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Research Article

Adaptive Urban Morphologies in Semi-Arid Contexts: Integrating Architectural Intelligence and Planning Systems for Climate Resilience in North African Cities

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Abstract:

Urban resilience frameworks remain insufficiently adapted to semi-arid cities characterized by rapid urbanization, climatic stress, and hybrid formal– informal morphologies. This article identifies a structural gap in the integration of climate-responsive architectural strategies with urban-scale planning systems in North African contexts. It advances a morphology-driven analytical model linking spatial configuration, microclimatic performance, and socio-spatial adaptability. A mixed-method approach is employed, combining urban morphological analysis, environmental simulation, and comparative case studies. The study demonstrates that compact, climate- responsive morphologies significantly improve thermal comfort and reduce energy demand compared to fragmented expansion patterns. The findings support a transition from universal sustainability models toward context- specific, performance-based urban design frameworks.

1. Introduction

Urbanization in semi-arid regions is intensifying under conditions of environmental constraint, including rising temperatures, water scarcity, and increasing energy demand. Global planning paradigms, largely developed in temperate contexts, have been transferred to these regions without sufficient adaptation, resulting in spatial inefficiencies and environmental vulnerability.
North African cities present a layered urban structure shaped by pre-colonial medina fabrics, colonial planning systems, and post-independence informal expansion. These layers coexist without functional integration, producing fragmented urban environments. Architectural interventions frequently operate at the building scale without alignment with broader urban systems, limiting their effectiveness in addressing climatic challenges.This study positions urban morphology as the critical interface between architecture and urbanism, arguing that spatial configuration governs environmental performance and must be central to resilience-oriented design strategies.

2. Literature Review

2.1 Limitations of Conventional Sustainable Urbanism

Sustainable urbanism promotes density, mixed-use development, and transit- oriented planning. However, its application in semi-arid regions often neglects microclimatic conditions and local socio-spatial dynamics. Empirical studies indicate that high-density models without climatic adaptation can exacerbate heat stress.

2.2 Urban Climate and Microclimate Research

Urban climate studies demonstrate that morphology influences heat distribution, airflow, and radiation balance. The concept of Local Climate Zones (Stewart C Oke, 2012) provides a classification system linking urban form to climatic behavior, yet its application in North African contexts remains limited.

2.3 Informality and Hybrid Urban Systems

Informal urbanization constitutes a significant component of North African cities. Existing planning frameworks often exclude these areas, despite their adaptive spatial characteristics. Research suggests that informal morphologies may contain embedded resilience strategies, such as compactness and shading.

2.4 Gap Synthesis

The literature reveals three critical gaps:
Insufficient integration of microclimatic analysis into urban planning Limited coupling between architectural design and urban morphology Underrepresentation of semi-arid and Global South contexts in resilience frameworks

3 Research Problem and Objectives

3.1 Problem Statement

Urban development in semi-arid North African cities lacks a coherent framework linking spatial morphology, environmental performance, and architectural design, resulting in increased climatic vulnerability and inefficient urban systems.

3.2 Objectives

- To analyze the relationship between urban morphology and microclimatic performance
- To evaluate the role of architectural strategies within different spatial configurations
- To develop an integrated model for climate-responsive urban design in semi- arid contexts

3.3 Research Questions

- How do variations in urban morphology affect thermal comfort and energy performance?
- What is the effectiveness of architectural interventions when embedded within specific urban forms?
- How can traditional and contemporary spatial models be synthesized into a resilient urban framework?

4. Methodology

4.1 Research Design

A mixed-method approach combining quantitative simulation and qualitative spatial analysis is adopted.

4.2 Morphological Analysis

Urban fabrics are classified based on:

- Density (built-to-open space ratio)
- Street aspect ratio (height-to-width)
- Orientation and connectivity

4.3 Environmental Simulation

Simulation tools are used to evaluate microclimatic performance:

- ENVI-met for thermal behavior and airflow
- GIS-based solar analysis for radiation exposure

Key indicators:

- Air temperature
- Mean radiant temperature
- Physiological Equivalent Temperature (PET)

4.4 Comparative Case Study Approach

Three dominant urban typologies are analyzed:

- Traditional medina fabric
- Colonial grid system
- Contemporary peri-urban expansion

4.5 Validation Methods

- Field observations
- On-site temperature measurements (where available)
- Behavioral mapping of public space usage

5 Case Study Analysis

5.1 Traditional Medina Fabric

The medina represents a compact, inward-oriented morphology characterized by narrow streets and courtyard houses. This configuration reduces solar exposure and creates shaded microclimates. Thermal mass and limited surface exposure contribute to temperature stability. However, excessive density may restrict airflow under certain conditions.

5.2 Colonial Grid Systems

Colonial urbanism introduced orthogonal grids with wider streets and lower density. While improving circulation and visibility, these configurations increase solar gain and reduce shading. Buildings often lack climatic adaptation, resulting in higher cooling demands.

5.3 Contemporary Peri-Urban Expansion

Recent urban growth is dominated by low-density, fragmented development. This morphology leads to inefficient land use, increased reliance on private transportation, and poor environmental performance. Lack of vegetation and shading exacerbates heat island effects.

6 Results

6.1 Comparative Thermal Performance

Simulation results indicate:

- Compact morphologies reduce surface temperatures by measurable margins compared to dispersed layouts
- Street orientation significantly affects solar exposure
- Vegetation and shading elements improve thermal comfort across all typologies

6.2 Energy Implications

Buildings in climate-responsive morphologies exhibit lower cooling demand due to reduced heat gain and improved natural ventilation.

6.3 Socio-Spatial Adaptation

Traditional and informal environments demonstrate higher adaptability through flexible use of space and user-driven modifications.

7 Discussion

7.1 Morphology as a Determinant of Resilience

Urban form directly influences environmental performance. Compact, integrated morphologies provide passive climatic regulation, reducing dependence on mechanical systems.

7.2 Integration of Architecture and Urbanism

Architectural strategies must be embedded within urban systems. Building- level interventions are insufficient without alignment with spatial configuration.

7.3 Hybrid Design Model

A hybrid approach combining:

- Traditional compactness
- Modern infrastructure
- Climate-responsive technologies

is identified as the most effective pathway for resilience.

7.4 Implications for Policy and Planning

Planning regulations should incorporate:

- Climate-based design parameters
- Morphological performance indicators
- Inclusion of informal settlement strategies

8 Conclusion

Urban resilience in semi-arid North African contexts requires a shift from generalized planning models toward morphology-driven, climate-adaptive frameworks.The integration of architectural intelligence with urban planning systems enhances environmental performance and socio-spatial adaptability. Future research should extend this framework through parametric modeling and large-scale empirical validation.

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