

Heritage Architecture and Climate Resilience: Pathways to Mitigating Natural Risks

Dalel Kaoula ^{*1}

¹ University Blida 1, Institute of architecture and urban planning. kaoula_dalel@univ-blida.dz

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Abstract

Climate change can be understood as a profound and lasting alteration of global weather patterns, largely driven by human activities. The intensification of industrial processes, the reliance on fossil fuels, and unsustainable modes of production have significantly increased the concentration of greenhouse gases in the atmosphere. This accumulation is directly linked to global warming, which manifests through rising average temperatures, melting ice caps, and disruptions in hydrological cycles. The consequences are multifaceted: more frequent and severe natural hazards, extreme weather events such as floods, droughts, and heatwaves, and even indirect influences on geological phenomena, including seismic activity in certain vulnerable regions.

Within this context, the construction industry emerges as one of the most significant contributors to climate change. The sector's impact is twofold: on the one hand, the production of building materials such as cement and steel generates considerable CO₂ emissions; on the other, the operation and eventual demolition of buildings entail high energy consumption. Heating, cooling, and lighting, often dependent on fossil fuels, further exacerbate the environmental footprint of the built environment. This reality underscores the urgent need to rethink construction practices and to explore models that are both sustainable and resilient.

The present study seeks to evaluate the climatic resilience of Saharan heritage architecture, which embodies centuries of adaptation to harsh environmental conditions. Through dynamic simulations, the research has identified the principal sources of vulnerability and quantified their impact on energy performance and environmental sustainability. The findings highlight that traditional Saharan architectural solutions—such as passive cooling strategies, optimized orientation, and the use of local materials—offer valuable lessons for contemporary sustainable design. By integrating these principles into modern practice, it becomes possible not only to mitigate the effects of climate change but also to reduce exposure to natural hazards. Ultimately, this approach demonstrates that heritage architecture can serve as a foundation for innovative, climate-responsive solutions in the construction sector.

1. Introduction

Climate change has become one of the most pressing global challenges, with wide-ranging consequences for ecosystems, societies, and economies. Rising global temperatures, disrupted weather patterns, and the intensification of extreme events are directly linked to anthropogenic greenhouse gas emissions, particularly those resulting from fossil fuel combustion and deforestation (Lafond & Deboin, 2009; Godard & Tabeaud, 2002; Kandel, 2004). These changes threaten biodiversity, human health, and the livelihoods of millions worldwide, while also undermining the stability of infrastructure and urban environments.

Although earthquakes are primarily caused by tectonic movements, recent research suggests that climate change may indirectly influence seismic activity. The melting of glaciers and rising sea levels alter the distribution of mass on Earth, exerting pressure on tectonic plates and potentially triggering seismic events (Replumaz & Lasserre, 2020; Masson-Delmotte et al., 2020). This illustrates the complex interconnections between climatic and geological phenomena, highlighting the need for interdisciplinary approaches to risk assessment.

The building sector plays a pivotal role in amplifying climate change through the production of energy-intensive materials and the consumption of energy for heating, cooling, and lighting. Yet, it also holds significant potential for mitigation. Sustainable construction practices, energy-efficient technologies, and renewable energy integration can substantially reduce the sector's carbon footprint (Aykut & Castro, 2017; Bay-Laffite & Cointet, 2016; Cabeza & Chàfer, 2020).

This study focuses on Saharan heritage architecture as a potential contributor to climate change mitigation. By analyzing the environmental impacts of traditional dwellings and evaluating strategies adapted to this architectural type, the research aims to demonstrate how heritage knowledge can inform sustainable practices and reduce exposure to climate-related risks..

2. Material and Method

2.1 The Method Step

To achieve the objectives of this study, a structured methodological framework was applied. The approach was designed to capture the complexity of environmental impacts across the life cycle of traditional Saharan dwellings.

1. Modeling of the case study: A representative group of dwellings in the Tafilelt district of Ghardaïa, Algeria, was selected. This district is known for its compact urban morphology and traditional construction techniques, making it an ideal context for evaluating resilience. The dwellings were modeled using dynamic simulation tools capable of assessing energy performance and environmental impacts.

2. Evaluation of impacts: The environmental assessment was structured around five categories widely recognized in the literature: greenhouse effect, resource depletion, smog formation, cumulative energy demand, and eutrophication. These categories were chosen because they represent the most significant pathways through which buildings contribute to climate change.

3. Identification of sources: For each impact category, the methodology involved tracing the processes and activities within the building life cycle that generate environmental burdens. This step consisted of systematically mapping energy flows, material inputs, and waste outputs associated with construction, operation, and demolition. The purpose was to isolate the specific sources of impact without yet interpreting their relative magnitude.

4. Proposal of strategies: Based on the identified sources, a set of mitigation strategies adapted to Saharan architecture was formulated. These strategies included greening surfaces to improve thermal regulation, enlarging courtyards to enhance natural ventilation, adopting brick and masonry construction to reduce embodied energy, closed-island morphology to limit heat exposure, and interior zoning to optimize energy use.

5. Comparative analysis: Each strategy was tested through simulation across the three phases of the building life cycle: construction, use, and demolition. The methodology emphasized comparative evaluation, allowing the identification of strategies that performed best under different conditions.

6. Selection of optimal solutions! The final step consisted of synthesizing the comparative results to determine which strategies offered the greatest potential for reducing climate impacts. This methodological framework ensured that the analysis was systematic, transparent, and replicable.

2.1 Case study

The present method was applied to a traditional Saharan built environment, the Tafilelt district. In this context, a group of dwellings was selected for the series of assessments (Fig.1).



Figure 1. The case study: Tafilelt district (Ghardaia-Algeria)

3. Results and Discussion

3.1 Identification of Impact Sources

In order to achieve the objectives of climate change mitigation, five categories of environmental impacts were selected: the greenhouse effect, resource depletion, smog formation, cumulative energy demand, and eutrophication. These categories were analyzed across the entire life cycle of the case study dwellings in the Tafilelt district.

The assessment revealed that the generation of these impacts is closely linked to specific processes within the building life cycle. Cooling requirements emerged as a critical factor, particularly in the hot and arid Saharan climate where indoor thermal comfort is often achieved through energy-intensive mechanical systems. Heating, although less significant in this climatic context, was nonetheless identified as a major contributor to cumulative energy demand, especially during colder periods. Waste management also proved to be a substantial source of environmental burden, as construction debris, demolition residues, and household waste all contribute to emissions and resource depletion.

This identification stage highlights the importance of distinguishing between operational energy use and material-related impacts. It demonstrates that both daily energy consumption and lifecycle waste generation are central to understanding the environmental footprint of traditional dwellings.

3.2 Contribution of Impact Sources to the Different Impacts

The second series of simulations enabled a comparative analysis of the five selected impacts in relation to their sources. The findings indicate that cumulative energy demand is the most significant impact generated, surpassing the other categories by a considerable margin. This dominance reflects the high energy intensity associated with cooling and heating in the Saharan context.

Smog formation and the greenhouse effect were identified as secondary but still substantial contributors. Smog is primarily linked to fossil fuel combustion for electricity generation, while the greenhouse effect is directly tied to carbon dioxide emissions from both energy use and material production. Eutrophication and resource depletion were less pronounced but remain relevant, particularly in relation to waste disposal practices and the extraction of raw materials for construction.

The discrepancy between cumulative energy demand and the other impacts underscores the need to prioritize energy efficiency measures. At the same time, the role of smog and greenhouse gas emissions illustrates the broader environmental consequences of conventional building practices. This comparative analysis provides a clear hierarchy of impacts, guiding the selection of mitigation strategies.

3.3 Climate Change Mitigation Strategies

To reduce the generation of the five impacts, five strategies were tested through simulation:

Refurbishing houses by greening their surfaces: Vegetation on roofs and façades improves thermal regulation, reduces cooling demand, and contributes to air quality.

Enlarging courtyards: Expanded courtyards enhance natural ventilation and daylighting, thereby lowering reliance on mechanical cooling and artificial lighting.

Construction strategies using standard masonry and bricks: These materials, compared to stone or concrete, exhibit lower embodied energy and reduced emissions during both construction and demolition phases.

Closed island morphology: Compact urban forms limit exposure to solar radiation, reduce heat gain, and improve microclimatic conditions.

Interior zoning: Functional organization of spaces allows for differentiated thermal regulation, ensuring that energy is used more efficiently.

The comparative results (Fig.2-Fig.4) revealed that during the construction phase, brick and ordinary masonry generated significantly lower impacts than stone and other strategies. During the use phase, brick construction and closed-island morphology provided the best outcomes, reducing cumulative energy demand and greenhouse gas emissions. In the demolition phase, brick and masonry again proved optimal, minimizing waste-related impacts.

Overall, the strategies demonstrate that traditional Saharan architectural principles—such as compact morphology, passive cooling, and reliance on local materials—can effectively mitigate climate change impacts. These findings confirm the relevance of heritage architecture as a source of sustainable solutions for contemporary building practices.

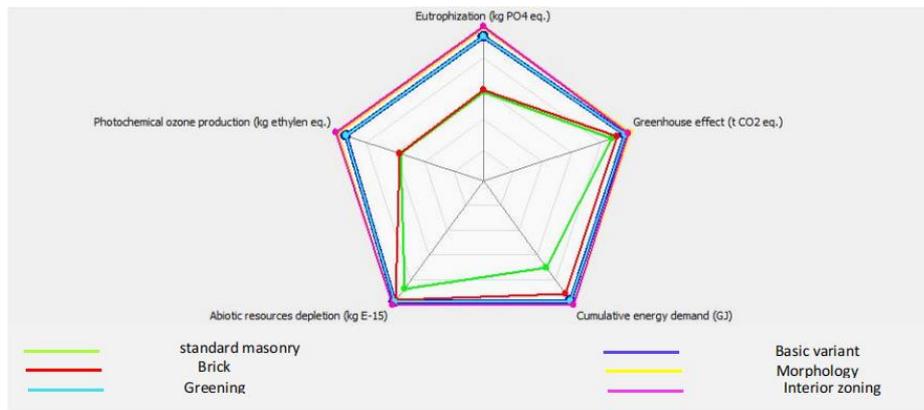


Figure.2. Comparison of climate change mitigation strategies during the construction phase

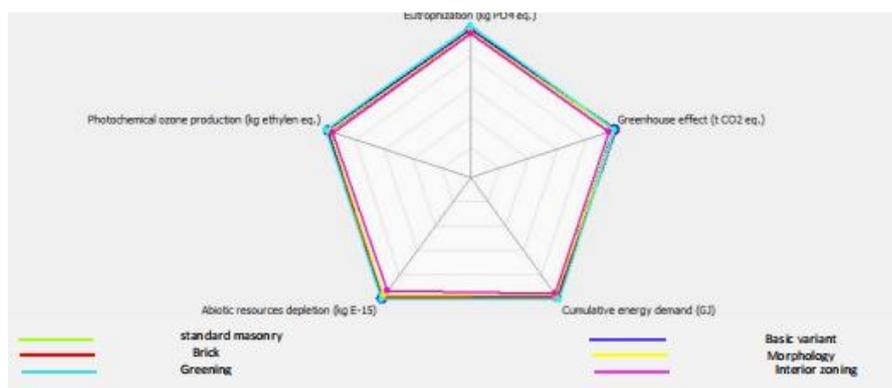


Figure.3. Comparison of climate change mitigation strategies during the use phase

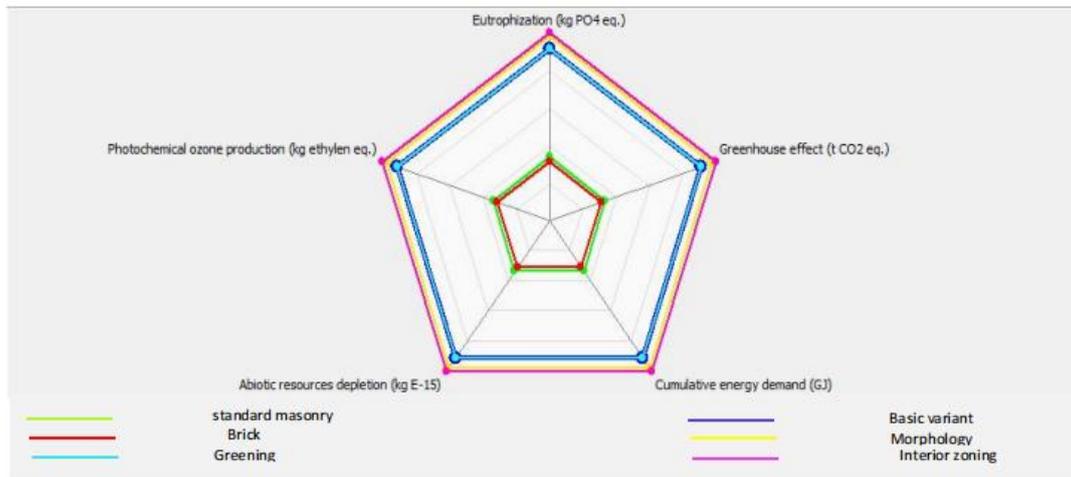


Figure.4. Comparison of climate change mitigation strategies during the demolition phase

4. Conclusion

The integration of sustainable construction methodologies and energy-efficient technologies within the building sector can substantially reduce greenhouse gas emissions. Low-carbon materials, retrofitting of existing structures, and renewable energy adoption are pivotal strategies. This research demonstrates that Saharan heritage architecture, with its passive cooling systems, spatial organization, and reliance on local resources, provides valuable lessons for modern sustainable design.

By transforming current practices, the building sector can mitigate its environmental impact and contribute to a more resilient future. The study emphasizes that heritage architecture is not merely a cultural asset but also a practical resource for addressing contemporary challenges. Its principles can inspire innovative approaches to sustainable construction, bridging the gap between tradition and modernity.

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