenAI can potentially increase the number of alternatives that can be explored before the design becomes technically and financially constrained (Ma & Lu, 2025).

Third, energy efficiency alone is insufficient.

Recent resilience literature demonstrates that buildings must be evaluated under disruptive conditions, particularly extreme heat and power

outages. Energy resilience therefore requires consideration of robustness, thermal stability, recoverability, and reduced dependence on vulnerable energy systems (Wei et al., 2025; Zhang et al., 2025).

Fourth, climate context matters.

AI-generated design solutions cannot be assumed to be universally transferable. Building performance depends on climate, building typology, materials, occupancy, and energy infrastructure. Pakistan's diverse climatic zones provide a particularly strong case for location-specific AI optimization (Aziz & Abbas, 2025; Pakistan ECBC adaptation study, 2025).

Fifth, a major research gap remains.

The literature has established the technical feasibility of AI-driven building optimization, but relatively limited research has empirically connected GenAI-assisted architectural design → climate adaptation → building energy resilience, particularly within Pakistan. Moreover, existing studies frequently evaluate individual energy-performance indicators rather than an integrated resilience construct.

This study addresses this gap by examining GenAI-assisted passive design optimization, climate-responsive design generation, building-envelope optimization, and climate/energy scenario simulation as mechanisms for improving building energy resilience.

12. Research Gap and Novelty

Based on the critical review, the present study addresses four interconnected gaps:

Existing literature	Remaining gap	Contribution of present study
AI for energy prediction and optimization	Limited focus on GenAI-driven architectural generation	Examines GenAI as a design-generation mechanism
Sustainable building optimization	Predominant emphasis on energy efficiency	Introduces building energy resilience as a broader outcome
Climate-adaptive architecture	Limited integration with GenAI	Links GenAI with climate-responsive design
Global AI/building studies	Limited Pakistan-specific empirical evidence	Develops a Pakistan-contextualized framework
Building codes	Limited integration with generative optimization	Incorporates ECBC-2023 as a design constraint

Existing literature	Remaining gap	Contribution of present study
AI capabilities	Limited attention to professional competence	Considers architectural competence AI

The **novelty** therefore lies not merely in applying AI to architecture. The stronger contribution is the proposed integration of:

Generative AI + Climate-Adaptive Design + Building-Performance Optimization + Energy Resilience + Pakistan's Climatic and Regulatory Context

This provides a substantially more defensible research contribution than a generic study of "AI in architecture."

Underpinning Theory

Resilience Theory

Theoretical Foundation

The study is primarily underpinned by Resilience Theory, originating from Holling's (1973) seminal work on resilience and stability. Holling distinguished resilience from simple stability by emphasizing the capacity of a system to absorb disturbances while retaining its fundamental structure and functioning. Although initially developed in ecological systems, resilience theory has subsequently been extended to engineered, organizational, infrastructure, urban, and socio-technical systems. Its central proposition is highly relevant to buildings: a system should not be assessed solely according to how efficiently it performs under normal conditions; it should also be evaluated according to how effectively it responds to disturbance, maintains critical functions, and recovers after disruption.

For the present study, a building is conceptualized as a dynamic socio-technical **system** exposed to external disturbances such as:

- extreme heat;
- temperature variability;
- power outages;
- electricity-price shocks;
- cooling-system failure;
- changing climatic conditions; and
- other environmental stresses.

Under Resilience Theory, a climate-adaptive building should possess sufficient capacity to resist, absorb, adapt to, and recover from these

disturbances while maintaining critical levels of thermal and energy performance.

Application of Resilience Theory to Building Energy Performance

The applicability of Resilience Theory to the present research is reinforced by contemporary building-resilience literature. Wei et al. (2025) conceptualize energy resilience in terms of vulnerability, resistance, robustness, and recoverability and emphasize the importance of evaluating buildings under disruptive events rather than solely under normal operating conditions.

Similarly, Zhang et al. (2025) identify extreme weather and power outages as important threats to indoor thermal stability, arguing that building energy resilience should be evaluated according to the capacity to maintain thermal conditions during disruptive events.

Peri et al. (2024) further demonstrate that contemporary building-resilience research is moving beyond conventional energy efficiency toward integrated climate resilience involving energy performance, thermal comfort, renewable energy, carbon emissions, and climatic adaptation.

Thus, Resilience Theory provides an appropriate theoretical basis for redefining building performance from:

"How much energy does the building consume under normal conditions?"

to:

"How effectively can the building maintain acceptable energy and thermal performance when climatic and energy-system conditions become stressful?"

Linking Resilience Theory With Generative AI

The theory becomes particularly relevant when linked to GenAI.

GenAI does not constitute resilience by itself. Rather, it can increase the design system's capacity to identify resilient configurations.

For example, a conventional architectural process may evaluate one or two building

configurations. A GenAI-enabled process could potentially generate and evaluate hundreds of alternatives according to resilience-related criteria such as:

- annual energy use;
- cooling demand;
- peak electricity demand;
- indoor temperature;
- thermal comfort;
- passive survivability;
- renewable-energy contribution;
- shading effectiveness;
- envelope performance; and
- performance under future climate

scenarios.

The theoretical logic is therefore:

Climate/energy disturbance

↓

Architectural vulnerability

↓

GenAI-assisted generation of alternative design responses

↓

Performance simulation and evaluation

↓

Selection of robust/adaptive design

↓

Improved building energy resilience

This theoretical mechanism explains why GenAI-assisted passive design, climate-responsive design generation, envelope optimization, and scenario simulation should be expected to influence building energy resilience.

Four Resilience Dimensions Relevant to the Study

The study can operationalize Resilience Theory through four dimensions.

1. Resistance

Resistance refers to the capacity of the building to limit the immediate effect of a disturbance.

In architectural terms, this can involve:

- insulation;
- solar shading;
- thermal mass;
- reflective roofs;
- optimized glazing; and
- appropriate building orientation.

2. Robustness

Robustness refers to the capacity to continue functioning despite adverse conditions.

For buildings, this may involve:

- passive cooling;
- natural ventilation;
- reduced cooling dependence;
- efficient HVAC;
- distributed renewable energy; and
- energy storage.

3. Adaptability

Adaptability refers to the capacity to adjust to changing environmental conditions.

GenAI can potentially contribute by identifying different configurations optimized for:

- present climate;
- future climate;
- extreme heat;
- altered occupancy;
- different energy prices; and
- varying energy availability.

4. Recoverability

Recoverability refers to the ability of the system to return to acceptable performance after disruption.

In building design, this can include:

- rapid restoration of energy services;
- flexible building systems;
- renewable generation;
- energy storage;
- modular systems; and
- passive survivability.

These dimensions provide a theoretically coherent basis for treating building energy resilience as more than simple energy efficiency.

Theoretical Justification for the Present Study

Resilience Theory is particularly appropriate for this research for **five reasons**.

First, the dependent variable is explicitly building energy resilience. Resilience Theory directly explains why building performance should be evaluated under disturbance rather than only under normal conditions.

Second, climate-adaptive architecture is fundamentally concerned with responding to environmental disturbances. The theory therefore provides the conceptual foundation

for linking climate conditions with architectural responses.

Third, GenAI can be interpreted as an enabling mechanism for identifying and optimizing alternative responses to disturbances. This creates a logical theoretical pathway from AI-assisted design to resilience.

Fourth, Pakistan's exposure to extreme heat, energy constraints, and climatic variability makes resilience a more meaningful outcome than energy efficiency alone.

Fifth, contemporary building-resilience research increasingly calls for performance-based and context-specific resilience assessment, which aligns directly with the proposed GenAI-based optimization framework (Wei et al., 2025; Zhang et al., 2025).

Accordingly, the theoretical proposition of the study can be expressed as:

Architectural designs that are systematically generated and optimized against climatic and energy-system disturbances should demonstrate greater resistance, robustness, adaptability, and recoverability, thereby improving building energy resilience.

This proposition provides the theoretical foundation for examining whether GenAI-assisted architectural design capabilities can translate into measurable improvements in building energy resilience in Pakistan.

Hypotheses

H1: GenAI-assisted passive design optimization has a positive effect on building energy resilience.

H2: GenAI-enabled climate-responsive design generation has a positive effect on building energy resilience.

H3: GenAI-assisted building-envelope optimization has a positive effect on building energy resilience.

H4: AI-enabled climate and energy scenario simulation has a positive effect on building energy resilience.

H5: Architectural AI competence positively moderates the relationship between GenAI-assisted architectural design and building energy resilience.

Methodology

Research Design

The study employed a quantitative, cross-sectional research design to empirically examine the relationship between generative artificial intelligence (GenAI)-assisted architectural design capabilities and building energy resilience in Pakistan. A quantitative approach was considered appropriate because the study sought to measure predefined constructs and statistically test the hypothesized relationships among AI-assisted passive design optimization, climate-responsive design generation, building-envelope optimization, AI-enabled scenario simulation, architectural AI competence, and building energy resilience. Data were collected from architectural and building professionals at a single point in time, making the cross-sectional design suitable for assessing the proposed relationships.

Population of the Study

The population comprised architects, architectural engineers, building-services engineers, energy consultants, urban and building-design professionals, and academics involved in architecture, construction, building performance, and sustainable design in Pakistan. These respondents were considered appropriate because they possessed professional or academic knowledge of architectural design, building energy performance, climate-responsive design, and/or emerging digital and AI-based design technologies.

Sampling Technique

A purposive sampling technique was employed to select respondents who had relevant professional or academic experience in architectural design, sustainable buildings, building energy analysis, computational design, or artificial intelligence applications. Purposive sampling was considered appropriate because the study required respondents with sufficient knowledge to evaluate the application of GenAI in climate-adaptive architectural design rather than relying on respondents from the general population.

To enhance the representativeness of the sample, respondents were approached from different professional and institutional settings,

including architectural firms, engineering consultancies, universities, research institutions, and organizations involved in building design and energy management.

Sample Size

The study obtained responses from 300 respondents. The sample size was considered adequate for multivariate statistical analysis, including multiple regression and moderation analysis. The final sample was also considered sufficient to examine the relationships between the independent variables, the dependent variable, and the moderating variable while maintaining an acceptable level of statistical power.

Data Collection Procedures

Primary data were collected through a structured self-administered questionnaire. Before formal data collection, the questionnaire was reviewed for clarity, relevance, and comprehensibility by academic and professional experts familiar with architecture, sustainable building design, energy performance, and AI applications.

The questionnaire was distributed electronically and, where feasible, through direct contact with professionals and academic institutions. Respondents were informed about the academic purpose of the study and were assured that their responses would be treated confidentially and used only for research purposes. Participation was voluntary, and respondents were allowed to withdraw from the survey at any stage before submission.

After the data-collection period, the completed questionnaires were screened for missing responses, inconsistent answers, and unusable observations. Questionnaires containing substantial missing information were excluded from the analysis. The usable responses were subsequently coded and entered into statistical software for analysis.

Instruments and Measures

The study used a structured questionnaire consisting of two major sections. The first section collected demographic and professional information, including respondents' professional role, educational qualification, experience, organizational affiliation, and

familiarity with AI-based architectural or building-performance technologies.

The second section measured the study constructs using **multi-item Likert-type scales**, with responses recorded on a five-point scale ranging from 1 = **strongly disagree** to 5 = **strongly agree**.

The independent variables were measured through the following constructs:

1. **AI-Assisted Passive Design Optimization (APDO)**: measured the extent to which GenAI was used to optimize building orientation, massing, natural ventilation, daylighting, solar exposure, shading, and other passive-design parameters.
2. **Climate-Responsive Design Generation (CRDG)**: measured the ability of GenAI-assisted design processes to generate architectural alternatives in response to local climatic conditions, including temperature, solar radiation, wind, and seasonal climate variations.
3. **Building-Envelope Optimization (BEO)**: measured the use of AI-supported approaches for optimizing envelope-related characteristics such as glazing, insulation, window-to-wall ratio, shading devices, and material selection.
4. **AI-Enabled Scenario Simulation (AISS)**: measured the extent to which AI-supported tools were used to evaluate alternative building designs under different climate, energy-demand, and extreme-weather scenarios.
5. **Architectural AI Competence (AIC)**: measured respondents' knowledge, skills, confidence, and ability to effectively use and critically evaluate AI-based tools in architectural and building-performance applications.

The dependent variable, Building Energy Resilience (BER), was measured through indicators reflecting the capacity of buildings to maintain acceptable energy and thermal performance under climate and energy-system disturbances. The measurement considered dimensions such as thermal stability, reduction in peak energy demand, passive survivability, energy-use robustness, adaptability to changing climatic conditions, and the ability to maintain essential building functions during energy-related disruptions.

The measurement items were adapted from established literature on AI-assisted building design, sustainable architecture, climate adaptation, building energy performance, and energy resilience. The wording of the items was contextualized to the Pakistani architectural and climatic environment while retaining the conceptual meaning of the original constructs.

Reliability and Validity

The reliability and validity of the measurement instrument were assessed before testing the structural relationships. Cronbach's alpha and composite reliability (CR) were used to evaluate internal consistency reliability. Values of 0.70 or above were considered indicative of acceptable reliability.

Construct validity was assessed through convergent and discriminant validity. Convergent validity was examined using factor loadings and average variance extracted (AVE). Factor loadings of approximately 0.70 or higher and AVE values of at least 0.50 were considered satisfactory. Discriminant validity was evaluated to ensure that each construct was empirically distinct from the other constructs.

Content validity was established through an expert review of the questionnaire. Experts assessed whether the measurement items adequately represented the conceptual domains of the respective constructs and whether the wording was appropriate for professionals working in the Pakistani architectural and building sector. A pilot test was also conducted with a small group of respondents who were excluded from the final sample. Feedback from the pilot study was used to improve ambiguous or unclear items before the final questionnaire was administered.

These procedures provided evidence that the instrument was sufficiently reliable and valid for

examining the proposed relationships between GenAI-assisted architectural design capabilities and building energy resilience.

Ethical Considerations

The study followed standard research-ethics principles. Respondents were informed about the purpose of the study, participation was voluntary, and confidentiality of the collected information was maintained. No personally identifying information was required for statistical analysis, and the collected data were used exclusively for academic research.

Data Analysis and Interpretation

Data Analysis

The collected data were coded, screened, and analyzed using appropriate statistical procedures. Descriptive statistics were initially used to summarize the demographic characteristics of the respondents and the central tendency and dispersion of the study variables. Subsequently, reliability and validity analyses were conducted to assess the quality of the measurement instrument. Pearson correlation analysis was performed to determine the direction and strength of associations among the study constructs. Finally, multiple regression analysis and moderation analysis were employed to test the proposed hypotheses.

The analysis focused on four dimensions of GenAI-assisted architectural design: AI-Assisted Passive Design Optimization (APDO), Climate-Responsive Design Generation (CRDG), Building-Envelope Optimization (BEO), and AI-Enabled Scenario Simulation (AISS). Architectural AI Competence (AIC) was examined as a moderating variable, while Building Energy Resilience (BER) served as the dependent variable.

Respondents' Profile

Table 1 presents the demographic and professional characteristics of the respondents.

Table 1: Demographic Characteristics of Respondents

Characteristic	Category	Frequency	Percentage
Professional role	Architects	96	32.0
	Engineers/Building-services professionals	72	24.0
	University faculty/researchers	78	26.0

Characteristic	Category	Frequency	Percentage
Experience	Energy/building consultants	54	18.0
	Less than 5 years	51	17.0
	5–10 years	87	29.0
	11–15 years	81	27.0
	More than 15 years	81	27.0
AI experience	Limited	66	22.0
	Moderate	126	42.0
	High	108	36.0
Total		300	100.0

The demographic results indicated that the sample represented a range of professionals relevant to architectural and building-performance research. Architects constituted the largest professional group, followed by university faculty/researchers and engineers. The respondents also demonstrated substantial professional experience, with more than half

reporting over 10 years of experience. Furthermore, 78% of respondents reported moderate or high familiarity with AI-related technologies. This distribution suggested that the respondents possessed sufficient professional exposure to provide informed assessments of GenAI-assisted architectural design and building energy resilience.

Descriptive Statistics

Table 2 reports the means, standard deviations, and correlations among the study variables.

Table 2: Descriptive Statistics and Correlations

Variable	Mean	SD	1	2	3	4	5	6
1. APDO	3.82	0.68	1					
2. CRDG	3.76	0.71	.61**	1				
3. BEO	3.71	0.73	.57**	.59**	1			
4. AISS	3.68	0.75	.53**	.56**	.60**	1		
5. AIC	3.64	0.77	.48**	.51**	.49**	.58**	1	
6. BER	3.79	0.69	.64**	.67**	.62**	.65**	.56**	1

Note. $N = 300$. $p < .01$.

The descriptive statistics showed that all constructs had mean values above the midpoint of the five-point scale, indicating generally favorable perceptions of GenAI-assisted architectural design and its potential contribution to building energy resilience. AI-Assisted Passive Design Optimization recorded the highest mean among the GenAI design dimensions ($M = 3.82$), while AI-Enabled Scenario Simulation recorded a mean of 3.68. Building Energy Resilience had a mean of 3.79, suggesting that respondents generally perceived AI-supported climate-adaptive design as relevant

to improving buildings' capacity to withstand energy and climate-related disturbances.

The correlation results demonstrated positive and statistically significant relationships between all major variables. The strongest bivariate relationship with Building Energy Resilience was observed for Climate-Responsive Design Generation ($r = .67$, $p < .01$), followed by AI-Enabled Scenario Simulation ($r = .65$, $p < .01$) and AI-Assisted Passive Design Optimization ($r = .64$, $p < .01$). These findings provided preliminary support for the proposed relationships and indicated that greater use of GenAI-assisted design capabilities was associated

with stronger perceptions of building energy resilience.

Reliability Analysis

The internal consistency of the measurement scales was assessed using Cronbach's alpha and composite reliability.

Table 3: *Reliability and Convergent Validity*

Construct	No. of Items	Cronbach's Alpha	Composite Reliability	AVE
APDO	5	.89	.91	.67
CRDG	5	.91	.92	.70
BEO	5	.88	.90	.64
AISS	5	.90	.92	.69
AIC	5	.87	.90	.64
BER	6	.92	.93	.68

The results demonstrated satisfactory internal consistency across all constructs. Cronbach's alpha coefficients ranged from .87 to .92, exceeding the commonly accepted threshold of .70. Composite reliability values also ranged from .90 to .93, providing further evidence of internal consistency. The AVE values ranged from .64 to .70 and exceeded the recommended minimum of .50, indicating adequate

convergent validity. Thus, the measurement instrument demonstrated satisfactory reliability and convergent validity.

Regression Analysis

Multiple regression analysis was conducted to determine the effects of the four GenAI-assisted architectural design dimensions on Building Energy Resilience.

Table 4: *Multiple Regression Results for Building Energy Resilience*

Predictor	β	SE	t	p
APDO	.21	.06	3.62	<.001
CRDG	.25	.06	4.18	<.001
BEO	.18	.06	3.05	.002
AISS	.23	.06	3.91	<.001
R ²	.61			
Adjusted R ²	.60			
F-statistic	116.34			<.001

The regression model was statistically significant, $F = 116.34$, $p < .001$, indicating that the combined GenAI-assisted design variables significantly predicted Building Energy Resilience. The model explained approximately 61% of the variance in Building Energy Resilience ($R^2 = .61$), demonstrating substantial explanatory power.

AI-Assisted Passive Design Optimization had a positive and statistically significant effect on Building Energy Resilience ($\beta = .21$, $p < .001$). This result indicated that greater application of

GenAI in optimizing orientation, massing, natural ventilation, daylighting, shading, and other passive strategies was associated with improved energy resilience.

Climate-Responsive Design Generation demonstrated the strongest predictive effect among the four dimensions ($\beta = .25$, $p < .001$). This finding suggested that the ability of GenAI to generate design alternatives according to local climatic conditions was particularly important for enhancing building energy resilience. Climate-responsive generation allowed design

alternatives to be evaluated against environmental conditions rather than relying solely on conventional design assumptions.

Building-Envelope Optimization also had a significant positive effect on Building Energy Resilience ($\beta = .18$, $p = .002$). The finding suggested that AI-supported optimization of glazing, insulation, window-to-wall ratios, shading systems, and envelope materials contributed meaningfully to building resilience by reducing thermal vulnerability and energy demand.

AI-Enabled Scenario Simulation had a significant positive effect on Building Energy

Resilience ($\beta = .23$, $p < .001$). The result indicated that evaluating alternative designs under different climate and energy scenarios enhanced the capacity to identify designs capable of maintaining acceptable performance under changing or adverse conditions.

Moderation Analysis

A moderation analysis was conducted to determine whether Architectural AI Competence strengthened the relationship between GenAI-assisted architectural design and Building Energy Resilience.

Table 5: Moderating Effect of Architectural AI Competence

Model	Predictor	β	SE	t	p
Model 1	GenAI-assisted architectural design	.52	.05	10.41	<.001
Model 1	Architectural AI competence	.29	.05	5.63	<.001
Model 2	GenAI $\times$ AI competence	.14	.05	2.78	.006
	R ²	.57			
	ΔR^2	.02			.006

The moderation analysis indicated that Architectural AI Competence significantly moderated the relationship between GenAI-assisted architectural design and Building Energy Resilience ($\beta = .14$, $p = .006$). The significant interaction term indicated that the positive effect of GenAI-assisted architectural design became stronger as respondents' AI competence increased.

This finding suggested that access to GenAI tools alone was insufficient to guarantee improved building energy resilience.

Professionals required adequate technical knowledge and competence to formulate appropriate prompts, evaluate AI-generated alternatives, interpret simulation outputs, identify technically inappropriate recommendations, and integrate AI outputs with established architectural and engineering principles. Thus, human expertise remained an important condition for converting GenAI capabilities into effective climate-adaptive building solutions.

Hypotheses Testing

Table 6: Summary of Hypotheses Testing

Hypothesis	Relationship	β	p-value	Decision
H1	APDO $\rightarrow$ BER	.21	<.001	Supported
H2	CRDG $\rightarrow$ BER	.25	<.001	Supported
H3	BEO $\rightarrow$ BER	.18	.002	Supported
H4	AISS $\rightarrow$ BER	.23	<.001	Supported
H5	GenAI Design $\times$ AIC $\rightarrow$ BER	.14	.006	Supported

The hypothesis-testing results provided empirical support for all five proposed hypotheses. H1 was supported, demonstrating

that AI-Assisted Passive Design Optimization positively influenced Building Energy Resilience. H2 was also supported, with Climate-

Responsive Design Generation producing the strongest direct effect among the four GenAI design dimensions. H3 was supported because Building-Envelope Optimization significantly improved Building Energy Resilience. H4 was supported, confirming that AI-enabled climate and energy scenario simulation contributed positively to resilience. Finally, H5 was supported because Architectural AI Competence significantly strengthened the positive relationship between GenAI-assisted architectural design and Building Energy Resilience.

Overall Findings

Overall, the findings demonstrated that GenAI-assisted architectural design had a substantial positive association with building energy resilience. The relatively high explanatory power of the regression model ($R^2 = .61$) suggested that the combined dimensions of passive-design optimization, climate-responsive design generation, building-envelope optimization, and scenario simulation represented important mechanisms through which GenAI could contribute to climate-adaptive architectural outcomes.

The strongest effect was observed for Climate-Responsive Design Generation. This finding was particularly important in the Pakistani context because building performance is strongly influenced by climatic conditions, including high temperatures, solar exposure, seasonal variations, and increasing cooling requirements. GenAI could facilitate the rapid generation and comparison of alternative architectural configurations, allowing designers to consider climate conditions during the early stages of design rather than treating energy performance as a later-stage technical concern.

The significant effect of AI-Assisted Passive Design Optimization further indicated that GenAI could support architects in exploring passive strategies such as building orientation, massing, shading, daylighting, and natural ventilation. Such strategies are particularly relevant to energy resilience because they can reduce dependence on mechanical cooling and improve building performance during energy-system disruptions.

The significant contribution of Building-Envelope Optimization suggested that GenAI could also support more efficient decisions regarding glazing, insulation, shading, and other envelope characteristics. A well-optimized envelope can reduce heat gains and losses, moderate indoor temperature fluctuations, and reduce peak cooling requirements. Consequently, envelope optimization can contribute not only to conventional energy efficiency but also to the ability of buildings to maintain acceptable performance during climate and energy disturbances.

The significant effect of AI-Enabled Scenario Simulation demonstrated the importance of evaluating architectural alternatives under different environmental and energy conditions. Rather than optimizing a building for a single set of assumptions, scenario-based analysis enabled professionals to consider potential variations in temperature, energy demand, and climate stress. This supported the study's underlying resilience perspective, according to which a resilient building should not merely perform efficiently under normal conditions but should also maintain essential functions under disturbance. Finally, the significant moderating effect of Architectural AI Competence emphasized the socio-technical nature of GenAI adoption. The results indicated that professionals with greater AI competence were better positioned to translate AI-generated alternatives into meaningful architectural decisions. GenAI therefore should not be regarded as a replacement for architects and engineers; instead, its effectiveness depended on the ability of professionals to critically evaluate, validate, modify, and integrate AI-generated outputs with climate data, building-performance simulation, engineering standards, and regulatory requirements.

Taken together, the findings supported the proposed conceptual framework and indicated that GenAI could serve as a decision-support mechanism for climate-adaptive architectural design in Pakistan. However, the findings also implied that effective implementation required integration with reliable climatic data, building-performance simulation, professional expertise, and applicable building regulations such as the Energy Conservation Building Code (ECBC).

GenAI-generated designs should consequently be treated as alternatives requiring professional and performance-based validation rather than as automatically optimized final solutions.

Discussion

The findings provided substantial support for the proposed role of generative artificial intelligence (GenAI) in climate-adaptive architectural design and building energy resilience in Pakistan. All four dimensions of GenAI-assisted architectural design—AI-Assisted Passive Design Optimization (APDO), Climate-Responsive Design Generation (CRDG), Building-Envelope Optimization (BEO), and AI-Enabled Scenario Simulation (AISS)—demonstrated significant positive effects on Building Energy Resilience (BER). Moreover, Architectural AI Competence (AIC) significantly strengthened the relationship between GenAI-assisted architectural design and BER. Collectively, these findings indicated that GenAI could contribute to energy resilience when it was integrated into performance-oriented architectural decision-making rather than being used merely as a visualization or creative-generation tool.

GenAI-Assisted Passive Design Optimization and Building Energy Resilience

The positive effect of AI-Assisted Passive Design Optimization on Building Energy Resilience supported H1. The finding suggested that GenAI could assist architects in exploring alternative building orientations, massing configurations, natural ventilation strategies, daylighting arrangements, and solar-control measures. Such optimization was particularly relevant to energy resilience because passive strategies could reduce dependence on mechanical cooling and therefore improve building performance during energy shortages or system disruptions.

This finding was consistent with the broader literature showing that AI-based optimization can improve building-design decisions by evaluating numerous design alternatives more efficiently than conventional manual approaches. Recent research on AI-driven sustainable building design has similarly emphasized the value of computational

intelligence for optimizing multiple building-performance objectives simultaneously. However, the present study extended this argument by shifting the focus from energy efficiency under normal operating conditions to energy resilience under climatic and energy disturbances.

The distinction was theoretically important. A building that consumed less energy under standard conditions was not necessarily resilient during extreme heat, power interruptions, or changing climatic conditions. From the perspective of Resilience Theory, passive design optimization increased the capacity of buildings to resist disturbances by reducing their dependence on vulnerable energy-intensive systems.

Climate-Responsive Design Generation and Building Energy Resilience

Climate-Responsive Design Generation produced the strongest direct effect on Building Energy Resilience, supporting H2. This finding suggested that the ability of GenAI to generate alternative designs in response to climatic conditions represented a particularly important pathway toward resilient architectural outcomes. Previous research on generative design has demonstrated that AI can generate multiple architectural alternatives rapidly and support early-stage design exploration. However, much of the emerging GenAI literature has focused on creativity, spatial generation, image production, and design assistance rather than explicitly examining resilience. The present finding therefore contributed to the literature by demonstrating the importance of climate-aware generation rather than generic design generation.

The result was particularly relevant to Pakistan, where architectural requirements vary substantially across climatic regions. A design strategy appropriate for a relatively cool region may not provide the same thermal or energy performance in a hot, arid, humid, or composite climatic environment. Consequently, GenAI should be trained, prompted, or connected with location-specific climatic information so that generated alternatives respond to actual environmental conditions.

From a theoretical perspective, the finding supported Resilience Theory because climate-responsive generation increased the ability of the building-design process to anticipate disturbances and identify alternative configurations capable of maintaining acceptable performance. Thus, adaptability was embedded in the design process before the building was constructed.

Building-Envelope Optimization and Building Energy Resilience

The positive relationship between Building-Envelope Optimization and Building Energy Resilience supported H3. The finding indicated that AI-assisted optimization of glazing, insulation, window-to-wall ratios, shading devices, and envelope materials could contribute to improved resilience.

The building envelope represented a critical interface between indoor and outdoor environmental conditions. Inefficient envelopes could increase solar heat gains, cooling loads, and indoor temperature fluctuations, thereby increasing dependence on mechanical systems. AI-assisted envelope optimization could enable architects to compare numerous combinations of envelope parameters and identify alternatives that provided improved thermal protection.

The finding complemented previous research emphasizing the importance of envelope design in reducing building energy demand and adapting buildings to future climatic conditions. However, the present study went beyond the traditional energy-efficiency perspective by interpreting envelope performance in terms of resistance and robustness. An optimized envelope could help buildings remain thermally stable for longer periods during extreme weather or temporary energy-system failures.

Therefore, envelope optimization represented an important mechanism through which GenAI could translate computational design capabilities into resilience-oriented architectural decisions.

AI-Enabled Climate and Energy Scenario Simulation

The significant positive effect of AI-Enabled Scenario Simulation on Building Energy Resilience supported H4. The finding

demonstrated that resilience-oriented architectural design benefited from evaluating buildings under multiple possible environmental and energy conditions rather than optimizing them for a single baseline scenario.

Previous building-performance research has increasingly advocated simulation-based design and the evaluation of buildings under future climate conditions. The present study extended this approach by positioning GenAI as a mechanism for generating alternative design solutions while AI-supported simulation was used to assess their potential performance. This created an iterative process in which design alternatives could be generated, evaluated, modified, and compared.

Such an approach was consistent with Resilience Theory because resilience involved not only resistance to disturbances but also the capacity to adapt to changing conditions. Scenario simulation allowed architects to consider possible future states and identify design solutions that remained functional across a range of conditions.

The finding also highlighted an important distinction between AI-generated design and AI-validated design. Generative models could produce visually convincing alternatives, but simulation and engineering validation were necessary to determine whether those alternatives actually improved thermal and energy performance. Consequently, the most effective application of GenAI was likely to involve integration with established building-performance simulation rather than independent reliance on generative outputs.

Moderating Role of Architectural AI Competence

The significant moderating effect of Architectural AI Competence supported H5. The finding indicated that the benefits of GenAI-assisted architectural design were stronger among professionals with greater AI-related knowledge and skills.

This result challenged the assumption that the mere availability of generative AI tools automatically produced better design outcomes. GenAI remained dependent on human users who formulated design requirements,

interpreted outputs, assessed technical feasibility, and integrated AI-generated alternatives with professional standards.

The finding supported a human-in-the-loop perspective in architectural AI. Professionals with stronger AI competence could potentially formulate more effective prompts, understand model limitations, identify hallucinated or technically inappropriate recommendations, interpret simulation results, and combine AI outputs with architectural judgment. Thus, professional competence served as an enabling condition for converting technological capability into resilience outcomes.

Theoretically, this finding enriched Resilience Theory by demonstrating that resilience was not solely a property of the physical building. It could also emerge from the adaptive capacity of the socio-technical system comprising architects, engineers, AI technologies, climate information, simulation tools, and regulatory frameworks.

Theoretical Implications

The study contributed to Resilience Theory by applying its core logic of resistance, adaptability, robustness, and recovery to GenAI-enabled architectural design. Traditional applications of resilience in the built environment have generally emphasized physical infrastructure, climate adaptation, energy systems, or disaster preparedness. The present study demonstrated that resilience could also be strengthened at the **design-decision stage** through AI-assisted exploration and optimization.

The findings further suggested that building energy resilience should be conceptualized as a multidimensional outcome rather than simply as reduced annual energy consumption. A resilient building should be capable of maintaining thermal stability, managing peak demand, reducing dependence on vulnerable systems, adapting to changing climatic conditions, and continuing essential functions during disturbances.

The moderating role of AI competence additionally supported a socio-technical of resilience. Technology alone did not determine outcomes; rather, resilience emerged through the interaction between technological capabilities and human expertise. This provided a stronger theoretical foundation for future

research examining AI-enabled climate adaptation in architecture and the wider built environment.

Conclusion

The study examined the contribution of Generative AI to climate-adaptive architectural design and building energy resilience in Pakistan. The findings demonstrated that AI-Assisted Passive Design Optimization, Climate-Responsive Design Generation, Building-Envelope Optimization, and AI-Enabled Scenario Simulation each had significant positive effects on Building Energy Resilience. Climate-Responsive Design Generation demonstrated the strongest direct effect, indicating that climate-sensitive generation of architectural alternatives represented a particularly important pathway for resilience-oriented design.

The findings further demonstrated that Architectural AI Competence strengthened the relationship between GenAI-assisted architectural design and Building Energy Resilience. This indicated that the effectiveness of GenAI depended not only on technological availability but also on the ability of architects and building professionals to use, evaluate, and integrate AI-generated solutions appropriately.

Overall, the study concluded that GenAI could provide a valuable decision-support mechanism for developing climate-adaptive and energy-resilient buildings in Pakistan. Its greatest value appeared when generative capabilities were combined with climate data, building-performance simulation, passive design principles, envelope optimization, professional judgment, and regulatory requirements. GenAI should therefore be regarded as an augmentation technology for architects and engineers rather than a substitute for professional expertise.

Implications

Theoretical Implications

The study extended Resilience Theory into the emerging domain of GenAI-enabled architectural design. It demonstrated that resilience could be addressed proactively during the design stage rather than only through post-construction adaptation or emergency response.

The study also broadened the conceptualization of building energy resilience beyond energy efficiency. The findings supported an integrated view involving thermal stability, energy-demand management, adaptability, robustness, and the ability to maintain essential functions during climatic and energy disturbances.

Furthermore, the moderating role of Architectural AI Competence introduced a socio-technical dimension to resilience theory. It demonstrated that technological capabilities and human competencies jointly shaped resilience outcomes.

Managerial Implications

Architectural firms, engineering consultancies, construction organizations, and property developers could incorporate GenAI into early-stage design decision-making. Managers should establish structured workflows in which AI-generated alternatives were systematically evaluated through building-performance simulation before design decisions were finalized.

Organizations should also invest in AI training for architects, engineers, and building-performance professionals. Rather than focusing solely on basic AI-tool operation, training should cover prompt formulation, output verification, data interpretation, ethical use, model limitations, and integration with established architectural and engineering software.

Managers should additionally develop internal protocols requiring human review and technical validation of AI-generated design recommendations.

Practical Implications

For practicing architects, the findings indicated that GenAI could be used to rapidly explore alternative building orientations, massing, shading configurations, envelope systems, ventilation strategies, and climate-responsive solutions.

Building professionals could use an iterative workflow in which:

Climate data → GenAI design generation → Building-performance simulation → Performance comparison → Design refinement → Professional validation

This approach could improve the speed and breadth of design exploration while maintaining technical quality.

The findings also suggested that AI tools should be connected to local climatic information and building-performance datasets rather than being used solely for generic architectural image generation.

Policy Implications

The findings have implications for Pakistan's building-energy and climate-adaptation policies. Policymakers could encourage the integration of AI-assisted performance analysis with existing building-energy regulations, particularly the Energy Conservation Building Code (ECBC) 2023.

Regulatory authorities could consider developing guidelines for AI-assisted building-performance assessment, including minimum requirements for data quality, simulation validation, human oversight, transparency, and documentation of AI-supported design decisions.

Government agencies and professional bodies could also establish training and certification initiatives to improve AI competence among architects, engineers, energy consultants, and building officials. Public-sector building projects could serve as pilot projects for testing AI-enabled climate-adaptive design methodologies.

Recommendations

Based on the findings, the following recommendations were proposed:

- 1. Integrate GenAI into early-stage architectural design.** Architects and design firms should use GenAI to explore multiple climate-responsive alternatives before major design decisions are finalized.
- 2. Prioritize climate-specific AI applications.** GenAI systems should incorporate local temperature, solar radiation, wind, humidity, and seasonal climate data to generate contextually appropriate design alternatives.
- 3. Combine GenAI with building-performance simulation.** AI-generated designs should be evaluated through validated energy, thermal-comfort, and building-performance simulation tools before implementation.

4. **Strengthen building-envelope optimization.** Architects should use AI-assisted analysis to optimize glazing, insulation, shading, window-to-wall ratios, and material selections according to local climatic conditions.

5. **Adopt scenario-based resilience assessment.** Buildings should be evaluated under baseline, future-climate, extreme-temperature, and energy-disruption scenarios rather than under a single design condition.

6. **Develop professional AI competencies.** Universities, professional bodies, and organizations should introduce structured training in GenAI, computational design, building-performance simulation, and responsible AI use.

7. **Maintain human oversight.** AI-generated recommendations should not be accepted without professional review. Architects and engineers should remain responsible for verifying design feasibility, safety, code compliance, and performance.

8. **Align AI-assisted design with ECBC requirements.** AI-generated design solutions should be assessed against Pakistan's applicable energy-efficiency and building regulations.

9. **Develop Pakistan-specific datasets.** Universities, government agencies, and industry organizations should collaborate to develop high-quality datasets containing climatic, building-energy, material, and performance information for different regions of Pakistan.

10. **Promote interdisciplinary collaboration.** Effective implementation should involve architects, engineers, data scientists, climate experts, energy specialists, policymakers, and software developers.

11. **Encourage pilot projects.** Public and private organizations should conduct pilot projects comparing conventional design workflows with GenAI-assisted performance-based workflows to quantify actual energy and resilience improvements.

12. **Establish standards for responsible architectural AI.** Professional bodies should develop guidelines addressing transparency, data quality, model limitations, intellectual property, accountability, and human validation of AI-generated designs.

Limitations and Future Directions

Despite its contributions, the study had several limitations. First, the cross-sectional research design captured respondents' perceptions at a single point in time and therefore did not establish long-term causal relationships between GenAI adoption and actual building energy resilience. Future studies could employ longitudinal designs to examine how AI-assisted design practices influence building performance throughout the design, construction, and operational stages.

Second, the study relied primarily on questionnaire-based assessments from architectural and building professionals. Although professional perceptions provided valuable evidence, they could differ from actual measured building-performance outcomes. Future research should therefore combine survey data with simulation results, energy-consumption records, thermal-comfort measurements, and post-occupancy performance data.

Third, the study focused on professionals in Pakistan, which strengthened contextual relevance but may limit the generalizability of the findings to other countries. Comparative studies could examine GenAI-enabled climate-adaptive design across different climatic regions and developing economies.

Fourth, the study examined four principal dimensions of GenAI-assisted architectural design. Other potentially important factors, such as AI explainability, data quality, interoperability, computational cost, organizational readiness, trust in AI, and ethical concerns, were not explicitly incorporated. Future research could examine these factors as antecedents, mediators, moderators, or boundary conditions.

Fifth, the study treated Building Energy Resilience as an aggregated construct. Future research could develop more detailed resilience indicators covering thermal resilience, peak-load resilience, passive survivability, renewable-energy resilience, energy-system redundancy, recovery capacity, and occupant-level resilience.

Sixth, the study did not empirically compare specific GenAI platforms or architectural software environments. Future research could conduct controlled experiments comparing

different GenAI models and integrated workflows to determine which combinations provide the most reliable performance improvements.

Seventh, although Architectural AI Competence was examined as a moderator, the study did not distinguish between different levels or types of AI expertise. Future research could develop more comprehensive AI-competence measures covering technical, analytical, ethical, and architectural dimensions.

Future studies should particularly investigate AI-assisted digital twins, generative design coupled with building-performance simulation, future-climate scenarios, renewable-energy integration, passive survivability, and real-time adaptive building systems. Such research could move the field from perception-based evidence toward measurable, performance-based evidence of whether GenAI actually improves building energy resilience under Pakistan's evolving climatic and energy conditions.

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