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Investigating Climate Risk Impacts on Architecture to Formulate Adaptive Design Strategies for Storm Resilience

Phuc Dao Hong[1]

Abstract

Increasing frequency and intensity of storms, driven by climate change, present significant challenges to architectural resilience in vulnerable regions. Adaptive design strategies, which integrate risk-informed architectural responses, have become essential for reducing structural and social vulnerability. This research focuses on evaluating climate risk impacts on the built environment and formulating adaptive design approaches for storm resilience. The primary objective is to identify architectural modifications that enhance safety, durability, and functional continuity during extreme weather events. Data collection involved semi-structured interviews with 245 local residents in storm-prone coastal areas to understand practical adaptation strategies and community-level perceptions of structural vulnerability. Analysis employed a mixed-methods approach, combining qualitative thematic coding of interview responses with quantitative assessment of structural and environmental risk indicators. Key metrics included material durability (MD), Roof reinforcement effectiveness (RRE), Wall reinforcement effectiveness (WRE), spatial layout effectiveness (SLE), and drainage efficiency (DE). Correlation and regression tests were conducted using SPSS to evaluate relationships between climate exposure variables and architectural adaptation measures. Results reveal that adaptive architectural strategies, including storm-resistant materials, significantly enhance storm resilience. T-tests show higher mean scores for adaptive measures (SLE: 4.1, DE: 4.2) compared to traditional designs. Chi-Square and Analysis of Variance (ANOVA) confirm significant differences, while multiple regression and correlation analyses highlight RRE, DE, and SLE as key predictors, emphasizing spatial layout, drainage efficiency, and storm-resistant materials in reducing vulnerability. In conclusion, the research underscores the value of combining empirical climate data, architectural assessment, and community experience to formulate practical adaptive design strategies.

Keywords: *Climate Risk, Adaptive Architecture, Storm Resilience, Structural Vulnerability, Design Strategies, Disaster Preparedness*

Introduction

Climate change has become one of the most significant global issues of the 21st century, which further exacerbates the frequency and severity of storms, cyclones, hurricanes, excessive rainfall as well as coastal flooding. These increasing and aggressive climate risks have a direct impact on the built environment, which is exposing the vulnerability of the long-standing methods of building architecture and has become emblematic of the high-adaptive design requirements [1]. Buildings are the first line of defense against the extreme weather conditions; since they were destroyed and rejected the risk the storms represented, they have turned into a vital determinant of sustainable development [2]. Architectural resilience is not cited as structural durability anymore; it takes into consideration a holistic strategy of environmental, technological and socio-economic dimensions [3]. Architectural resilience to storms needs to foresee the uncertainty of the climatic conditions, comprehend place-related risks, and implement the design approaches to the minimal losses, be operational in the disruptive times, and facilitate quick recovery measures [4]. The rising sea level, wind pressures, storm surge, and long-term flooding require new solutions or solutions like high-rise buildings, permeable surfaces, adaptable forms to wind, hardened material choices, and intelligent controls [5]. The objective of these strategies is the protection of not only physical structures but also human life, vital services and the welfare of the community. Figure 1 shows a cyclic model of strengthening the architectural structure against storming effects. It focuses on four major stages: Resilient Reconstruction, Risk-Preventive Design, Rapid Response and Post-Storm Recovery. The phases are associated with the specific strategies that focus

[1]Marlborough College Malaysia; mrphucdao2007@gmail.com (corresponding author).

on hazard assessment, performance evaluation, vulnerability analysis, and adaptive design implementation, with the emphasis on the integrated approach to structural vulnerability decrease and facilitating the storm-resilient architecture.

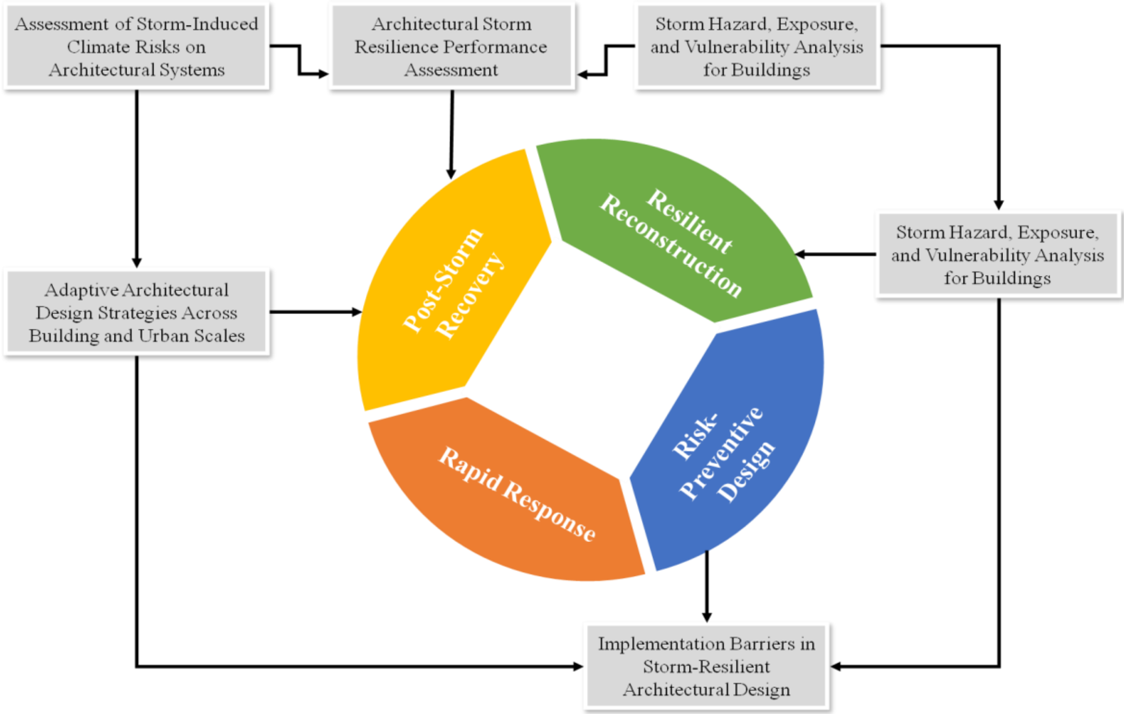

Figure 1:Framework of Storm-Resilient Architectural Strategies for Adaptive Design.

Additionally, adaptive architecture underlines that buildings have to adapt accordingly to dynamic climatic conditions instead of being fixed [6]. These include dynamic design processes, performance-based design processes and continuous feedback systems, which improve the resiliency with time. Adaptive design is also enhanced by incorporating local knowledge, ecological principles and vernacular practices that offer solutions that are specific to context and culturally appropriate [7]. As the threats of climate augmentation grow, it is important that architects, planners, engineers, and policymakers should join hands to come up with mechanisms that will incorporate resilience in not only new buildings but also the conversion of current buildings [8]. By developing conversation-based adaptive design models founded on climate-related (scientific) knowledge and creative architectural reasoning, the built environment can be able to shift its vulnerability perspective to resilience [9]. Designing to endure the storm creates the precedent to discuss extremely workable, generalizable, and long-term resilient architectural solutions to hazards produced by nature.

Although the focus on climate-adaptive architecture and storm-resilience buildings is increasingly common, there are still a number of constraints [10]. The costs of implementation are high and not all people could access more sophisticated materials and the technology itself is restrictive. Climate data is not well obtained in many areas, minimizing the predictive design approaches. Renovation of a current structure is a hard task to do in practice, and the relevant legal authority structures tend to be outpaced by the changing realities of climate change. Secondly, socio-economic inequality denies vulnerable communities the value of equal benefits, thus constraining the value of resilient architectural delivery on the scale. The aim was to evaluate climate risk impacts on the built environment and develop adaptive architectural design strategies that improve structural safety, durability, and operational continuity, ultimately strengthening storm resilience and supporting sustainable, future-ready built environments.

Key Contribution of the Research

Data Collection: 245 residents in storm prone coastal locations were interviewed using semi-structured interviews to collect local perceptions, practical strategies of adaptation, and structural vulnerability based on views as a way of informing climate resistant architectural response to the climate.

- **Key Variables:** MD, RRE, WRE, SLE, and DE were measured in order to determine architectural resilience and steer the adaptive design directions towards extreme weather.
- **Data Analysis:** Mixed-methodology of qualitative/quantitative analysis through thematic coding on data followed by quantitative analyses, which involve correlation analysis, multiple regression, t-test, ANOVA and chi-square as a measure of relations and predictors of practical architectural measures and group differences.
- **Findings:** There are significant advantages with adaptive techniques, particularly roof reinforcement, drainage effectiveness and spatial arrangement, which enhance the storm resilience. T-tests, ANOVA, and regression prove the validity of these measures in decreasing vulnerability and development of structural performance in times of extreme events.

The structural framework of the work is listed as follows: A list of literature reviews was provided in Section 2. The method is explained in Section 3. Section 4 presents the results, while Section 5 contains the discussion. Section 6 provides the conclusion.

Related Works

The generalized approach to resilience-based construction materials that combines climate risk assessment, multi-criteria material assessment, innovation pathway, and governance was examined by [11]. The outcome is a roadmap of organized infrastructure that is delivered through climate responsive infrastructure with sturdy, sustainable and adaptable materials, increasing environmental and social economic resilience in the long term. The systematic cluster and justified climate adaptation actions employing the principles of Risk Management, Asset Management and Urban Resilience Evaluation were analyzed by [12]. The Built Environment, Open Spaces, Buildings, and user adaptive design approaches and flood reduction strategies were investigated in [13]. The outcome offers a compounded insight into the adaptive practices and urban plans that facilitate realistic and climate adaptive architecture and cities.

The Climate Resilience Assessment Framework, based on scoring the capacity of buildings to predict, survive and recover following climate risks through exposure-regulated, weighting and qualitative measures, was investigated by [14]. Findings indicate flexibility to a variety of climates, which can be used as a standard of resilience and aid in climate-resilient design, stock analysis of buildings and well-informed decisions. The holistic model that incorporates the principles of resilient design into low-cost housing to improve its flood resistance, energy consumption, and disaster preparedness was explored by [15]. The findings indicate that implementation of the Resilient Design Principles (RDP) contributes to a large extent towards enhancing sustainability, mitigating the risks imposed by climate as well as enhancing community safety. The climate change effects on housing and development by means of an in-depth examination of the architectural, environmental, health and socio-economic literature, and flood-related case studies in Pakistan were examined by [16]. The findings report 14 housing flaws of vital importance and postulate adaptive, community-aware approaches to resilient housing to be applied internationally. Table 1 shows the overview of research addressing climate risk impacts and adaptive strategies.

Table 1: Summary of Related Works on Climate-Resilient Architectural Design.

Reference No.	Aim	Result	Advantages	Disadvantages
[17]	To develop a holistic framework for enhancing climate-resilient urban infrastructure through comprehensive Climate Risk Assessments, innovative engineering, resilient supply chains, and digital technologies.	Integrated, stakeholder-driven strategies significantly improve infrastructure durability, sustainability, and equity, strengthening long-term urban climate adaptation.	Improves infrastructure resilience, sustainability, and equity; promotes stakeholder engagement; supports long-term adaptation.	May require high financial investment, complex coordination, and advanced technical expertise.

[18]	To explore how the design disciplines Architecture, Urban Planning, and Landscape Architecture can enhance Disaster Risk Reduction and post-disaster recovery through systems-based approaches.	Integrating design thinking into disaster management education strengthens community resilience, supports coordinated spatial responses, and improves long-term rebuilding capacity.	Enhances community resilience; improves spatial coordination; promotes interdisciplinary learning.	Implementation may be slow; it requires curriculum changes and stakeholder collaboration.
[19]	To analyze resilience strategies for coastal cities facing typhoon-related disasters under climate change.	Refined theoretical frameworks, improved quantitative assessment methods, adaptable structural and non-structural strategies, with identified gaps requiring advanced big data, Artificial Intelligence, and integrated modeling solutions.	Provides adaptable strategies; enhances planning accuracy; supports data-driven decision-making.	Needs advanced technology, data availability, and technical expertise; may be resource-intensive.
[20]	To develop a scientific, quantitative framework to assess urban stormwater resilience	Effectively converts qualitative indicators into precise values, offering reliable guidance for enhancing urban stormwater resilience.	Provides precise, quantitative assessment; supports decision-making; integrates multiple assessment methods.	Requires expert input for Delphi process; computationally intensive; may be complex for non-technical users.
[21]	To design sustainable and storm-resilient houses in Vietnam's coastal areas.	Validated design framework and tested prototype enhance energy efficiency and wind-resilience, offering practical guidelines.	Practical, tested solutions; improve energy efficiency and wind-resilience; applicable to local conditions.	It may be location-specific; construction costs may be higher than conventional designs.
[22]	To explore amphibious retrofit construction as an adaptive flood-resilience strategy for heritage buildings.	Buoyant retrofits provide culturally sensitive, affordable protection for vulnerable historic communities, preserving physical history and reducing climate-driven displacement.	Preserves heritage; cost-effective; adaptable to floods; culturally sensitive.	Retrofitting may be technically challenging, limited to specific building types, and require community acceptance.
[23]	To evaluate strategies for enhancing resilience in renewable energy infrastructure under climate risks, market volatility, and policy uncertainties.	Integration of energy storage, smart grids, diversified energy portfolios, and supportive policy frameworks strengthens	Enhances energy system resilience; supports sustainability; reduces vulnerability to climate and market changes.	Implementation cost may be high; it requires policy coordination and technological integration.

		adaptability and, robustness.		
[24]	To investigate how climate-related hazard exposure influences individuals' perceptions of climate change using survey data from 142 countries.	Hazard exposure consistently increases risk perception across eleven hazard types, with effects varying by country and hazard type.	Supports climate education; informs risk communication strategies; globally representative.	Perceptions may not always lead to action; variability across countries complicates interventions.
[25]	To examine the effects of risk perception and vulnerability on flood-resilient architecture.	Higher risk perception positively influences architectural adaptation, while greater vulnerability negatively impacts adaptation, acting as a barrier to effective flood resilience.	Highlights the role of human perception in adaptation; informs community-targeted interventions.	Vulnerability factors may limit effectiveness; context-specific findings may not generalize.

The resilience of pavements to climate change through assessing the vulnerability and evidence-based adaptation techniques, such as monitoring, structural design, materials, maintenance, and regulations, was explored by [26]. It defined the findings as the incorporation of adaptation strategies into the design standards, together with the increasing awareness among engineers of improving pavement performance and minimizing the environmental effects in the shifting climate conditions. The question of the resilience of urban drainage networks to future climate in Knoxville, Tennessee, USA, through the Storm Water Management Model (SWMM) with bias-corrected downscaled climate projections to urban drainage networks with bioretention cells was investigated by [27]. Findings show that carrying out bioretention surface area improvements gives the best benefit in terms of infiltration and reduction of surface overflow, which in turn improves system performance under the uncertainty of climate change. The Two-Stage Risk-Informed Decision-Dependent Resilience Planning (RIDDRP) model to improve the resiliency to ice storms through optimizing the allocation of resources was examined in [28]. The outcomes illustrate better investment options, effective use of dispatchable resources, and system readiness for extreme weather conditions.

Research Gaps

Regardless of the important contribution of the earlier research, some limitations exist. The structure of [11] is centered on the choice of materials, which is not empirically tested in a variety of climatic conditions. The qualitative-based assessment in [14] based on Smart Readiness Indicator implies that it might be less accurate in measuring resilience with the heterogeneous stock of buildings. Additionally, the flood-resilient architecture research in [25] is constrained by a small sample size of 35 participants in a single locality, reducing the generalizability of its findings to broader flood-prone regions. To address this, the research develops evidence-based adaptive design strategies by assessing climate risk impacts and proposing resilient architectural modifications that improve safety, durability, and functional continuity during extreme weather events.

Methodology

The research collected data using semi-structured interviews with 245 of the local residents to elicit viable strategies for adapting to altered conditions and views on the structural vulnerability. The important variables were MD, RRE, WRE, SLE and DE. The data were analyzed with the application of SPSS, quantitative/qualitative measures: correlation, multiple linear regression, t-tests and ANOVA were used to compare group means, and Chi-Square tests ranked the relations of categorical variables, which fully assessed adaptive strategies in architecture. Figure 2 illustrates the process linking climate risks to storm-resilient architecture strategies.

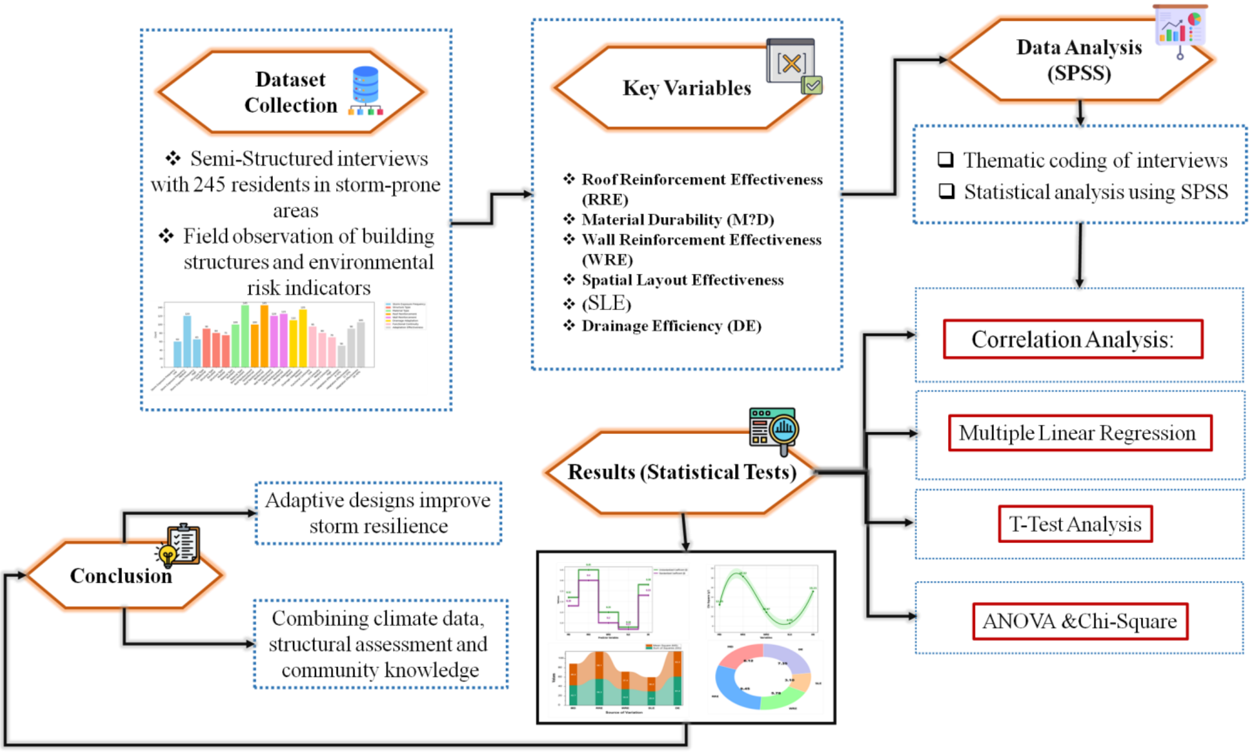

Figure 2: Climate Risk Impact Flow on Adaptive Architectural Design in Storm Resilience.

Data Collection

The data were collected using semi-structured interviews with 245 local residents who reside in storm-prone coastal communities to include the pragmatic methods of adaptation and the feeling of vulnerability in the community in terms of structure. The respondents were asked about the frequency of storm exposure, and 60 reported low (< 2 per year) exposure, 120 reported medium (3-5 per year) exposure and 65 reported high (>5 per year) exposure. Data of the structural type showed 90 normal unreinforced, 80 elevated and 75 modular layouts; material utilization data showed 100 average masonry and 145 storm-resistant materials. Participants also gave the information regarding the reinforcement of roofs and walls; 145 reinforced roofs and 125 reinforced walls, as well as 110 without the drainage adaptations and 135 with the drainage. The under storm functional continuity was rated as low (95), medium (80), or high (70), and the effectiveness of adaptations in mitigating the projected damage was rated as 0–10% (50), 1125% (90), or 2640% (105). Such mixed data made possible the assessment of technical and community-informed resilience metrics. Table 2 and Figure 3 provides an overview of participant, structural and adaptation effectiveness counts.

Table 2:Variable Distribution of Architectural Adaptations and Climate Risk Impacts.

Parameter	Category / Measurement	Count
Storm Exposure Frequency	Low (≤2 per year)	60
	Medium (3–5 per year)	120
	High (>5 per year)	65
Structure Type	Traditional unreinforced	90
	Elevated structures	80
	Modular layouts	75
Material Type	Standard masonry	100
	Storm-resistant materials	145
Roof Reinforcement	Unreinforced	100
	Reinforced	145

Wall Reinforcement	Unreinforced	120
	Reinforced	125
Drainage Adaptation	Absent	110
	Present	135
Functional Continuity	Low (high damage risk)	95
	Medium	80
	High (low damage risk)	70
Adaptation Effectiveness	Damage reduction 0–10%	50
	Damage reduction 11–25%	90
	Damage reduction 26–40%	105

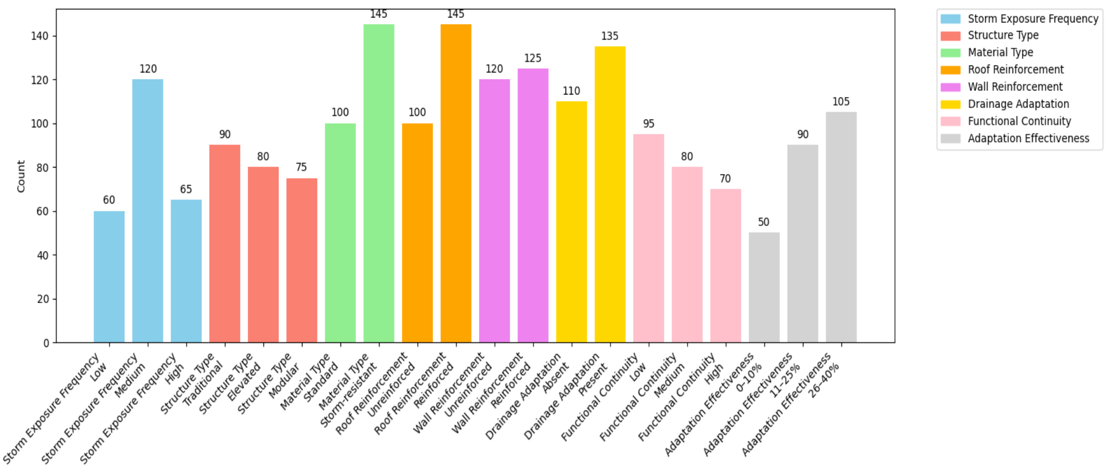

Figure 3:Distribution of Architectural Adaptations and Climate Risk Parameters.

Inclusion Criteria: The research involves 245 storm prone coast residents. The only buildings that were analyzed were those whose design was traditional unreinforced, elevated, or modular buildings and materials like typical masonry or storm resistant material. The most important ones are storm exposure frequency, reinforcement of roof and walls, material, drainage adaptation, effectiveness of spatial layout, effectiveness of functional continuity, and effectiveness of adaptations. They observed and interviewed in relation to community-informed adaptation mechanisms and feasible structural changes.

Exclusion Criteria: Areas that fell out of storm-prone coastal areas and residents who did not experience the effects of the storm directly were excluded. The non-structural adaptation activities, the global climate variables such as the trends in the temperatures or the humidity, and the simulation-based judgments without the field validation were not entertained. Structures with an insufficiency of survey data or community feedback and interventions that were not connected to storm resilience (e.g., aesthetical changes) were not included. The mixed-method on variables directly associated with structural performance and storm-adaptive design strategies was analyzed.

Key Variables

- **Material durability (MD)** - The measure assessed how the materials of construction react to extreme weather conditions, such as extreme winds, heavy rains and exposure to water. It gauges wear, corrosion, and structural integrity resistance, which guarantees stability over the long-term and reduces the cost of repair and replacement in the face of storms and post storm.
- **Roof reinforcement effectiveness (RRE)** - This is an assessment of the impact on roof constructions by reinforcing them, whether in material terms or designing to minimize the storm damages. It is premised on the resistance of winding uplifts, load-carrying capacity, and

elimination of leakages that ensure that the roof areas are not exposed to structural collapse, and water infiltration of interior areas.

- **Wall reinforcement effectiveness (WRE)** - This measure exudes the effect of increasing the strength of walls on the stability of a building during storms. Reinforced walls can withstand the lateral forces, do not collapse or crack, and increase the structural continuity. The assessment entails the quality of the materials, anchoring, and construction procedures that enhance the maximum ability of the building to withstand the maximum wind and impact load.
- **Spatial layout effectiveness (SLE)** - It tests the impact of room layout, orientation of the building, and the positioning of its structures on storm resilience. Good layouts make the use of wind effective, limit water pooling, and make evacuation easy, as well as cause minimal damage. Measurements can be dimensions, modularity, and safeguarding methods to provide increased functional and structural security.
- **Drainage efficiency (DE)** – This measure is used to determine how the building and site can manage the excessive runoff during rainy conditions or floods. It identifies the water logging, structural weakening, and interior water-way properties of what the drains, slopes, permeable surfaces, and retention systems have been able to withstand when the volume of water in transit surpasses and the risk to the property and occupants is diminished by chance.

Statistical Assessment

SPSS was used to analyze the data to assess the success of adaptive architectural strategies in improving storm resiliency. Correlation analysis was used to research the dependence between the variables of climate exposure and the main architectural adaptation measures and determine which of them is strongly linked with better resilience. The contributing role of individual measures of adaptation, including material durability, roof reinforcement, wall reinforcement, spatial layout and drainage efficiency, was quantified using Multiple Linear Regression Analysis, indicating the highest predictor of storm resistance. ANOVA was applied to determine the difference among the various groups in terms of the effectiveness of adaptation to establish whether adaptive designs were significantly better than traditional designs. The Chi-Square Test was used to test the relationship between the categories, including community-perceived vulnerability and using adaptive measures. Lastly, t-tests were used to compare the mean scores of adaptive and traditional architectural strategies as an affirmative of increased performance of adaptive measures. These SPSS analyses combined together made up strong, evidence-based information about climate-resilient building design.

Result

The relationships between the continual variables were analyzed with the help of Correlation Analysis to determine the strength and direction of the relationships between two variables to reveal whether the increase or decrease of one variable was related to the change of another variable. The Multiple Linear Regression Analysis was used to determine the effect of a combination of independent factors on a dependent outcome simultaneously, and the most important predictors and their corresponding contribution. ANOVA was used to ascertain whether the means of three or more groups were significantly different, which is useful in establishing variation between categories. The Chi-Square Test was used to test the relationship between categorical variables, allowing to determine whether the distributions that occurred were dissimilar to the expected models. Lastly, the t-test used was the comparison of means of two groups to show whether the differences between them were statistically significant. This set of tests created a multidimensional model of relationships to be analyzed, outcomes to be predicted and group differences to be compared. Some of the important variables were MD and RRE and WRE and SLE and DE, which reflected the strength-based design, optimization of design, and management of water. These indicators were quantifying the building's resilience, adaptive capacity, and effectiveness of architectural strategies to extreme weather and storm-related impacts.

Categorization of Structural Adaptation Performance Scores in Storm-Resilient Architecture

The findings categorize the architectural resilience variables based on a scoring pointer x, an indicator to reflect the normalized performance value (of between 0 and 1.0) of each of the parameters: Material Durability, Roof Reinforcement Effectiveness, Wall Reinforcement Effectiveness, Spatial Layout Effectiveness, and Drainage Efficiency. At a value of 0.2 to 1, the system has very low durability, reinforcement strength, spatial functionality, and drainage capacity, which demonstrates extremely high vulnerability. The range from $0.2 < x \leq 0.4$ is characterized by a poor performance in each of the variables that demonstrates the absence of resilience. The variation between the range of 0.4 and 0.6

points shows that it has mediocre architectural resilience, and this gives moderate protection against storms. Between x (0.6-0.8), there is high longevity of buildings, massive reinforcement of roofs and walls, effective space planning and drainage. The range of (0.8< x ≤ 1.0) shows that the performance of all the parameters is very high, implying that the structure and functional resistance to the storm hazards are optimum. These are the score ranges that can be used to impact certain adaptive design interventions. Table 3 presents the adaptation variable scores in five resiliency levels.

Table 3:Score Classification of Architectural Adaptation Variables for Storm-Resilient Design.

Score Range	MD	RRE	WRE	SLE	DE
$0 < x \leq 0.2$	*Very low* durability	*Very low* roof reinforcement	*Very low* wall reinforcement	*Very low* spatial effectiveness	*Very low* drainage efficiency
$0.2 < x \leq 0.4$	Low durability	Low roof reinforcement	Low wall reinforcement	Low spatial effectiveness	Low drainage efficiency
$0.4 < x \leq 0.6$	Average durability	Average roof reinforcement	Average wall reinforcement	Average spatial effectiveness	Average drainage efficiency
$0.6 < x \leq 0.8$	High durability	High roof reinforcement	High wall reinforcement	High spatial effectiveness	High drainage efficiency
$0.8 < x \leq 1.0$	*Very high* durability	*Very high* roof reinforcement	*Very high* wall reinforcement	Very high spatial effectiveness	Very high drainage efficiency

Correlation Analysis of Architectural Variables Influencing Storm Resilience

Correlation analysis may be used to determine the direction and strength of a relationship between both variables. Regarding climate risk and architecture, it is able to determine the relationship between variables such as material resilience or roof reinforcement and storm resilience in equation (1).

$$r = \frac{\sum \quad (X_i - \hat{X})(Y_i - \hat{Y})}{\sqrt{\sum \quad (X_i - \hat{X})^2 (Y_i - \hat{Y})^2}} \qquad (1)$$

The results of correlation indicate that there are positive relationships between the variables. MD-RRE has the greatest correlation of 0.68, then MD-WRE of 0.55 and lastly MD-DE of 0.50. There is also an outstanding correlation of 0.60 in RRE -WRE and 0.45 in RRE -DE. There are moderate correlations between WRE-DE, (0.42) and SLE; other relationships lie between 0.30 and 0.40. Altogether, the variables show the stable interdependence with each other, which means significant patterns of influence that are applicable to storm-resilient architectural strategies. Table 4 indicates the intensity of relationships between architectural variables that impact storm resilience.

Table 4: Correlation Matrix of Architectural Variables for Storm Resilience Assessment.

Variable	MD	RRE	WRE	SLE	DE
MD	1	0.68	0.55	0.40	0.50
RRE	0.68	1	0.60	0.35	0.45
WRE	0.55	0.60	1	0.30	0.42
SLE	0.40	0.35	0.30	1	0.38
DE	0.50	0.45	0.42	0.38	1

Multiple Linear Regression Results for Storm-Resilient Architectural Design Effectiveness

This is a technique of forecasting a dependent variable by using multiple variables as independent variables. To be storm resilient, it models the cumulative effect of drainage efficiency, wall reinforcement, and space layout towards architectural adaptation in equation (2).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \in \quad (2)$$

In a series of regressions, Unstandardized Coefficient (B) is obtained to demonstrate how a predictor varies storm resilience. Standard Error (SE) demonstrates B variability, Standardized Coefficient (β) shows comparison across variables, t-value provides evidence of significance of tests and p-value provides evidence of whether the effect is significant or not. The regression analysis shows that all predictors significantly contribute to storm-resilience design effectiveness. $MD\ (B = 0.32, SE = 0.08, \beta = 0.28, t = 4.00, p < 0.001)$ demonstrates moderate influence. RRE shows the strongest effect $(B = 0.45, SE = 0.07, \beta = 0.40, t = 6.43, p < 0.001)$. WRE also contributes meaningfully $(B = 0.25, SE = 0.09, \beta = 0.20, t = 2.78, p = 0.006)$. SLE indicates a smaller but significant impact $(B = 0.18, SE = 0.06, \beta = 0.17, t = 3.00, p = 0.003)$. DE provides a strong positive effect $(B = 0.38, SE = 0.08, \beta = 0.33, t = 4.75, p < 0.001)$. Overall, all variables significantly improve architectural resilience to storm risks. Table 5 and Figure 4 display the detailed statistical outputs showing predictors influencing storm-resilient architectural performance.

Table 5:Multiple Regression Results for Key Storm-Resilient Architectural Design Variables

$Predictor\ Variable$	$Unstandardized\ Coefficient\ (B)$	$Standard\ Error\ (SE)$	$Standardized\ Coefficient\ (\beta)$	$t - value$	$p - value$
MD	0.32	0.08	0.28	4.00	< 0.001
RRE	0.45	0.07	0.40	6.43	< 0.001
WRE	0.25	0.09	0.20	2.78	0.006
SLE	0.18	0.06	0.17	3.00	0.003
DE	0.38	0.08	0.33	4.75	< 0.001

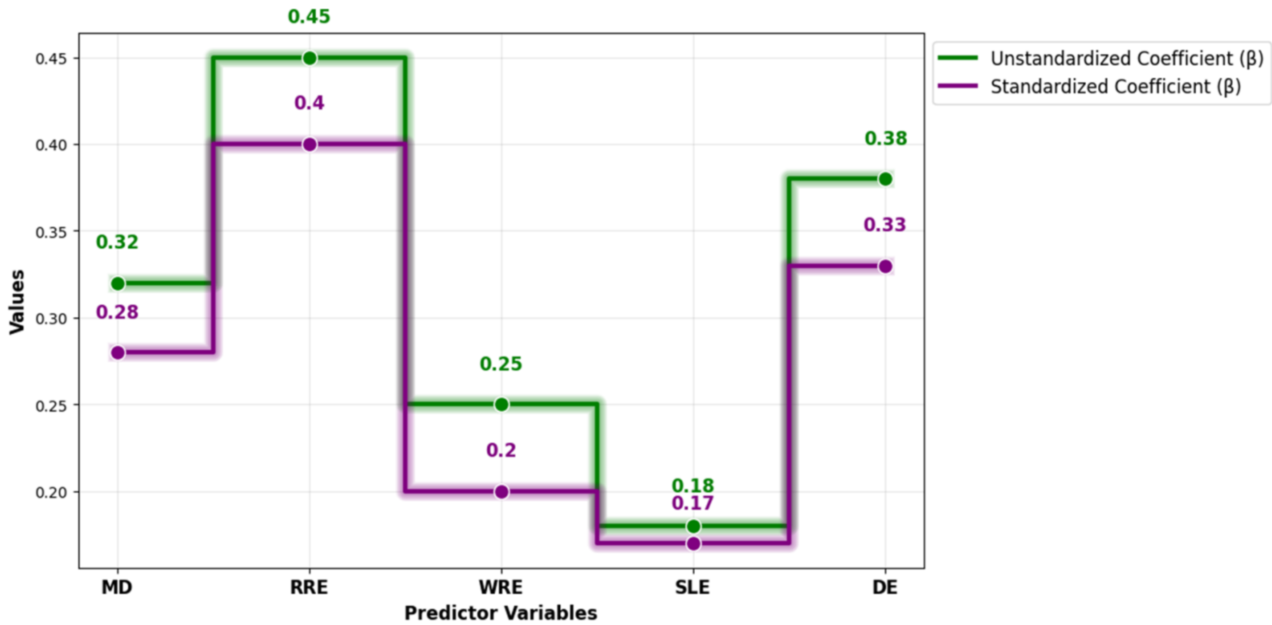

Figure 4: Regression Analysis of Architectural Variables for Storm Resilience.

ANOVA Evaluation of Key Variables for Storm-Resilient Architectural Design

ANOVA determines if the means of more than one group differ significantly from one another. For adaptive design, it can evaluate if different architectural strategies produce significantly different resilience outcomes in equation (3).

$$F = \frac{MS_{between}}{MS_{within}} = \frac{SS_{between}}{SS_{within}} \quad (3)$$

In ANOVA for storm-resilient design variables, the Sum of Squares (SS) measures total variability, Mean Square (MS) is SS divided by degrees of freedom, F-value compares between-group and within-group variance, and The probability that the findings happened by chance is indicated by the p-value; lower values (< 0.005) imply significance. The ANOVA results show that all five variables significantly influence adaptive architectural design for storm resilience. MD exhibits SS=42.7, MS=46.2, F=8.95, and p=0.004, indicating strong impact. RRE records SS=56.3, MS=58.1, F=11.80, and p=0.001, showing high effectiveness. WRE presents SS=34.5, MS=37.4, F=7.22, and p=0.009, confirming meaningful contribution. SLE displays SS=29.8, MS=30.2, F=6.23, and p=0.015, indicating moderate influence. DE shows the highest significance with SS=61.2, MS=62.2, F=12.83, and p=0.0005, emphasizing its critical role in storm-resilient design. Table 6 and Figure 5 illustrate an ANOVA evaluation showing variable significance in adaptive storm-resilient architectural design.

Table 6:ANOVA Summary Table for Key Storm-Resilient Architectural Design Variables.

$Source\ of\ Variation$	$Sum\ of\ Squares\ (SS)$	$Mean\ Square\ (MS)$	$F - value$	$p - value$
MD	42.7	46.2	8.95	0.004
RRE	56.3	58.1	11.80	0.001
WRE	34.5	37.4	7.22	0.009
SLE	29.8	30.2	6.23	0.015
DE	61.2	62.2	12.83	0.0005

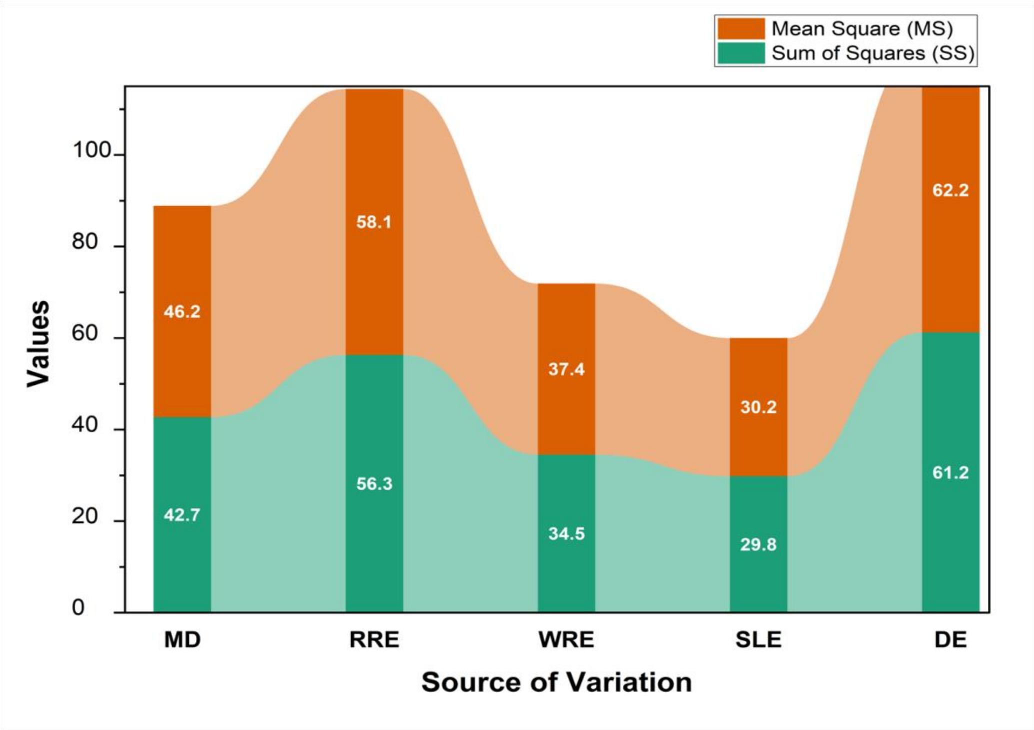

Figure 5:Analysis of ANOVA Variance for Key Storm-Resilient Design Variables

Chi-Square Climate risk on Architecture towards adaptive storms risks design

The chi-square test is used to test the relationship between variables that are categorical. In this context, it could test if building types or materials are significantly associated with storm damage frequency in equation (4).

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (4)$$

In chi-square analysis of architectural resilience variables, Chi-Square (χ^2) measures the p-value, indicating the likelihood that observed outcomes happened by chance; a lower value (< 0.005) indicates significance; degrees of freedom (df) represent the number of categories minus restrictions; and the difference between reported and expected frequencies. The chi-square analysis shows varied significance across architectural resilience variables. MD recorded $\chi^2 = 12.45$ with $df = 3$ and $p = 0.006$, indicating strong significance. RRE showed $\chi^2 = 18.32, df = 5, p = 0.002$, confirming a highly significant influence. WRE had $\chi^2 = 10.87, df = 2, p = 0.004$, also significant. SLE presented $\chi^2 = 8.56$ with $df = 6 \, and \, p = 0.201$, suggesting non-significance. DE yielded $\chi^2 = 15.21, df = 4, and \, p = 0.005$, indicating strong significance. Overall, MD, RRE, WRE, and DE significantly affect storm-resilient architectural performance, while SLE shows no statistical impact. Table 7 and Figure 6 show the chi-square statistical significance assessment of variables influencing storm-resilient architectural design.

Table 7:Chi-Square Statistical Results for Key Architectural Resilience Variables.

Variable	Chi-Square (χ^2)	Degrees of Freedom (df)	p-value
MD	12.45	3	0.006
RRE	18.32	5	0.002
WRE	10.87	2	0.004
SLE	8.56	6	0.201
DE	15.21	4	0.005

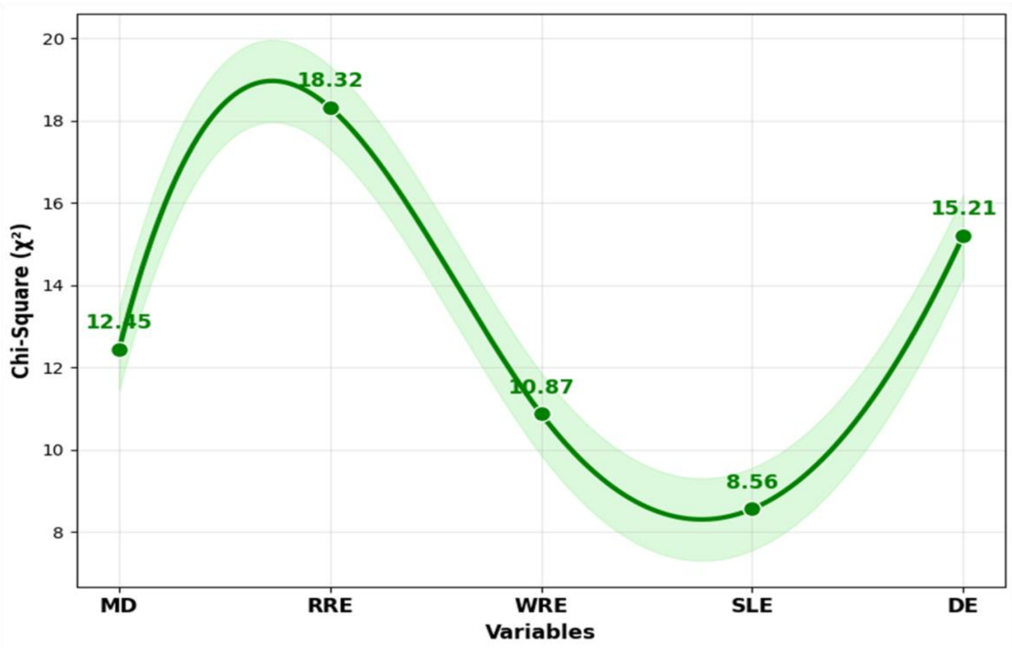

Figure 6:Chi-Square Analysis of Key Architectural Resilience Variables.

T-Test Analysis of Traditional vs Adaptive Architectural Strategies for Storm Resilience

A t-test determines whether there is a significant difference between two groups' means. For storm resilience, it could compare performance between traditional and adaptive design strategies in equation (5).

$$t = \frac{X_1 - X_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad (5)$$

In a t-test comparing traditional and adaptive architectural strategies, Group Means represent average resilience scores for each approach, The difference in relation to variability is measured by the $t - value$, df denotes degrees of freedom, and $p - value$ displays the probability that the observed outcomes were the result of chance; lower values (<0.005) suggest significance.The t-test results compare traditional and adaptive architectural strategies across five variables: MD, RRE, WRE, SLE, and DE. For MD, the mean increased from $3.2\ to\ 4.5$ with a $t - value\ of\ 6.12, df\ 184$, and $p < 0.001$, indicating significant improvement. RRE rose from $2.8\ to\ 4.8\ (t = 9.45, df = 144, p < 0.001)$, while WRE increased from $3.0\ to\ 4.3\ (t = 5.78, df = 153, p < 0.001)$. SLE showed a smaller but significant increase from $3.5\ to\ 4.1\ (t = 3.10, df = 182, p = 0.002)$. DE improved from $2.9\ to\ 4.2\ (t = 7.35, df = 189, p < 0.001)$. Overall, adaptive strategies significantly enhance all measured aspects of storm resilience. Table 8 and Figure 7 display the t-test statistical analysis of key variables for storm resilience effectiveness.

Table 8: T-test Comparison of Traditional and Adaptive Architectural Strategies

Variable	Group Mean (Traditional)	Group Mean (Adaptive)	t-value	df	p-value
MD	3.2	4.5	6.12	184	<0.001
RRE	2.8	4.8	9.45	144	<0.001
WRE	3.0	4.3	5.78	153	<0.001
SLE	3.5	4.1	3.10	182	0.002
DE	2.9	4.2	7.35	189	<0.001

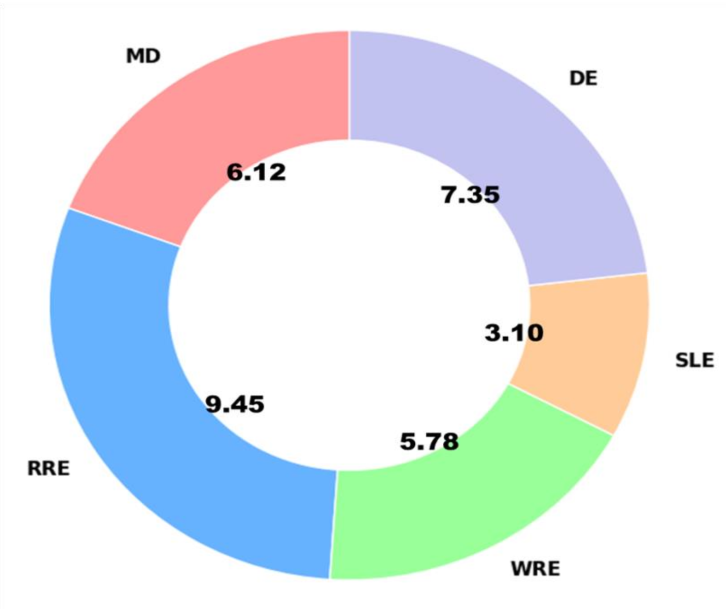

Figure 7:T-test Comparison of Traditional vs Adaptive Architectural Strategies.

Discussion

Storm frequency and intensity pose risks to the resilience of architectures because of climate change. This research examines the risk of climate on the structures and spatial arrangement to institute the adaptive design techniques that create greater storm-resistance, minimize structure weakness, and improve safety to promote sustainable, risk-proof architectural designs in prone areas. Significant correlations are evident in the analysis of the key structural variables of the storm resilience concerning the features of the design and adaptive performance. The applicability of Green Storm Infrastructure (GSI) employing the Storm Water Management Model (SWMM), such as biological retention and rain gardens, in boosting urban storm sewer resilience in a future climatic scenario was investigated by [29]. Findings indicate that GSI American Water -Results show that GSI decreases floods by 86 to 98 percent, pipe surcharging by 78 to 89 percent and noxious nodes by 75 to 90 percent, and as such, GSI is applicable to urban water management on a sustainable basis. The impact of the placement of Green Infrastructure (GI) on the resilience of urban drainage in Urban Drainage Systems (UDS) using Interpretive Spatial Data Analysis (ESDA) was investigated [30]. The result revealed that permeable pavements, and green roofs have different spatial autocorrelations, and clusters, indicating trade-offs of optimal location. There exist moderately high positive associations among variables, as the correlation matrix shows that MD has strong correlations with roof reinforcement effectiveness (RRE, r = 0.68) and wall reinforcement effectiveness (WRE, r = 0.55), which implies that strong materials and structural reinforcements are compared and correlated in achieving resilience. Results of multiple regression also support the significance of RRE (β = 0.40, t = 6.43, p < 0.001), drainage efficiency (DE, 2 = 0.33, t = 4.75, p < 0.001) as well as MD (2 = 0.28, t = 4.00, p < 0.001) in predicting storm-resilient performance, which shows that the material strength, reinforced roofing, and efficient drainage are significant. The explanations for these effects are confirmed by ANOVA, where reference to the most significant one, which is the DE, shows the highest F-value of F = 12.83, p = 0.0005, and in the second position, RRE which shows an F-value of F = 11.80, p = 0.001. The information presented in Chi-Square tests shows that MD (2 = 12.45, p = 0.006, df = 3), RRE (2 = 18.32, p = 0.002, df = 5), WRE (2 = 10.87, p = 0.004, df = 2), and DE (2 = 15.21, p = 0.005, df = 4) are significantly different at the category level. The traditional and adaptive designs have significantly higher mean scores in support of the effectiveness of adaptive interventions with t-tests comparing the traditional and adaptive designs indicating that very high scores were recorded in adaptive strategies, especially RRE ($4.8\ vs. 2.8, t = 9.45, p < 0.001$) and DE ($4.2\ vs. 2.9, t = 7.35, p < 0.001$). On the whole, the presented findings support the main role of reinforced materials, spatial arrangement, and draining in the attainment of storm-resilient architecture.

Conclusion

The rising incidence and severity of storms as a result of climate change pose risks to the safety of buildings. This paper will analyze climate risk issues in architecture with a focus on the application of adaptive design that promotes superior structural vulnerability and resilience, minimizes susceptibility, and provides safer and more sustainable built habitats. The data was gathered by semi-structure interviewing of 245 local residents, obtaining a range of practical skills of adaptation and social views of structural vulnerability by the community. Five main architectural variables were considered in the research, namely MD, RRE, WRE, SLE and DE. These variables have been chosen to assess structural, functional and environmental factors that affect the storm resilience. The analyses were done through SPSS, which encompassed correlation, multiple regression, ANOVA, Chi-Square and t-tests. The correlation analysis showed that variables have moderate and strong positive correlations where MD was strongly correlated with $RRE\ (r = 0.68)\ and\ WRE\ (r = 0.55)$. The multiple regression revealed that RRE ($\beta = 0.40, t = 6.43, p < 0.001$), DE ($\beta = 0.33, t = 4.75, p < 0.001$) and MD ($\beta = 0.28, t = 4.00, p < 0.001$) are significant factors that predict storm-resilient performance. The importance of these variables was proven by ANOVA and Chi-Square tests, but t-tests proved that adaptive architectural strategies worked much more successfully than traditional designs, in particular, in RRE ($4.8\ vs. 2.8, t = 9.45, p < 0.001$) and DE ($4.2\ vs. 2.9, t = 7.35, p < 0.001$). It has been stressed that the incorporation of strong materials, strengthened structural components, streamlined space design, and effective drainage systems makes a significant difference in the architecture's strength. These adaptive strategies can enhance the safety, functionality and disaster preparedness in storm prone areas. The shortcoming is that it is restricted by the focus it has on particular storm prone areas, and it might not represent all climatic changes within the globe. Generalizability may also be limited by the availability of data and the use of existing architectural practices. Future scope must also be able to accommodate a wide range of geographic settings, plan ad hoc the use of real time weather modelling, and experiment boldly with adaptive design using new materials and technologies.

Applicability can be improved by increasing the engagement of stakeholders, such as community-based resilience strategies. Also, proactive architectural planning of storm resilience and long-term climate adaptation will be helped by developing predictive tools and simulation frameworks to support the proactive architectural planning.

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