Bridging Land Use Planning, Resilience and AI for Flood-Induced Urban Management

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Abstract. Natural hazards are becoming more frequent and severe due to climate change, laying bare the limitations of conventional land use planning and risk management approaches. For instance, events like floods and other disruptions highlight the importance of developing adaptive and resilient strategies that can respond to diverse hazards, especially in rapidly urbanizing regions. In existing studies, land use, infrastructure, and risk assessment are treated separately. Moreover, planning processes do not integrate local knowledge and AI-based predictive tools, particularly in developing countries.

This paper aims to bridge this gap by proposing a conceptual framework that connects all the previously mentioned elements. Using a multi-scalar approach that funnels from global experiences to the Moroccan context, it identifies relevant challenges and opportunities. In this context, the paper advances three research pillars: (1) adaptive land use planning and multi-hazard resilient infrastructure, (2) integration of local knowledge with science-driven solutions, and (3) AI-driven predictive modeling for multi-disruption scenario planning.

Keywords: Adaptive land use planning · multi-hazard resilience · climate change adaptation · AI-driven prediction · local knowledge · urban resilience

1 Introduction

1.1 Global Climate Risk Context and the Inadequacy of Traditional Planning

Across the globe, climate change has deeply spread its roots, burgeoning into intense natural hazards such as floods, droughts, heatwaves, and earthquakes, which place a huge pressure on urban systems (IPCC 2021). When combining their repercussions with already existing vulnerabilities, human settlements are now more than ever in need of coping with and withstanding the consequences of past interventions in the natural environment.

As climate change increases both the frequency and intensity of hazards, existing vulnerabilities are exacerbated, particularly in rapidly urbanizing areas where development often expands into high-risk zones. This dynamic raises critical questions about the relationship between risk management, climate adaptation, and spatial planning (Farinós-Dasí et al. 2025). In this context, planning becomes a form of governance

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arena for disaster risk management where governance can metaphorically be seen as the controlling strings. It converts scientific knowledge into tangible actions and mediates between all the actors and sectoral policies.

1.2 From Traditional Disaster Management to Disaster Risk Management

The transition from traditional disaster management to disaster risk management (DRM) shows a fundamental shift in perspective. Conventional disaster management focuses on addressing disasters after they occur, whereas DRM prioritizes anticipating their impact through proactive risk assessment. The first approach treated disasters as isolated events. The latter, however, highlights that climate change has altered hazard patterns, exacerbating their intensity and frequency. As a result, risks are no longer static but evolving, which requires constant assessment and adaptation (Farinós-Dasí et al. 2025).

Furthermore, the Hyogo Framework for Action (2005–2015) and its successor, the Sendai Framework (2015–2030), formalized this transition. They emphasized that climate change adaptation can be established through risk and hazard mapping and vertical coordination between all stakeholders. As such, climate change adaptation can be understood as the process of adjusting to current and future effects of climate change using spatial planning as a key means to implement it.

1.3 The Planning Implementation Gap: Lessons from the International Practices

However, even if climate adaptation and resilience plans widely exist in large cities worldwide, they remain ineffective. Olazabal et al. (2021) justify this weakness by a planning-implementation disconnection. In essence, climate adaptation plans are often non-binding, poorly financed, and weakly connected to land-use regulation (Olazabal et al. 2021). Thus, these plans frequently exist as standalone policy documents without integration into legally binding planning instruments that govern development decisions (Olazabal et al. 2021).

In many African cities, including Moroccan urban centers, local adaptation planning is minimal or absent. This reveals significant regional disparities in the institutionalization and operationalization of climate adaptation. Therefore, the challenge lies in how to bridge risk knowledge and enforceable planning action.

1.4 The Role of Communities, Data, and Artificial Intelligence

Beyond technical and institutional dimensions, recent literature emphasizes the importance of communities in resilience. Farinós-Dasí et al. (2025) underscore the importance of the local community participation and knowledge as well as the active involvement of stakeholders. These insights pinpoint the importance of multi-level and data-informed planning that can predict risk and improve decision-making.

Simultaneously, the rise of artificial intelligence AI-driven tools for extreme event modeling and impact assessment presents a revolutionary opportunity (Camps-Valls et al. 2024). Through leveraging AI, planners can enhance detection, prediction, and scenario analysis, which will highly support anticipatory strategies.

1.5 Research Problem and Objectives

Despite the increasing importance of climate risks and the availability of technical tools, the impacts of disasters in Morocco are devastating in terms of human and material losses. The limited integration of risk prevention in land-use planning tools is to blame. In fact, current planning instruments in Morocco remain largely reactive and lack the integration of hazard mapping and indigenous knowledge into planning documents (The N.S.D.R.M, Morocco 2020). In fact, the disconnection between the comprehension of risks and the implementation of planning regulations exacerbates vulnerability. Indeed, this is mainly true in rapidly urbanizing areas where development pressures overlook safety considerations.

This paper addresses this critical gap through three primary objectives: (1) to examine international practices in adaptive land use planning and identify transferable lessons. (2) Analyze the Moroccan context, and (3) conceptualize a framework grounded in three pillars: adaptive land use strategies, hybrid knowledge integration, and AI-driven planning.

1.6 From International Examples to the Moroccan Context: A Funnel Approach

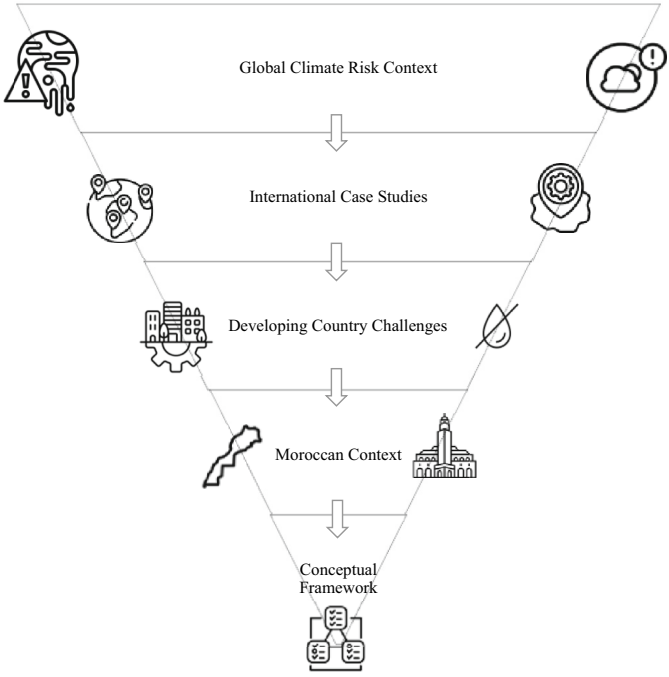

Fig. 1. The Funnel Approach: From Global Climate Risk Context to a Context-Specific Adaptive Land-Use Framework for Morocco. Source: Developed by Author

Thus, this chapter seeks to explore adaptive land use, resilient strategies, hybrid knowledge, and AI-driven planning. The analysis unfolds through a funnel approach,

beginning with global perspectives on adaptive planning and resilience, narrowing progressively to the context of developing nations. These countries share challenges (e.g. rapid urbanization, governance fragmentation, and limited resources) with Morocco, facilitating a smooth transition to the Moroccan case. This progression allows us to identify transferable lessons while taking context-specific limitations into consideration (Fig. 1).

2 Global Overview: Adaptive Land Use and Resilient Strategies

2.1 Evolution of Urban Planning Under Climate Risk: Transitioning from Hazard-Centric to Resilience-Oriented Strategies

Over the past decades, urban and territorial planning systems all around the world have faced a lot of natural hazards whose intensity is drastically increasing. In essence, floods, heatwaves, droughts, and all of their compound effects have unearthed deficiencies in land-use planning approaches that were initially designed to tackle hazards separately. In fact, traditional planning paradigms treated natural hazards as independent events requiring distinct sectoral responses. Therefore, this siloed approach overlooks the interconnected nature of urban systems and the cascading effects of multiple hazards.

In response, planning has progressively shifted towards resilience-based approaches that orbit around systemic thinking and long-term adaptability. Instead of treating hazards in isolation, resilience thinking tends to conceptualize cities as interconnected socio-ecological systems where infrastructure, ecosystems, and human communities interact through dynamic feedback loops (Magoni 2017). Moreover, resilience thinking in spatial planning is linked to the city's ability to change, adapt, and transform while facing outside disturbances rather than bouncing back to its initial state (Udovyk et al. 2025). Taken together, this shift reflects a broader transformation in planning philosophy, from reactive hazard control toward an anticipatory governance of risk.

2.2 Resilience Frameworks: Ecological, Social and Urban

Urban climate adaptation is closely linked to three resilience paradigms: ecological, social, and urban resilience. They have evolved in separate disciplines, yet they converge in practice.

Ecological resilience refers to a system's capacity to absorb disturbances while maintaining its core functions (Holling 1973). Social resilience extends this perspective to human communities, emphasizing their capacity to anticipate, respond to, and recover from these disturbances while maintaining social cohesion (Wannewitz et al. 2024). It also highlights that vulnerability is unevenly distributed and is shaped by socio-economic and political factors.

Accordingly, urban resilience integrates these dimensions within the city through frameworks such as the socio-ecological-technological systems (SETS), where social, ecological, and technological components interact in disaster management (Lee & Hong 2024). However, empirical applications often reveal imbalances due to emphasizing technical solutions over ecological and spatial ones.

2.3 International Case Studies: Operationalizing Adaptive Planning

The following international case studies illustrate diverse approaches to adaptive land use planning. They demonstrate the integration of technical innovation, local knowledge, and governance reform.

Case Study 1: Rotterdam Netherlands: Resilience Through Placemaking
Rotterdam, located in the Rhine-Meuse delta in the Netherlands, mainly faces multiple flooding hazards due to its low-lying geography. While the city relies on extensive flood protection infrastructure, climate change projections suggest that "hard" measures alone are insufficient. (Peinhardt 2021).

Katherine Peinhardt (2021) examines the Rotterdam case study in the Netherlands, where climate adaptation is integrated into spatial planning by transforming public squares into multifunctional flood risk infrastructure. In essence, the Waterplein Benthemplein water square serves two finalities: providing a well-kept public space while absorbing the excess storm water. Decision makers opted for reshaping the current square rather than designing an invisible technical amenity underground, which would have provided no additional benefits.

However, despite its potential, several barriers may hinder its implementation. At the municipal level, limited staff expertise regarding climate adaptation, insufficient data, and financial constraints are problematic. Other barriers can also emerge, namely political obstacles and poor coordination between departments. These barriers are particularly relevant for the Moroccan context, where municipal capacity, interdepartmental coordination, and dedicated climate adaptation funding are often limited.

Case Study 2: Peruvian Amazon: Integrating Indigenous Knowledge
In the Peruvian Amazon, indigenous communities have developed detailed knowledge of environmental risks, seasonal cycles, and ecosystem dynamics. However, formal planning processes have often overlooked this knowledge in favor of external technical expertise.

Furthermore, adaptive land-use planning has shown improvement when local knowledge is integrated with scientific tools such as satellite imagery and hydrological modeling. According to Rodriguez et al., this hybrid approach enhances the contextual understanding and supports effective planning decisions. Nevertheless, challenges remain, especially in scaling knowledge co-production within formal governance systems as well as overcoming institutional rigidity. In fact, these challenges are highly relevant for Morocco, where local and traditional knowledge exists. However, these precious assets are rarely integrated into formal planning instruments. In this context, the Peruvian case illustrates both the value of knowledge integration and the institutional reforms needed to enable it.

Ultimately, both the Rotterdam and Peruvian Amazon cases reveal two complementary dimensions of adaptive planning. On one hand, Rotterdam illustrates spatial integration of infrastructure within a high-capacity governance system. On the other hand, the Peruvian example emphasizes community co-production in a more context-sensitive environment. Even if their institutional conditions differ, both cases show that resilience emerges when planning moves beyond siloed technical solutions toward multi-actor

governance structures. Nevertheless, their contrasting institutional capacities reveal that adaptive planning models cannot be directly transplanted across contexts. Thus, it is imperative to consider governance frameworks and cultural contexts.

2.4 Emerging Knowledge Integration: Connecting Scientific and Local Knowledge

The integration of local knowledge with scientific approaches has emerged as a critical frontier in climate adaptation. Olazabal et al. (2021) argue that subaltern knowledge can be an important source of innovation and can further enhance adaptation solutions. The article discusses the disconnect between climate adaptation planning and its tangible implementation. This is due to overreliance on technical knowledge, namely, scientific data and models. They often fail to consider local contexts and social inequalities.

Overall, the article concluded that we urgently need to move away from purely technocratic approaches in order to ensure an inclusive and adaptive environment. Ultimately, integrating indigenous knowledge is more about empowering local communities and involving them in shaping their own future in the face of climate change.

2.5 AI-Driven Predictive Tools: Opportunities and Challenges

Artificial intelligence and machine learning have rapidly emerged as transformative tools for urban planning and climate risk assessment. In this work, Kesavan et al. (2024) focuses on using AI to assess risk precisely and address flooding risks. The research introduces AI for the resilient cities model and applies it in the vulnerable area of Penthakata in the coastal city of Puri, Odisha. The study leverages cutting-edge geospatial technology, deep learning, and multi-parameter analysis to evaluate flood vulnerabilities.

Furthermore, the paper emphasizes integrating technology with community volunteers and local knowledge, whose role was mainly to assist in data collection and implement mitigation measures. Therefore, AI complements rather than replaces human knowledge.

3 Developing Countries Context

3.1 Developing Countries' Challenges

Developing nations are more exposed to climate change impacts and have less adaptive capacity. Tarhule (2012) discusses the NAPA (National Adaptation Programs of Action), which is a mechanism under the UNFCC (United Nations Framework Convention on Climate Change). It aims to help developing countries to reach climate adaptation and, more importantly, provide funding in order to ensure its implementation (Tarhule 2012).

Initially, more attention was directed towards mitigation, which aims to reduce greenhouse emissions, in other words, preventing the situation from getting worse. Later, there was a realization that even if we stopped greenhouse gas emissions completely, the effects of past emissions will still be felt for decades to come. Unfortunately, developing countries will bear the heavier consequences due to their vulnerability. Vulnerability can be

defined as a function of exposure, sensitivity, and adaptive capacity (IPCC). This framing shows that vulnerability is not solely environmental but structurally embedded within socio-economic and institutional systems, especially in rapidly urbanizing contexts.

3.2 Rapid Urbanization and Informal Settlements as Amplifiers of Climate Risks

Rentschler et al. (2022) provides systematic evidence that countries are involuntarily increasing their exposure to flooding. As a matter of fact, settlements in flood-prone areas have expanded faster than those in safer zones since 1985, especially in low- and middle-income countries. These trends show that urban expansion patterns actively shape exposure, stressing the fact that land-use governance is central to disaster risk reduction.

Furthermore, disaster losses are constantly climbing. This is mainly due to the fact that informal settlements often emerge in marginal lands such as floodplains, steep slopes, and coastal edges, where land is affordable but hazardous. In such areas, disaster losses are not only driven by intensifying hazards but also by planning decisions that allowed such risky expansion.

Overall, in areas with high flood exposure, it is crucial to invest in disaster preparedness. On the other hand, in areas where exposure is still low but increasing rapidly, it is essential to revise land-use and urbanization plans as well as building codes and infrastructure master plans.

3.3 Governance Gaps and Institutional Weaknesses in Climate Adaptation

Termeer et al. (2017) argue that adaptation to climate change is primarily a governance issue and is not only limited to technical solutions. It is about the interaction between public and private actors aiming to solve societal problems related to climate change. However, climate adaptation faces several challenges on the governance level.

First, institutional fragmentation undermines coordination, while unclear mandates blur responsibility. The second challenge is uncertainty. No one knows for sure future climate impacts, so it is difficult to plan effective policies. The third challenge concerns the long-term horizon of climate impacts. Decisions should be made in the present, but their repercussions should be felt years later. Balancing short-term economic interests with long-term climate risks is hard. Unlike mitigation, adaptation is new on the policy agenda, so responsibilities, procedures, and solutions are weakly defined.

Therefore, effective governance arrangements require multi-level coordination, alignment of sectoral boundaries, and clear policy instruments. Overall, the paper suggests that the development of governance arrangements for climate adaptation is both context and time specific. There is no one-size-fits-all solution since it depends on existing institutions. In that sense, governance is a continuous process of adaptation and learning rather than a fixed institutional design.

3.4 Infrastructure Deficiencies and Cascading Vulnerabilities

Kiunsi (2013) discusses in his article the complexities of dealing with climate change in a rapidly developing urban environment. Through the example of Dar Es Salaam, a major

city in Tanzania, the author highlights the challenges it faces and their role as stressors in worsening climate change impacts. It shows how inadequate drainage, sanitation, and waste management exacerbate flood impacts. Hence, the city's top priority is to address these challenges before tackling climate adaptability. Moreover, informal settlements are particularly vulnerable due to the absence of foundational infrastructure, especially those located in low-lying areas. Consequently, this reveals that adaptation cannot be effectively implemented where basic services are lacking.

More importantly, the case of Dar Es Salaam illustrates that climate adaptation in developing cities must be integrated into every aspect of urban development, from infrastructure planning to community engagement. In this sense, this case study reflects structural issues observed in other developing contexts, such as informal urbanization and fragmented governance.

3.5 Social Vulnerabilities and Environmental Injustice

Climate risk is socially differentiated. Andersen et al. (2023) examine the health risk of climate change in Mukuru informal settlement, Nairobi, Kenya. The case study was chosen because Mukuru lacks basic services and its residents are particularly vulnerable to climate change, which makes it a critical area to study. The study aims to investigate what the local residents know and think and how they act in regard to climate change and climate change-mediated health risks.

The study deduced that there is a strong awareness foundation that can be leveraged for action. The collected findings are useful for policymakers, planners, and researchers to work locally on adaptive and mitigation strategies. For example, intervention can focus on improving housing, sanitation, and access to clean water, which will in turn reduce vulnerability to climate-related health risks. Overall, this suggests that knowledge alone is insufficient without institutional and infrastructural support. Additionally, the study also reflects that vulnerability is not only spatial but also socio-economic and cultural. Therefore, resilience planning should not focus solely on technical solutions, but it also needs to take social equity into consideration.

3.6 Opportunities and Lessons: Hybrid Strategies from Similar Regions

In his article on urban development and governance in Nigeria, Awuah (2018) unveils the opportunities hidden behind several urban weaknesses. In fact, the literature enumerates many weaknesses, such as rapid urban growth and rising urban poverty, which created opportunities for large-scale urban development. In other words, these conditions show that even a flawed system can offer meaningful opportunities if its potential is recognized. In the end understanding the perspectives of key stakeholders is crucial.

On another note, the author explains pluralistic social steering, which means that urban planning and governance can succeed through diverse sources of social inputs and directions. It is not just top-down; it involves various actors working together. To sum up, the combination of innovative approaches, stakeholder involvement, as well as strong government support is required to step forward since it provides the infrastructure, the very foundation of urban development. It is about recognizing both the challenges and the opportunities and working collaboratively to build a better urban environment.

4 Moroccan Context: Need for Context-Specific Adaptive Strategies

4.1 Climate Hazards in Morocco: A Multi-hazard Landscape

Morocco's diverse geography and variable climate expose it to major natural hazards such as floods, droughts, earthquakes, and tsunamis in addition to forest fires, heat waves, cold snaps, storms, submergence, landslides, locust infestations, and blizzards. The first four natural hazards have a significant impact on the human and economic level, which is why they need serious and urgent attention (OECD 2024). Throughout modern history, Morocco has been marked by several key natural catastrophes whose effects were disastrous. The tsunami of 1755 was a direct result of the Great Lisbon Earthquake, the 1960 Agadir earthquake, and the 2004 Al Hoceima earthquake. During the end of 2025 and the beginning of 2026, due to intense and sudden rainfall, Morocco faced one of the deadliest flooding events ever witnessed in the past decade, which occurred in Safi, with an important number of human casualties (Al-Jazeera 2025). Moreover, other cities across the countries suffered from the excess of rain but with fewer human losses, such as Ksar Lekbir, where prevention measures have been carefully enforced (Africa Climate Reports 2026).

4.2 Urban Expansion and Peri-Urban Growth Pressures

Tribak & El Amrani (2018) explain that the Great Nador agglomeration faces critical climate hazards, primarily floods, which are exacerbated by rapid and unplanned urban expansion. Thus, this dynamic creates considerable pressure on land use and increases vulnerability within the region. In short, the article highlights how human interventions and rapid urban expansion worsen those hazards.

In this context, the rapid urbanization in the Great Nador territory is characterized by excessive spatial growth that encroaches upon sensitive and risky areas. The study also answers the following question: What are the factors that drive sprawl into risk areas? First, strong land pressure reduces the effectiveness of development plans for urban agglomeration. Moreover, technical errors, such as overlooking non-buildable zones (ZNA) in the absence of hydrological studies, lead to the construction of buildings in high-risk areas.

This dynamic is driven by a notable imbalance between land supply and demand, which has caused land prices to triple in the recent decades. Consequently, affordable and accessible building lands are rare, which will force the low-income population to settle in marginal and dangerous areas of the agglomeration. Additionally, the authors state that the population is strongly attached to their place of residence and relatives. This leads to buildings being constructed in areas frequently threatened by natural hazards, despite official urbanization policies.

Over time, the spatial dispersion of urbanization and the occupation of flood-prone areas created fragmented urban fabric. Therefore, flood risk management became a priority, especially in highly populated and dangerous areas. Historically, areas near main rivers in Great Nador were free of construction until the late 1950s. The plains were solely reserved for agriculture and fishing. However, over the past 50 years, urbanization

expanded into flood zones, and human settlements developed in marshy and floodable areas, significantly increasing vulnerability. This transformation illustrates how spatial planning decisions can "formalize" long-term vulnerability when they are misaligned with environmental realities.

4.3 Infrastructure Gaps and Socio-Economic Vulnerabilities

Morocco has faced severe droughts leading to water scarcity. Water infrastructure deficits represent critical vulnerabilities across Morocco's urban systems. Despite the government's efforts to build over 153 dams exceeding 19 billion cubic meters of storage capacity and target 51% renewable energy by 2030, severe challenges persist in improving drinking water infrastructure, especially in low-income districts (Dahchour et al. 2025).

At the same time, vulnerability is not only infrastructural but socio-economic. The case of Tetouan illustrates how rapid urbanization along with landscape characteristics, increases flood exposure (Salhi et al. 2024). Moreover, risk perception and response may vary according to gender, education and socio-economic conditions, therefore shaping how communities anticipate and cope with flood risks.

While awareness exists, it does not always translate into effective action due to structural constraints. This highlights that vulnerability is both spatial and social. Thus, it is crucial to have integrated approaches that combine infrastructure development with social, institutional along with measures centered around communities.

4.4 Vulnerability of Housing

The late Haouz earthquake that occurred in 2023 marked the region's history as the most devastating natural hazard in over a decade. Ait Zamzami et al. (2024). Discusses the housing vulnerability in the western High Atlas of Morocco, namely traditional dwellings. These structures are built with natural materials such as earth, stone and wood, reflect local knowledge and resource availability but remain structurally vulnerable to seismic risks (Ait Zamzami et al. 2024). Beyond emergency reconstruction, integrating disaster risk into rural planning frameworks is essential for sustainable territorial planning in Morocco (Amini Alaoui et al. 2024).

The aim of the reconstruction process is to create a balance between strengthening the existing building method and introducing more resilient materials while respecting the cultural heritage of the region. Simply put, the local identity should be preserved while ensuring the safety of residents. Additionally, understanding the seismic risks and adapting practices are very essential for protecting these communities from future disasters.

4.5 Local Knowledge and Community Practices

Morocco has a rich heritage of traditional water management systems. It has sustained communities in arid and semi-arid environments for centuries. For instance, the khettarat system of Marrakech illustrates this indigenous socio-technical heritage. They are

underground systems of wells and channels for sustainable water delivery and have met Marrakech's drinking water needs until the early 1990s. This demonstrates their effectiveness in oasis environments (Messous 2025). Although their use has declined due to institutional and economic changes, they remain relevant as models for contemporary adaptation strategies.

Similarly, vernacular architecture in Morocco has evolved over centuries, shaped by adaptation to local conditions and material availability as well as cultural preferences. Traditional construction practices in mountain villages use natural materials such as earth, stone, and wood, which reflect knowledge of local resources and environmental constraints (Ait Zamzami et al. 2024). However, these practices face challenges from a durability and resistance perspective, especially in the face of earthquakes.

Conversely, reconstruction efforts reveal tensions between traditional knowledge and modern building regulations. In essence, the states introduce administrative regulations into vernacular construction processes, which challenges local builders' credibility (Belahnech 2025). Overall, the challenge is to develop eco-construction approaches that take into account vernacular building culture while addressing contemporary safety and performance requirements. Simply put, we should recognize that traditional practices embody valuable climate adaptation knowledge. For instance, thermal mass for temperature regulation, natural ventilation strategies, and water-sensitive design should not be replaced by modern construction methods.

On another note, community-based adaptation strategies further illustrate the importance of local knowledge. Practices developed by farmers and livestock breeders vary across regions and respond to specific environmental and socio-economic conditions (Snaibi 2020). At the same time, there are differences between local priorities and external planning approaches which stresses the need for participatory and context-sensitive strategies (Olazabal et al. 2021).

Urban contexts present different community adaptation challenges. Research in Tetouan emphasizes that solely relying on structural engineering for risk management is inadequate. Instead, we should advocate for tailored awareness campaigns, educational initiatives, and capacity-building programs that enhance social engagement and resilience (Salhi et al. 2024). Therefore, the psychosocial dimensions of risk and resilience are acknowledged.

4.6 Synthesis: Why Morocco Requires Context-Specific Research

To summarize, Morocco's position at the intersection of Mediterranean, Atlantic, and Saharan climate zones creates exceptional variability in precipitation and temperature (Ongoma et al. 2024). Moreover, the semi-arid to arid climate generates fundamental water scarcity constraints with uneven rainfall distribution, which necessitate context-specific management systems (Hafyani et al. 2020; Dahchour et al. 2025). Furthermore, coastal areas face sea level rise (Chtioui et al. 2024), mountainous regions face flash floods (Sallak 2019). All of these demand different adaptation strategies depending on their unique context.

On the other hand, the colonial-era transformations created a path full of vulnerabilit**ies** with contemporary high-risk zones connected to areas transformed under the protectorate (Bolca 2025). Additionally, cultural practices influence settlement patterns

and risk perceptions (Tribak et al. 2018) and gender as well as education differences affect risk awareness (Salhi et al. 2024). Traditional systems such as khettarat are still relevant (Messous 2025) but integrating vernacular practices with contemporary requirements requires negotiation between state systems and local knowledge networks (Belahnech 2025).

Despite the existence of progressive frameworks like Water Law 36–15 (Grijsen et al. 2017), implementation challenges persist. For example, Bouaakkaz et al. (2018) show that the Souss watershed has insufficient institutional frameworks and inadequate flood management. Moreover, national strategies face implementation delays while flood risk integration into urban planning remains inadequate (Tribak et al. 2018). Therefore, Morocco requires solutions specific to its own institutional structures and capacity constraints.

5 Critical Gaps in Literature

Despite growing attention to climate adaptation and resilience, there are still gaps in the literature, especially in the developing country context. This section synthesizes four key gaps that this research addresses.

Existing literature often treats land use planning and infrastructure development as separate domains, with limited attention to their interdependencies (Ahern 2011). In fact, resilience strategies focus on either spatial planning or infrastructure without adequately addressing how they interact. For example, flood risk management may emphasize drainage infrastructure without considering how land-use patterns may contribute to flood risks (Balvanera et al. 2013). This is clearly illustrated through impervious surfaces and loss of green space.

Ultimately, this research addresses this gap by developing integrated approaches that link land use strategies with infrastructure resilience. Therefore, it recognizes that sustainable adaptation requires coordinated interventions across multiple domains (Biggs et al. 2012).

Moreover, combining scientific and local knowledge is still difficult even if its value has been widely recognized. The reason lies in the fact that much of the literature discusses the importance of local knowledge vaguely without providing concrete methods on merging both.

On the other hand, even if AI is advancing rapidly, its implementation in urban planning and DRM remains quite limited, especially in developing countries. Existing research often focuses on technical capabilities without addressing implementation challenges, ethical considerations, or integration with participatory processes.

Additionally, much of the resilience literature emphasizes technical and environmental dimensions while neglecting social equity, cultural values, and governance structures. Adaptation strategies that fail to address inequalities will exacerbate existing vulnerabilities and create new forms of marginalization. On another note, ignoring cultural values and governance contexts can lead to solutions that are technically correct but socially unacceptable or even institutionally infeasible. Therefore, there is a need for an integrated, context-sensitive, and governance-aware adaptive land-use framework for multi-hazard contexts such as Morocco.

6 Conclusion: From Context to Framework

This paper attempted to trace a funnel from global climate risks and international practices to the specific context of Morocco. Rotterdam's multifunctional infrastructure and the Peruvian Amazon's hybrid knowledge integration offer valuable lessons in multifunctionality, nature-based solutions, knowledge integration, and participatory processes. However, the analysis reveals that Morocco's unique combination of multi-hazard exposure, rapid urbanization, governance challenges, and rich traditional knowledge demands context-specific approaches. Therefore, the direct transplantation of these models is insufficient.

In light of the above, effective climate-responsive spatial planning in Morocco requires the following elements (Table 1).

Table 1. Key Requirements for Effective Climate-Responsive Spatial Planning in Morocco

Dimension	Requirements	Intended Outcome
Risk Assessment	Develop context-adapted multi-hazard protocols	Prioritized and feasible climate risk management
Knowledge Systems	Institutionalize local knowledge integration	Inclusive and context-sensitive planning
Planning Instruments	Strengthen and enforce existing regulatory tools	Reduced Implementation gap
Governance	Reform coordination and accountability mechanisms	Improved institutional coherence
Management Approach	Embed adaptive and learning-based processes	Long-term resilience and flexibility

The path forwards requires learning from global experiences while developing distinctly Moroccan approaches. Morocco is exposed to a variety of natural hazards and it is worsening because of climate change and the already deeply embedded vulnerabilities related to rapid urbanization. Yet, the kingdom possesses numerous assets such as policy commitment, rich traditional knowledge as well as growing technical capacity. If the country develops a framework adapted to its context it can pave a path towards climate-responsive spatial planning. More importantly, this framework should integrate scientific rigor with local knowledge, and address governance challenges pragmatically as well as prioritizes equity and participation. Therefore, it can serve as a model for other countries facing similar challenges. Overall, this chapter outlined a framework that provides a theoretical foundation that will serve as a basis for more detailed and focused future research.

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