

CLIMATIC CHALLENGES AND URBAN LANDSCAPE DESIGN RESPONSES IN HOT CLIMATES: INSIGHTS FROM NORTH AFRICA

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Abstract. North Africa faces a unique set of climatic challenges, including extreme heat, arid environments, and water scarcity, which are intensified by rapid urbanization and demographic pressures. These conditions necessitate architectural and urban design solutions that not only address environmental constraints but also preserve cultural heritage and promote sustainability. This article examines the integration of climate-responsive strategies in the architectural landscapes of North Africa, with a particular focus on sustainable urban practices in Morocco.

Traditional architectural elements, such as thick insulated walls, small windows, shaded public spaces, and central courtyards, have long served as passive design solutions to mitigate the effects of heat and optimize thermal comfort. In Moroccan urban settings, these elements are often complemented by water features—fountains, pools, and canals—that contribute to natural cooling and enhance the aesthetic and social value of spaces. Adaptive land use practices, such as terraced gardens in mountainous areas and coastal developments, further demonstrate the region's ability to harmonize natural resources with urban functionality.

The pressing issue of water scarcity, as illustrated by regional rainfall patterns and climate projections, underscores the critical need for resource-efficient urban planning. North Africa's predominantly arid zones require innovative water management strategies, including the integration of drought-resistant plants, shaded green spaces, and systems that optimize the use of limited water resources. These approaches highlight the potential of combining vernacular knowledge with contemporary technologies to develop resilient urban environments.

The study emphasizes the importance of aligning environmental stewardship with cultural identity in urban design. By reinterpreting traditional practices within modern frameworks, North African cities can address the dual challenges of climate change and socio-economic pressures. This fusion of heritage, sustainability, and innovation positions North Africa as a model for climate-responsive architecture in arid regions, offering insights that are replicable in similar global contexts.

Keywords: Climate-Responsive Architecture, Water Scarcity, Sustainable Urban Design, Thermal Comfort, North Africa, Traditional Materials, Environmental Resilience.

Introduction. The study of climate-responsive architectural and urban design in North Africa is particularly relevant due to the region's extreme climatic conditions, including high temperatures, minimal rainfall, and chronic water scarcity. These challenges are intensified by rapid urbanization and growing demographic pressures, placing significant stress on infrastructure, natural resources, and living conditions [11, 10].

Creating sustainable and livable urban environments in such conditions requires innovative solutions that integrate environmental adaptability with cultural preservation. Traditional design practices in North Africa, such as thick walls, shaded courtyards, and water features, reflect an intuitive understanding of the climate. However, their adaptation to contemporary urban contexts and modern sustainability standards remains underexplored.

This study addresses the pressing need for resilient architectural strategies that mitigate climate impacts while balancing cultural identity, ecological sustainability, and socio-economic

development. It contributes to the growing body of research on sustainable architecture by offering insights into the application of traditional methods and modern innovations for arid and water-stressed regions.

Analysis of the recent research and publications. Key studies on climate-responsive architecture emphasize the role of vernacular design and sustainable urban planning in addressing challenges in arid regions. Hassan Fathy's *Natural Energy and Vernacular Architecture* [1] highlights passive cooling techniques and local materials for thermal comfort in hot climates. Dua Alaoui: Silva's *Urban Planning in North Africa* [2] examines the integration of sustainability into urban development amidst rapid urbanization. Roaf's *Ecohouse: A Design Guide* [3] and Oliver's *Encyclopedia of Vernacular Architecture of the World* [4] provide frameworks for energy-efficient design rooted in traditional practices [8].

Recent research by Fuentes Pardo [6] and Santos et al. [7] explores low-carbon construction techniques and the relevance of vernacular architecture for contemporary sustainable design. Attia [5] further demonstrates the adaptation of traditional systems, such as windcatchers, to modern low-rise housing. These studies collectively underscore the importance of merging traditional solutions with modern technologies to address North Africa's climatic and environmental challenges [12].

Statement of the objective. North Africa's arid climate, with extreme heat, scarce rainfall, and growing water shortages, poses substantial challenges for sustainable architectural and urban development. These issues are further intensified by rapid urbanization and increasing pressure on natural resources.

Although traditional architectural methods, such as passive cooling and water-efficient designs, have proven effective in the past, their adaptation to modern urban demands remains limited. This study addresses the need for integrating these vernacular approaches with contemporary sustainable solutions to create resilient, resource-efficient, and culturally relevant environments in North Africa.

The Aim of the Study. The aim of the study is to analyze climate-responsive architectural and urban design strategies to address the challenges of extreme heat and water scarcity in North Africa.

Research Objectives. To identify traditional and contemporary architectural solutions for thermal comfort and water management in arid climates. To analyze the integration of vernacular design principles with modern sustainable practices in urban development. To propose approaches for creating resilient and resource-efficient environments in North Africa.

The Scientific Novelty of the Study. Climate-responsive design strategies in North Africa are comprehensively analyzed through the lens of environmental adaptability and sustainability.

The integration of traditional architectural solutions with modern technologies for resource efficiency is explored as a framework for sustainable urban development.

Main material and results. North Africa's arid climate, with its intense heat, scarce rainfall, and widespread water shortages, poses significant challenges for sustainable architectural and urban development. These issues demand the integration of traditional design wisdom with contemporary innovations to enhance thermal comfort, water efficiency, and environmental resilience.

Climate-Responsive Architecture in North Africa. Traditional architecture across North Africa has long demonstrated a remarkable ability to adapt to the region's harsh climatic conditions. Thick walls, narrow openings, and the use of central courtyards are integral features that reduce heat gain while promoting natural ventilation [1, 4]. Hassan Fathy's research into vernacular design highlights the efficiency of passive cooling systems, particularly in hot, arid climates, where minimizing reliance on artificial energy is essential [1].

In Moroccan urban design, central courtyards play a dual role in cooling spaces and creating microclimates within dense urban areas. These courtyards provide shaded zones, allow for natural airflow, and often integrate water features such as fountains and reflective pools, which enhance evaporative cooling (Fig.1) [2, 3]. The interplay between thermal comfort and cultural heritage is particularly significant in regions like Marrakesh and Fez, where these traditional elements remain central to urban life.

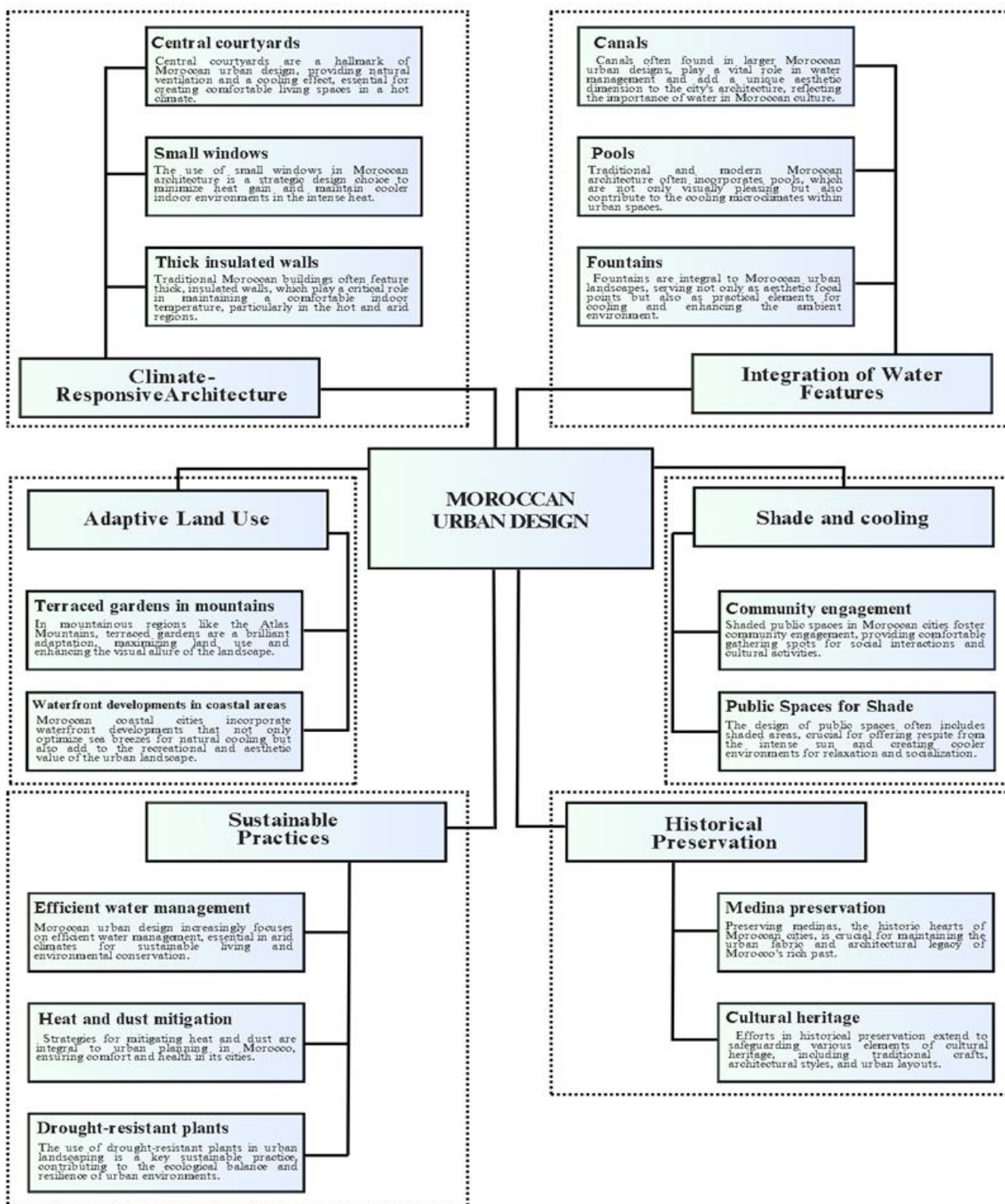


Fig.1. Shaping Spaces: Sustainable and Cultural Dimensions of Moroccan Urban Design - Reflections on the Evolution of Urban Spaces in Morocco.

Water features are more than aesthetic additions; they are functional elements in mitigating the heat. Fountains, canals, and pools reflect and cool air, helping to regulate the microclimate of public spaces. This principle, deeply rooted in Islamic architecture, continues to offer effective solutions for modern urban contexts [4,13].

Water Scarcity and Resource Management. Water scarcity remains one of the most critical challenges in North Africa, driven by minimal and irregular rainfall, climate change, and increasing urbanization. This environmental stress is further visualized through regional rainfall patterns and water scarcity projections (Fig.2). These realities underscore the urgent need for sustainable water management strategies in both rural and urban environments. As Silva (2016) emphasizes, integrating effective water systems into urban planning is vital to ensuring resilience and long-term sustainability in cities where resources are limited [2].

Historically, North African societies have developed advanced systems to cope with limited water availability. The qanats and foggaras, for instance, are highly efficient underground channels designed to extract groundwater and distribute it across long distances without evaporation losses. These systems have sustained agricultural lands and settlements in arid regions for centuries, offering time-tested solutions for managing scarce water resources. As Attia (2009) explains, adapting these techniques to modern residential developments allows for efficient water harvesting and distribution, especially in regions with limited infrastructure [5].

In recent years, researchers have underscored the importance of combining traditional methods with modern water-saving technologies. Santos et al. (2023) emphasize the role of drought-tolerant vegetation in reducing irrigation needs while contributing to urban greening. Urban areas can incorporate green spaces with native and resilient plant species that thrive in arid climates, reducing overall water consumption [7, 14]. This approach aligns with sustainable urban planning efforts to improve thermal comfort and mitigate the urban heat island effect while conserving resources [6].

Modern water management systems, such as greywater recycling, provide additional opportunities to optimize water use in urban areas. Greywater systems allow wastewater from domestic activities (e.g., showers, sinks) to be filtered and reused for irrigation, reducing reliance on fresh water. Similarly, advanced irrigation techniques, such as drip irrigation, are increasingly employed in agricultural and urban green spaces to minimize water waste and ensure targeted, efficient delivery of water to plants [6, 7].

Innovative rainwater harvesting methods also play a critical role in water conservation efforts. By capturing and storing rainwater during infrequent precipitation events, urban areas can alleviate pressure on municipal water supplies and ensure a backup source for landscaping or non-potable uses. Incorporating these systems into urban infrastructure, such as permeable pavements and rooftop collection units, further enhances water retention and reduces runoff.

Furthermore, sustainable urban design prioritizes green infrastructure to manage water efficiently. Features such as bioswales, retention basins, and permeable surfaces help to recharge groundwater, reduce flood risks during heavy rainfall, and maintain ecological balance. Silva (2016) notes that implementing these systems in cities is essential to counteract the environmental impacts of rapid urbanization [2, 15].

Addressing water scarcity in North Africa requires a multi-tiered approach that merges traditional wisdom with modern technologies. Systems like qanats and foggaras provide models of efficiency, while solutions such as greywater recycling, drought-resistant vegetation, and rainwater harvesting present practical and scalable innovations for today's urban environments. By incorporating these strategies into urban planning, cities can ensure water resilience, environmental sustainability, and improved quality of life for their growing populations.

Adaptation of Vernacular Techniques in Modern Design. The adaptation of vernacular architecture to meet contemporary needs is a critical aspect of sustainable development in North Africa. Traditional building techniques and materials, honed over centuries, offer valuable solutions for addressing environmental challenges such as extreme heat, water scarcity, and resource inefficiency. However, for these techniques to remain relevant in modern contexts, they require careful adaptation through research, innovation, and integration with current technologies.

One of the most notable examples of vernacular systems is the wind catcher (or *Masqat*), a traditional natural ventilation structure. Windcatchers function by capturing cooler breezes and channeling them into building interiors, expelling warm air to maintain thermal comfort without

mechanical systems. Attia's research demonstrates how this ancient cooling technique can be modernized for contemporary low-rise housing designs. By strategically positioning windcatchers and combining them with complementary passive design elements, such as cross-ventilation and shaded spaces, significant reductions in indoor temperatures can be achieved. This adaptation minimizes reliance on energy-intensive air conditioning, contributing to energy conservation and reducing carbon emissions [5, 17].

Locally sourced materials are another cornerstone of vernacular architecture that remains highly relevant today. Materials such as clay, adobe, and stone provide exceptional thermal insulation, stabilizing indoor temperatures and reducing the need for mechanical heating or cooling. For example, clay bricks, often used in traditional buildings, have low embodied energy and are effective in mitigating heat gain in arid climates. Fathy (1986) emphasized the importance of such materials for both their thermal properties and their availability in the local environment [1]. Santos et al. further highlight how the use of these low-carbon materials can minimize environmental footprints by reducing transportation distances and energy costs associated with modern construction [7, 16]. This approach promotes resource efficiency while maintaining the ecological integrity of the built environment.

The adaptation of vernacular techniques is not limited to individual buildings but extends to urban planning and landscape design. Silva underscores the importance of incorporating cultural continuity into modern infrastructure [2, 14]. Traditional urban design practices, such as the creation of central courtyards, terraced gardens, and shaded public spaces, continue to serve as effective tools for improving urban livability and resilience. For instance, terraced gardens in mountainous areas optimize water use and minimize soil erosion while providing natural cooling. These techniques, combined with green infrastructure initiatives like bioswales, permeable surfaces, and drought-resistant landscaping, address contemporary urban challenges such as water scarcity and the urban heat island effect [3, 10].

Water features, such as fountains and reflective pools, remain a prominent element in vernacular design due to their cooling effects through evaporation. These features are not only functional but also enhance the aesthetic and social value of urban spaces, creating environments that foster community interactions. In cities like Marrakesh and Fez, the integration of water systems into public courtyards and gardens has historically contributed to climate adaptation (Fig.1). Modern urban projects can reinterpret these elements to align with contemporary sustainability goals while preserving cultural authenticity [4].

The synthesis of vernacular architecture with modern approaches has significant implications for addressing the challenges of climate change and urbanization. As Fuentes Pardo (2023) notes, vernacular architecture offers valuable lessons in achieving thermal comfort and resource efficiency in arid regions [6]. Contemporary strategies, such as integrating low-carbon materials, water management systems, and drought-tolerant vegetation, complement these traditional methods and respond to the increasing demands of growing urban populations [18].

Synthesis of Findings. The findings reveal that North Africa's architectural and urban responses to climatic challenges successfully combine traditional design wisdom with modern innovations to address environmental and resource-related pressures. Vernacular systems such as windcatchers, central courtyards, and water features remain essential tools for achieving thermal comfort in arid environments. These techniques, rooted in centuries of experience, demonstrate the effectiveness of passive cooling systems in minimizing reliance on energy-intensive mechanical solutions [1, 5].

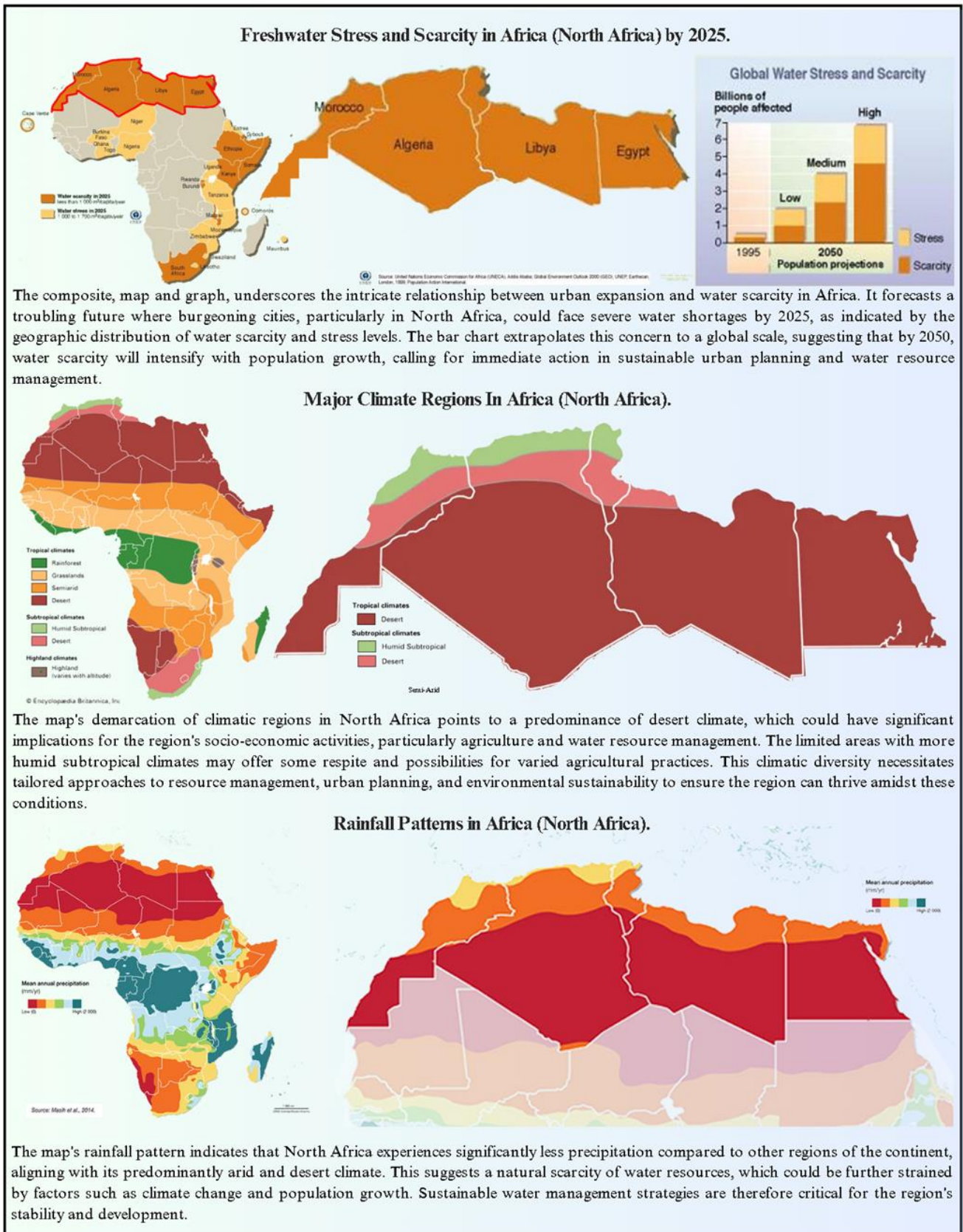


Fig. 2. Arid Realities: Visualizing Rainfall, Climate, and Water Scarcity in North Africa. (earth scans from: United Nations Environment Programme (UNEP). (1999). *Global Environment Outlook 2000 (GEO)*. Earthscan.)

Locally sourced materials, including clay, adobe, and stone, further enhance the sustainability of vernacular architecture. Their exceptional thermal insulation properties reduce energy consumption, while their availability lowers transportation costs and environmental impacts. Fathy highlights their ecological relevance, while recent studies confirm their value in achieving low-carbon construction [1, 9].

Modern technologies, such as greywater recycling, drought-resistant landscaping, and green infrastructure, expand the functionality of these traditional methods. By addressing water scarcity and urban heat challenges, these solutions enhance resource efficiency and resilience in growing urban areas [6, 7]. Sustainable urban planning practices, such as permeable pavements and bioswales, further integrate natural systems into urban landscapes, ensuring long-term environmental stability [2].

Figures 1 and 2 collectively highlight the interconnected challenges of climate adaptation and urbanization in North Africa. Shaded public spaces, terraced gardens, and passive cooling strategies demonstrate how traditional design principles can be adapted to modern contexts. These findings underscore North Africa's ability to merge cultural heritage with innovative approaches, positioning it as a model for climate-responsive and sustainable design in arid regions.

Conclusions: North Africa's architectural responses, including central courtyards, water features, and windcatchers, effectively mitigate extreme heat and promote thermal comfort by relying on passive cooling systems [1, 5].

The use of locally sourced materials like clay and stone remains essential for sustainable construction, offering thermal insulation and minimizing environmental impact [7, 13].

Addressing water scarcity requires innovative solutions such as greywater recycling, drought-tolerant landscaping, and traditional water management systems like qanats, which remain highly relevant for modern urban contexts [2, 6].

Moroccan urban design exemplifies the balance between cultural heritage and sustainability, as seen in practices that incorporate shaded public spaces, green infrastructure, and adaptive land use strategies (Fig.1).

The analysis of rainfall patterns and climate projections (Fig.2) highlights the need for urgent water-efficient planning to mitigate environmental stress in arid regions.

Combining vernacular knowledge with modern technologies offers a replicable model for other regions facing similar climatic challenges, ensuring resilient, resource-efficient, and culturally relevant urban environments.

Future development must prioritize climate adaptability, resource efficiency, and the preservation of cultural identity to achieve sustainable and livable urban spaces.

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КЛІМАТИЧНІ ЗМІНИ ТА РЕАКЦІЯ МІСЬКОГО ЛАНДШАФТНОГО ДИЗАЙНУ В УМОВАХ ЖАРКОГО КЛІМАТУ (НА ПРИКЛАДІ ПІВНІЧНОЇ АФРИКИ)

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Одеська державна академія будівництва та архітектури

Анотація. Північна Африка стикається з унікальним набором кліматичних проблем, включаючи екстремальну спеку, посушливе середовище та нестачу води, які посилюються швидкою урбанізацією та демографічним тиском. Ці умови зумовлюють необхідність архітектурних та містобудівних рішень, які не лише вирішують екологічні обмеження, а й зберігають культурну спадщину та сприяють сталому розвитку. У цій статті розглядається інтеграція стратегій, орієнтованих на клімат, в архітектурні ландшафти Північної Африки, з особливим акцентом на сталих міських практиках у Марокко.

Традиційні архітектурні елементи, такі як товсті утеплені стіни, невеликі вікна, затінені громадські простори та центральні двори, довгий час служили пасивними дизайнерськими рішеннями для пом'якшення впливу тепла та оптимізації теплового комфорту. У марокканських містах ці елементи часто доповнюються водними об'єктами – фонтанами, басейнами та каналами – які сприяють природному охолодженню та підвищують естетичну та соціальну цінність просторів. Адаптивні практики землекористування, такі як терасові сади в гірських районах та прибережна забудова, ще більше демонструють здатність регіону гармонізувати природні ресурси з міською функціональністю.

Нагальна проблема нестачі води, що ілюструється регіональними моделями опадів та кліматичними прогнозами, підкреслює критичну потребу в ефективному міському плануванні. Переважно посушливі зони Північної Африки вимагають інноваційних стратегій управління водними ресурсами, включаючи інтеграцію посухостійких рослин, затінених зелених насаджень і систем, які оптимізують використання обмежених водних ресурсів. Ці підходи підкреслюють потенціал поєднання знань народної мови з сучасними технологіями для створення стійкого міського середовища.

У дослідженні наголошується на важливості узгодження раціонального використання навколишнього середовища з культурною ідентичністю в міському дизайні. Переосмислюючи традиційні практики в сучасних рамках, міста Північної Африки можуть вирішити подвійні проблеми: зміну клімату та соціально-економічний тиск. Це поєднання спадщини, сталого розвитку та інновацій позиціонує Північну Африку як модель кліматично чутливої архітектури в посушливих регіонах, пропонуючи ідеї, які можна відтворити в подібних глобальних контекстах.

Ключові слова: кліматична архітектура, дефіцит води, сталий міський дизайн, тепловий комфорт, Північна Африка, традиційні матеріали, екологічна стійкість.