



ZERO-CARBON ARCHITECTURE FOR COASTAL COMMUNITIES: INVESTIGATING THE IMPACT OF CLIMATE CHANGE ON VULNERABLE POPULATIONS AND DEVELOPING ADAPTIVE DESIGN STRATEGIES

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Abstract

Climate change poses significant threats to coastal communities, particularly vulnerable populations. This study investigates the impact of climate change on these communities and develops adaptive design strategies for zero-carbon architecture. This study aim to identify effective design strategies and technologies for zero-carbon coastal architecture, prioritizing the needs of vulnerable populations. It explores the potential of passive design, renewable energy systems, and community led design approaches. The study employs a mixed-methods approach, combining case studies, simulations, and stakeholder engagement. The study demonstrates the effectiveness of zero-carbon architecture in enhancing resilience and sustainability in coastal communities. This research has implications for designers, policymakers, and stakeholders seeking to create zero-carbon, climate resilient architecture that supports the well-being of vulnerable populations. The findings inform policy and practice in the architecture and urban planning fields, supporting the development of climate resilient and sustainable coastal communities. The study informs the development of adaptive design strategies, enhancing the resilience and sustainability of coastal communities.

Keywords: Adaptive design strategies, Climate change, Coastal communities, Vulnerable populations, Zero-carbon Architecture

INTRODUCTION

As awareness grows around the uneven effects of carbon-neutral policies on different communities and regions, the idea of a “just transition” has emerged as a more socially fair and widely acceptable strategy for achieving carbon neutrality (McDowall et al., 2023). A just transition emphasizes the inclusive and equitable transformation of economies towards sustainability, ensuring that no group or stakeholder is left behind in the process (Evans and Phelan, 2016; Morena et al., 2020). This framework also critiques current low-carbon transitions for neglecting the root causes of social and economic injustice, which in turn gives rise to new forms of inequality and vulnerability across markets, social groups, and geographic areas (Wang and Lo, 2021).

Coastal regions are key areas where regional inequalities may surface in the shift toward net-zero emissions. While carbon-neutral strategies in these zones are vital for tackling the climate crisis, they often impose significant social and economic burdens on coastal communities. Historically, coastal areas

have been centers of intense human activity, offering ideal conditions for economic and industrial development, such as ports and energy infrastructure. These regions also support rich biodiversity, high productivity, and offer aesthetic and recreational value, making them prime locations for tourism and leisure (Lee et al., 2006).

Climate change mitigation and adaptation policies feature high levels of uncertainty and risk. The sustainable management of ecosystems, along with the decision-making process it entails, typically necessitates the examination of ecological, social, and economic data. The importance of stakeholder engagement in climate change adaptation is underscored by the literature advocating participatory approaches to enhance resilience and foster sustainable development (Roukounis et al, 2024).

The assessment of climate change impacts and the formulation of adaptation and mitigation strategies within the realm of climate economics have traditionally relied on the use of integrated assessment models (IAMs). Furthermore, various adaptation measures for climate change in coastal areas have been explored in the literature, including coastal defense, coastal management, and water management (Dijkstra et al, 2024)

Over the past decade, city governments, private sector developers and urban designers have increasingly worked towards low-carbon and sustainable neighbourhoods. Now is the time to accelerate action and increase our ambition (Hélène et al, 2021).

Coastal communities are at the frontline of climate change impacts due to their geographical location and exposure to sea level rise, storm surges, coastal erosion, and flooding. According to the Intergovernmental Panel on Climate Change (IPCC, 2021), over 680 million people live in low-lying coastal zones, many of whom are in the Global South and are highly vulnerable due to socioeconomic and infrastructural constraints. These communities often lack adequate drainage, storm-resistant housing, and access to essential services, making them more susceptible to displacement, health risks, and economic instability. The compounded vulnerabilities ecological, physical, and social, highlight the urgency of developing sustainable and resilient built environments.

ZERO CARBON ARCHITECTURE

According to an article by International Finance Corporation (IFC) (2025), buildings consume more than half of the world's electricity used for heating, cooling, and lighting. They account for more than one-third of energy-related greenhouse-gas emissions when building materials and construction are added. Because of their huge impact, experts agree that without changing how buildings are built and operated, there is no chance of confronting the climate crisis.

A zero-carbon building is one that achieves net-zero energy consumption or carbon emissions over the course of a year. Ferdinand et al (2018) describe a zero-energy building (ZEB) as “a residential or commercial building with greatly reduced energy needs through efficiency gains, allowing the remaining energy requirements to be met with renewable technologies”. In many countries, zero-carbon or low-carbon buildings have become a key strategy for conserving energy and reducing greenhouse gas emissions. For such changes to gain widespread acceptance, there must be compelling reasons to move away from long-established building practices.

Net-zero buildings integrate innovative architectural designs with energy-efficient technologies. They are insulated and constructed with materials that minimize heat loss, while also incorporating smart systems to monitor and manage energy use. Advanced energy recovery systems ensure that no excess energy is wasted, while cutting-edge renewable technologies like photovoltaic panels or wind energy systems generate clean energy. The importance of net-zero carbon architecture cannot be overstated in the context of today's environmental challenges. As urban populations rise, the demand for energy-intensive infrastructure also increases, leading to higher carbon emissions. Buildings are among the largest contributors to global CO₂ emissions, with operational energy use accounting for a significant portion of the carbon footprint.

Adaptive Architecture and Resilient Design

Adaptive architecture addresses the dynamic nature of climate threats through flexible, modular, and responsive design strategies. In coastal contexts, these include elevated structures to withstand flooding, floating architecture or amphibious housing, mangrove reforestation and green buffers, local material use (e.g., bamboo, palm thatch) for regenerative construction, community co-design to enhance local ownership and knowledge integration.

In the ever-evolving landscape of architecture, the concept of adaptability has become increasingly significant. Adaptable architecture refers to the ability of a structure to respond to changing needs and circumstances over time. In a world marked by rapid urbanization, climate change, and shifting socio-economic dynamics, buildings must be designed not just for the present, but with an eye towards the future. This approach ensures that they remain relevant, functional, and resilient in the face of unforeseen challenges. In this blog post, we will delve into the principles of adaptable architecture, exploring how designers are integrating flexibility and resilience into their creations.

Case studies from the Philippines, Bangladesh, and parts of West Africa demonstrate that locally adapted, low-tech solutions often outperform imported systems in terms of durability, affordability, and community acceptance (Kelman et al., 2015).

While literature on zero-carbon architecture is growing, there is limited research at the intersection of carbon neutrality, architectural design, and community resilience in informal coastal settlements, particularly in sub-Saharan Africa. Most studies focus on urban areas or developed contexts with more resources and institutional support.

Furthermore, there is a gap in comparative analysis of local materials (like bamboo vs. mangrove wood) for both their ecological impact and suitability in zero-carbon coastal architecture.

EFFECTIVE DESIGN STRATEGIES AND TECHNOLOGIES FOR ZERO-CARBON COASTAL ARCHITECTURE

Designing zero-carbon coastal architecture that prioritizes the needs of vulnerable populations such as low-income communities, the elderly, or climate-displaced persons requires a combination of context-sensitive design, sustainable technologies, and resilient planning. These includes:

Passive and Climate-Responsive Design

Passive cooling is commonly understood as a set of natural processes and techniques to reduce indoor temperatures, in contrast to the use of 'active' mechanical equipment. Nonetheless, this binary distinction presents problems in practice, addressed by several authors when stating that the use of minor mechanical equipment such as fans and pumps is allowed under the term 'passive' if their application might result in a better performance (Prieto, 2018).

Passive design is a set of principles and techniques that use natural forces and resources, such as sun, wind, water, and vegetation, to regulate the indoor environment of a building without relying on mechanical systems. Passive design can reduce the energy demand and environmental impact of a building, as well as improve the comfort and well-being of the occupants. Some examples of passive design are natural ventilation, solar heating, daylighting, thermal mass, insulation, shading, and evaporative cooling. The correct orientation to the sun can make up to 30% difference in energy use. Correct orientation can make all the difference between a nice comfortable place to be and an unattractive place you prefer not to be (Rene, 2025).

Use of Local and Low-Carbon Materials

Using local and low-carbon materials in construction promotes sustainable practices, reducing environmental impact and supporting local economies. This approach minimizes transportation emissions by sourcing materials closer to the construction site and reduces reliance on carbon-intensive materials like traditional concrete. It also fosters local industries, provides employment, and can lead to more climate-appropriate building materials.

According to the review by UNCTCN (2025), low carbon building materials and products have been the subject of research and development. This has resulted in many innovative building material products through the use of by-products and recycled products. Some examples of recently developed low-carbon materials and products in the market include but are not limited to:

Low-carbon bricks: These have been rolled out for mass production and implementation since 2009. The use of 40% fly ash (Ritch, 2009) helps to reduce embodied carbon found in conventional bricks. Fly ash is a fine glass powder that consists primarily of silica, iron and alumina. It is a byproduct of coal combustion from electricity generation and is disposed of after being separated from the flue gas.

Green concrete: The raw materials to form conventional concrete can be substituted with byproducts of industrial processes and recycled materials. For example, carbon intensive Portland cement can be substituted by fly ash and granulated blast-furnace slag. Aggregate or sand can be substituted by washed copper slag, and granite by recycled granite from demolished debris.

Green tiles: These are ceramic material made from over 55% recycled glass and other minerals. The products turn waste glass into tiles for use in buildings' internal and external flooring and cladding. The sparkling recycled glass components add an aesthetic quality to the products.

Recycled metals: The production process of metal products is highly carbon intensive. However, the life cycle performance of metal products can significantly reduce their energy production consumption, for example, by 95% for aluminum, 80% for lead, 75% for zinc and 70% for copper. This is because repeatedly recycled metals can still maintain their properties (Stewart et al., 2000). Other forms of

utilizing metal products without the full recycling process (which includes re-melting the old metal products and re-molding them into new products) is to reuse existing metal structural components, such as steel columns and beams that still maintain their structural performance. Lastly, building-unrelated metal products, such as shipping containers, can also be adaptively reused in new building projects.

Renewable Energy Integration

Renewable energy integration refers to incorporating various renewable energy sources, like solar, wind, and hydroelectric power, into existing power grids and infrastructure. This integration is crucial for transitioning to a sustainable and low-carbon energy system. It involves balancing the intermittent nature of renewable sources with the constant demand for electricity, often requiring strategies like energy storage and smart grid technologies.

Renewable Energy Integration focuses on incorporating renewable energy, distributed generation, energy storage, thermally activated technologies, and demand response into the electric distribution and transmission system. A systems approach is being used to conduct integration development and demonstrations to address technical, economic, regulatory, and institutional barriers for using renewable and distributed systems. In addition to fully addressing operational issues, the integration also establishes viable business models for incorporating these technologies into capacity planning, grid operations, and demand-side management (US-DoE, 2025).

Others include: Water and Waste Management, Community-Centered Design, Resilience to Climate Impacts, Scalability and Replicability etc.

An effective zero-carbon coastal architecture strategy must balance environmental performance, cultural relevance, and socioeconomic equity. For vulnerable populations, this means creating safe, affordable, and empowering spaces that respond not only to climate realities but also to community aspirations.

EFFECTIVENESS OF ZERO-CARBON ARCHITECTURE IN ENHANCING RESILIENCE AND SUSTAINABILITY IN COASTAL COMMUNITIES

Zero-carbon architecture enhances the resilience and sustainability of coastal communities by minimizing environmental impact and reducing vulnerability to climate change. It achieves this through efficient design, renewable energy, and smart technologies, significantly lowering carbon emissions and boosting energy efficiency. Climate-resilient features help communities withstand sea-level rise, flooding, and extreme weather.

Key benefits include:

Reduced Carbon Footprint & Energy Use: Integration of solar, wind, and smart systems cuts emissions and improves efficiency.

Climate Resilience: Adaptive designs address local vulnerabilities like saltwater intrusion and storm surges.

Sustainability & Ecosystem Support: Green infrastructure (e.g., green roofs, permeable surfaces) restores ecosystems, reduces urban heat, and enhances biodiversity.

Community & Equity Focus: Engaging locals ensures solutions meet their needs and benefits are equitably shared.

Climatic Adaptability: Effectiveness depends on regional conditions—e.g., solar systems in sunny zones or passive cooling in humid regions.

Holistic Implementation: Success requires a comprehensive approach tailored to local climate, resources, and community needs.

The research adopted a qualitative case study approach to explore zero-carbon architectural strategies in the coastal community of Oworonshoki, Lagos. Data collection involved field observations, semi-structured interviews, focus group discussions, material analysis, and participatory design workshops to understand local vulnerabilities, construction practices, and adaptation potentials. Convenience sampling was employed to select participants, engaging readily available community members, local builders, and stakeholders who were accessible and willing to contribute during the fieldwork period. Although this non-probability sampling method may limit the generalizability of findings, it allowed for practical and timely access to relevant insights within existing resource constraints. Thematic analysis was used to identify patterns across qualitative data sources, with triangulation enhancing the reliability and depth of the findings.

The study revealed that Oworonshoki, Lagos, is highly vulnerable to climate change impacts such as sea-level rise, flooding, and heat stress, which disproportionately affect marginalized groups including women, children, and the elderly. The community's informal housing and poor infrastructure exacerbate these risks, while strong social cohesion and local adaptive practices offer valuable foundations for resilience. Analysis of local materials highlighted bamboo as a more sustainable and structurally viable option compared to mangrove wood, due to its rapid renewability and lower environmental impact. Existing buildings largely lack climate-responsive design elements such as passive cooling and flood resilience. However, opportunities exist to integrate zero-carbon strategies including elevated modular housing, renewable energy systems, and improved water and waste management. Community engagement emerged as essential to ensure design appropriateness and acceptance. Overall, the findings point to a clear need for context-sensitive, low-carbon architectural interventions that address both environmental and social vulnerabilities.

This research demonstrates that zero-carbon architecture can play a pivotal role in enhancing the climate resilience and social equity of vulnerable coastal communities like Oworonshoki. By leveraging local materials, integrating passive design principles, and promoting community participation, sustainable housing solutions can be both environmentally responsible and socially inclusive. The proposed adaptive strategies, including stilted modular housing and renewable energy integration, offer practical pathways to reduce carbon footprints while improving living conditions. Nonetheless, challenges related to cost, policy frameworks, and material durability remain and must be addressed through multi-stakeholder collaboration. Ultimately, this study underscores the necessity of tailoring zero-carbon design approaches to local socio-economic realities and environmental conditions, positioning architecture not just as a technical solution but to foster human dignity and resilience in the face of climate change.

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