

From Resistance to Mediation: Translating Mangrove Ecosystem Principles into Site-Specific Coastal Architecture in Batang Salak, Sarawak

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ABSTRACT

Coastal settlements in Sarawak are increasingly affected by sea-level rise, erosion, ecological degradation and developmental pressures. Conventional coastal protection such as seawalls, revetments and breakwaters, often rely on resistance-based infrastructure which may provide short-term protection but can reduce ecological connectivity and long-term adaptability. This paper investigates how mangrove ecosystem principles can inform site-specific coastal architectural design through a research-by-design study in Batang Salak and Pulau Salak, Sarawak. The study combines literature review, state-of-the-art precedent analysis, site observation, contextual mapping, photographic documentation and conceptual design exploration. Mangrove behaviours such as tidal adaptation, root porosity, wave attenuation, filtration, habitat creation and ecological interdependence are abstracted into architectural strategies. The findings suggest that mangrove-informed architecture is most meaningful when understood not as visual imitation, but as behavioural translation. The paper contributes a site-specific design process that shifts coastal architecture from hard resistance toward adaptive mediation between people, water and mangrove ecology.

Keywords: coastal resilience, mangrove, biomimicry, research-by-design, architecture.

INTRODUCTION

Coastal environments are dynamic territories where land, water, sediment, vegetation, climate and human settlement continuously interact. In tropical regions such as Sarawak, coastal and estuarine landscapes are especially significant because they support biodiversity, fisheries, rural livelihoods, ecological tourism and water-based mobility. However, these environments are increasingly vulnerable to the impacts of climate change, sea-level rise, tidal flooding, shoreline erosion and anthropogenic development pressures. These risks are not only environmental but also social and spatial, as coastal communities often depend on healthy ecosystems for protection, subsistence and livelihood (Steven, A. et al., 2023). According to Masselink and Lazarus (2019), the true definition of coastal resilience is the capacity of the natural and socioeconomic systems in coastal environments to withstand disruptions caused by factors such as sea level rise, extreme storm events and human impacts, by adapting whilst maintaining their core functions. Beyond just the physical and geological protection of coastal areas, a holistic coastal resilience must consider the health of three pillars; society, economy and the environment (NOAA, 2010 as cited in Sutton-Grier et. al., 2015).

Despite this, the response to coastal vulnerability conventionally employs protection strategies that often rely on hard engineering measures such as building seawalls, revetments, breakwaters and embankments. These interventions are often designed to resist coastal forces by establishing a fixed boundary between water and settlement. Although such infrastructure may offer short-term protection under certain conditions, its long-term suitability within dynamic coastal systems has been questioned. Hard coastal structures may interrupt sediment transport, reflect wave energy, contribute to erosion in adjacent areas, reduce ecological connectivity and require repeated maintenance or modification over time. As coastal systems become

increasingly uncertain due to climate change, static forms of resistance may become less responsive to changing environmental conditions.

This paper argues that coastal architecture should not be limited to a defensive paradigm. Instead of understanding resilience solely as the ability to resist water, architecture can learn from ecological systems that have long evolved to survive within such unstable environments. Mangrove ecosystems are particularly relevant to this discussion. Mangroves thrive within intertidal zones which are characterized by fluctuating water levels, salinity, soft soils and changing hydrodynamic forces. Their root systems attenuate wave energy, slow water movement, trap sediment, filter water, support habitat formation and contribute to biodiversity. These characteristics position mangroves not only as ecological assets, but also as sources of architectural and infrastructural intelligence to be mined for the application in coastal resilient solutions.

Within architecture, biomimicry provides a framework for learning from natural forms, processes and systems. However, biomimicry is often misunderstood as mere visual imitation; where buildings are shaped to resemble organisms without necessarily translating their behaviours or ecological logic. In coastal architecture, this may result in designs that appear organic or root-like but do not meaningfully respond to water movement, habitat, sediment, access or programme. This paper therefore positions biomimicry as a behavioural translation rather than aesthetic imitation. The focus is not on making architecture look like mangroves, but on understanding how mangroves can adapt, absorb, mediate, filter, regenerate and coexist. The research is sited in Batang Salak and Pulau Salak, Sarawak, an estuarine coastal context shaped by mangrove ecology, water-based access, village settlement patterns, ecological tourism potential and surrounding development pressures. Instead of proposing a universal model for all coastal settlements, the study examines how mangrove-inspired principles can inform site-specific architectural thinking. The central question of the paper is: **How can mangrove ecosystem principles be translated into site-specific architectural strategies for coastal resilience in Batang Salak, Sarawak?**

This paper then aims to contribute to built environment discourse in three ways. First, it reframes coastal resilience as a relationship between adaptation, porosity and ecological mediation rather than hard defense alone. Second, it demonstrates how mangrove biomimicry can be translated into architectural design through research-by-design. Third, it positions Batang Salak as a site-specific context where ecological principles, local conditions and design exploration can be connected to produce architectural strategies rooted in place.

LITERATURE REVIEW

Coastal Resilience and the Limits of Hard Infrastructure

Coastal resilience refers to the capacity of coastal systems, both natural and socio-economic, to absorb disturbances, adapt to change and maintain core functions over time (Masselink & Lazarus, 2019). However, coastal resilience is often simplified into the physical armouring of shorelines through hard infrastructure. Seawalls, revetments, breakwaters and bulkheads are commonly used to stabilise coastlines and protect assets by resisting or redirecting wave energy. While such measures may provide immediate protection, they may also create long-term ecological and social consequences.

Research has shown that conventional coastal protection strategies are costly to construct and maintain, often resulting in unintended shoreline erosion, habitat degradation and the disruption of sediment dynamics. These impacts are particularly significant in tropical regions, where coastal ecosystems such as mangroves, mudflats and wetlands play a critical role in buffering wave energy and supporting biodiversity. Furthermore, hard infrastructure can negatively affect coastal communities that depend on healthy ecosystems for livelihoods, subsistence and cultural practices (Steven, A. et al., 2023). From an architectural perspective, hard coastal infrastructure is often mono-functional. It protects, but it rarely educates, supports biodiversity, creates meaningful public experience or strengthens relationships between coastal communities and ecological processes. Local news reports offer a longitudinal perspective on the effectiveness of conventional coastal defence strategies implemented in Sarawak, revealing recurring limitations in hard-engineering methods. In Kampung Buntal, a seawall extension project funded by the government was announced in 2016, involving a 600-metre coastal revetment constructed at an estimated cost of RM7

million to RM10 million under the supervision of the Department of Irrigation and Drainage (Utusan Borneo, 2016). The project reflected a conventional resistance-based strategy that depended on physical barriers to mitigate wave action and coastal flooding.



Figure 1: The seawall in Kampung Buntal. Source: Norman Dunstan, Youtube

However, subsequent reports have shown that these measures did not fully resolve the area's exposure to flooding. According to another report by Utusan Borneo in the year 2020, Kampung Buntal continued to suffer from recurrent tidal flooding, with floodwaters affecting at least 20 homes during periods of extreme high tides. Emergency monitoring and evacuation preparedness by response agencies indicates that despite significant financial investment on hard coastal defensive measures, flood risk persisted several years after the project's completion. This temporal contrast highlights a critical limitation of hard coastal infrastructure; while effective in the short term or at specific locations, such structures often fail to adapt to changing coastal dynamics such as sea-level rise, tidal amplification, and sediment movement.

Similar shortcomings are evident in the breakwater development at Kampung Batu Satu, Miri. Completed in 2021 as part of a RM17 million coastal erosion management initiative, the 200-metre breakwater quickly resulted in unforeseen ecological and socio-economic consequences. A report by The Borneo Post (Kiew, 2024) stated that the accumulation of sand, organic debris, and wood chips within the breakwater structure resulted in shallow waters that obstructed fishermen's access to the sea, directly affecting local livelihoods. Authorities later acknowledged that the initial design did not sufficiently account for sediment transport during monsoon seasons, leading to the need for post-construction rehabilitation and design reassessment. Another article in the following year reports that although the breakwater had been successful in reducing wave impact along the coastline, the unintended sediment accumulation has created navigational issues for fishermen, as some areas are now shallower and harder for boats to traverse. The article reports that the Department of Irrigation and Drainage (DID) is required to conduct ongoing excavation works to clear the sediment buildup every fortnight to ensure the waterways remain passable (Moon, 2025). This case underscores how static coastal structures may interrupt, rather than accommodate, dynamic coastal processes.



Figure 2: Ongoing excavation work at Kampung Batu Satu to remove sediment buildup by the coastline.

Source: Katrinna Moon, Borneo Post Online.

In Sarawak, coastal settlements and estuarine environments are shaped by diverse site conditions, including hydrology, topography, settlement morphology, access, livelihood patterns, biodiversity and developmental pressures. This diversity makes it difficult to assume that one standardized coastal protection strategy can respond to all contexts. Therefore, coastal resilience should not be understood only as resistance against water, but as a broader process involving adaptation, ecological integration and social relevance.

Biomimicry as Behavioural Translation

Biomimicry is an interdisciplinary design approach that learns from biological forms, processes and systems to address human challenges (Benyus, 1997; Pawlyn, 2016). In architecture, biomimicry is often associated with nature-inspired forms or organic geometry. However, a more rigorous interpretation of biomimicry requires examining how natural systems function, adapt and interact with their environments.

Biomimetic design can operate at different levels, including organism, behaviour and ecosystem. Organism-level biomimicry often focuses on visible form, while behavioural and ecosystem-level biomimicry engage with performance, relationships and adaptive processes. For coastal architecture, ecosystem-level learning is particularly relevant because coastal resilience depends on relationships between water, sediment, vegetation, habitat, people and infrastructure.

Table 1: Design Aspects of Biomimicry in Architecture.

Design Aspects of Biomimicry in Architecture					
Natural Levels of Biomimicry	Form	Material	Construction	Process	Function
ecosystem	Resembles an ecosystem.	Used the same material as in an ecosystem.	Assembled similarly as an ecosystem, growing complexity over time.	Works similarly as an ecosystem.	Functions similarly as an ecosystem.
behaviour	Looks like it is made by an organism.	Made from the same material an organism uses.	Assembled in the same way an organism would.	Works in the same way as the home of an organism.	Functions in the same way as if an organism would have built it.
organism	Looks like an organism.	Made from the same material as an organism.	Made in the same way as an organism.	Works in the same way as an organism.	Functions in the same way as an organism.

This paper adopts biomimicry as a method of behavioural translation. Mangrove ecosystems are not studied as objects to be copied aesthetically, but as ecological systems whose behaviours can be abstracted into architectural principles. These include adaptation to tides, root porosity, distributed support, wave attenuation, filtration, habitat creation and interdependence. This approach allows biomimicry to become an analytical and design method rather than a decorative reference.

Mangrove Ecosystems as Models for Coastal Architecture

Mangroves are coastal wetland ecosystems that thrive in tropical intertidal environments. They are adapted to fluctuating tides, saline water, soft anaerobic soils and hydrodynamic forces. Their complex root systems,

including prop roots and pneumatophores, increase surface roughness, reduce water velocity, dissipate wave energy and encourage sediment deposition (Mastaller, 1997; Kathiresan & Bingham, 2001). Mangroves also provide nursery habitats for fish, crustaceans and molluscs, therefore supporting biodiversity and local livelihoods (Nagelkerken et al., 2008).

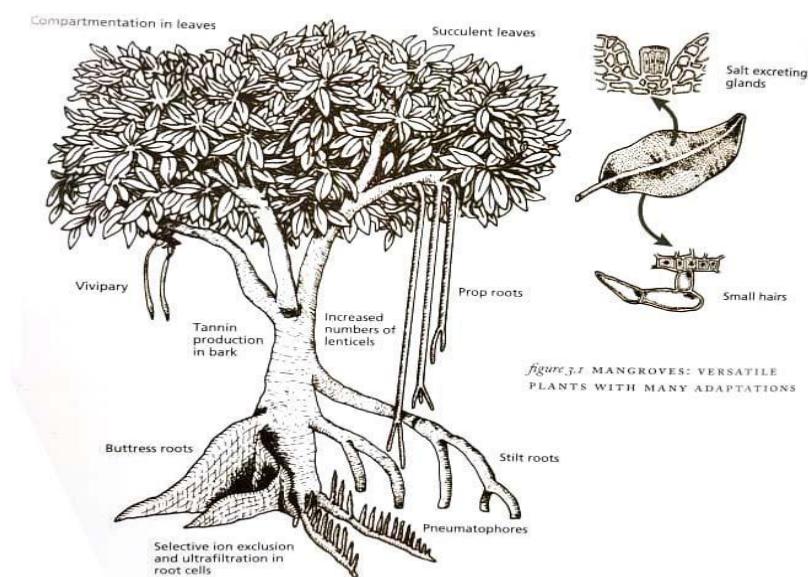


Figure 3: A conceptual diagram illustrating the structural characteristics of a mangrove tree. Source: Mangroves: The Forgotten Forest Between Land and Sea (Mastaller, 1997).

The architectural relevance of mangroves lies not only in their form but is found in their system logic. Mangroves do not operate as solid walls, instead, they act as porous, distributed and living infrastructures. Their roots allow water to pass through while gradually slowing and redistributing its movement. They also mediate between land and sea rather than separating them completely. This quality of mediation offers an alternative design logic for coastal architecture.

For architecture, mangrove principles may be translated in several ways. Tidal adaptation can inform elevated and flood-compatible buildings. Root porosity can inform fragmented spatial organization and permeable circulation. Wave attenuation can inform distributed structural systems. Filtration can inform water-sensitive environmental strategies. Habitat creation can inform ecological edges and multi-species design. Interdependence can inform programmes that connect people, ecology, education and livelihood.

Multi-species Architecture and Co-existence Theory

Architecture has historically been shaped by an anthropocentric worldview that prioritizes human comfort and control while excluding other forms of life. Buildings were designed to separate humans from environmental forces, regulating climate and managing nature as an external condition. This approach treated the environment as something to be managed rather than engaged with. Contemporary architectural theory increasingly challenges this paradigm, recognizing buildings as participants within ecological systems rather than isolated objects. Multispecies architecture emerges from this shift, proposing spaces that support co-existence, interdependence, and care across species. Architecture, in this sense, becomes not just an object, but an active participant in the environments it shapes (Andino, 2025).

This theoretical framework reframes architecture as shared habitat, where design decisions influence ecological relationships and biodiversity. In the context of coastal resilient architectural design, multi-species architecture provides an ethical and practical lens for integrating human activity with wildlife, ecological processes, and habitat creation.

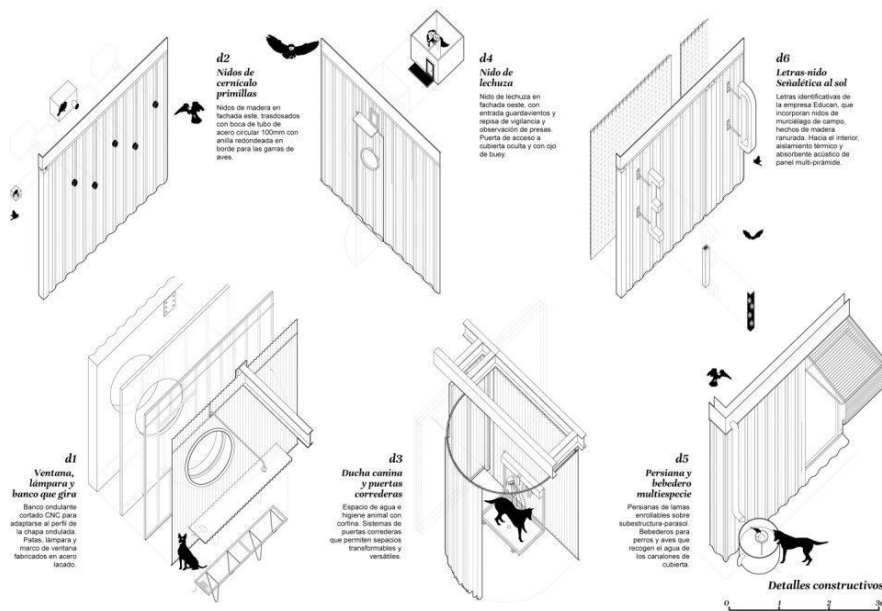


Figure 4: An example of Multi-species Architecture that designs features with considerations for non-human users, illustrated by diagrams of Educan School for Dogs. Source: Art4D.

State-of-the-art Review: Existing Case Studies Demonstrating the Intersection of Biomimicry Architecture and Mangrove Ecosystems

This section of the Literature Review analyses existing precedents of mangrove biomimicry from multidisciplinary backgrounds to gain an understanding of the potential of the application of mangrove biomimicry in built form. The reviewed precedents and research innovations demonstrate that mangrove-inspired design has been explored across several related themes; coastal protection, adaptability to changing water conditions, biodiversity enhancement and water-sensitive environmental systems. Collectively, these examples show how mangrove ecosystems can inform built environment strategies beyond literal visual imitation, particularly through principles such as porosity, wave attenuation, habitat creation, filtration and adaptation.

Theme 1: Coastal Protection and Erosion Control

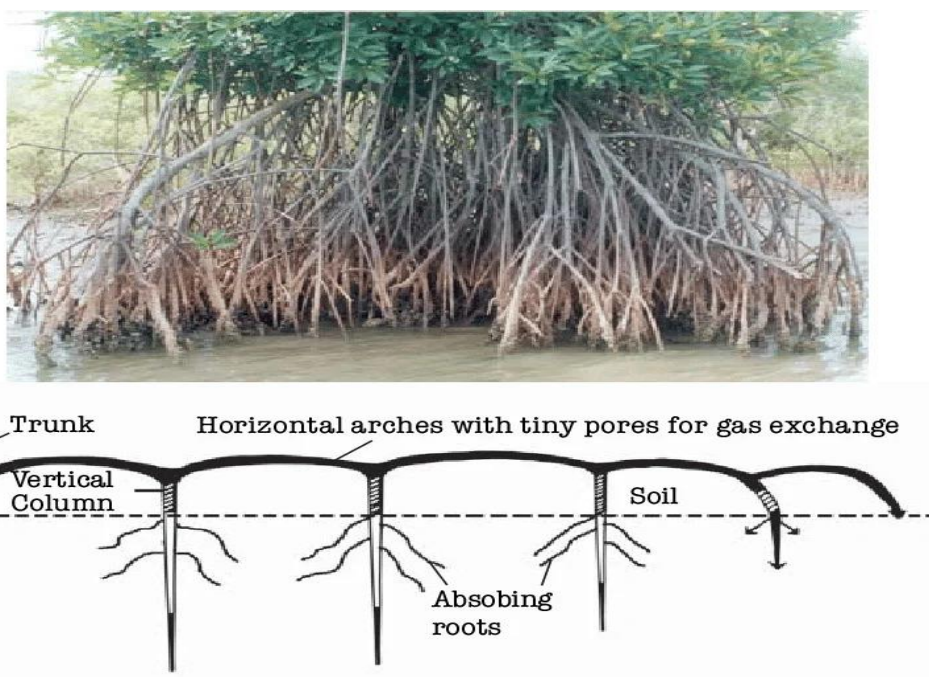


Figure 5: Rhizophora spp. mangrove species. Source: Selvam & Karunakaran (2019)

The first theme concerns coastal protection and erosion control, which relates closely to the porous and irregular root configuration of mangrove species such as the *Rhizophora* spp. Mangrove root networks reduce wave energy, trap sediment and stabilise shorelines through their complex arrangement and permeability. This principle has been explored in several biomimetic coastal barrier studies that use computational fluid dynamics (CFD) to test how root-like forms influence water flow, turbulence and energy dissipation.

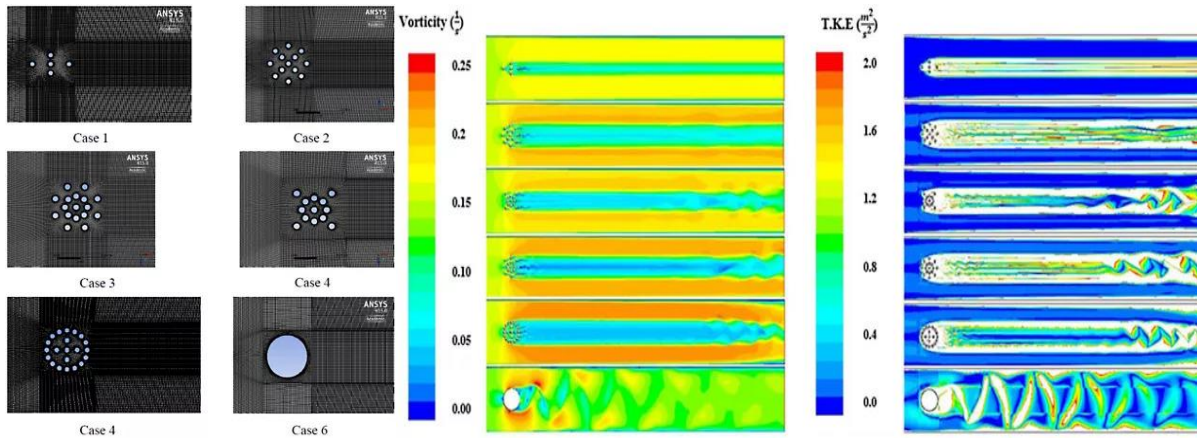


Figure 6: (Left) Six simulated patch configurations. (Middle) Ansys simulations of vorticity. (Right) Turbulent kinetic energy. Source: Van de Riet (2019)

A study by Van de Riet (2019) proposes a biomimetic coastal barrier system inspired by mangrove root formations. The project uses CFD analysis to study how root-like concrete projections affect water flow, vorticity and turbulent kinetic energy. Rather than treating the seawall as a flat and impermeable barrier, the design introduces textured, porous surfaces that allow water movement, create habitat pockets and encourage oyster colonisation. This precedent is significant because it demonstrates how mangrove biomimicry can operate performatively, contributing to hydrodynamic performance, habitat creation and coastal protection. Similarly, Zairudin et al. (2023) investigated biomimetic mangrove structures as a wave attenuation strategy in Kuala Sepetang, Perak. Their study models mangrove root behaviour using circular arrays of cylinders with varying porosity levels to understand how different configurations affect flow and turbulence. The findings suggest that certain porosity configurations can increase turbulent kinetic energy dissipation, indicating the potential of mangrove-inspired structural columns in coastal applications. However, both precedents remain largely focused on hydrodynamic and structural performance with limited discussion of architectural space, user experience or programme integration.

Theme 2: Adaptability in Changing Conditions

The second theme is adaptability in changing conditions. Mangroves exist within intertidal environments where water levels, salinity and ground conditions constantly fluctuate. Their ability to survive between land and sea suggests an architectural principle of accommodation rather than resistance.

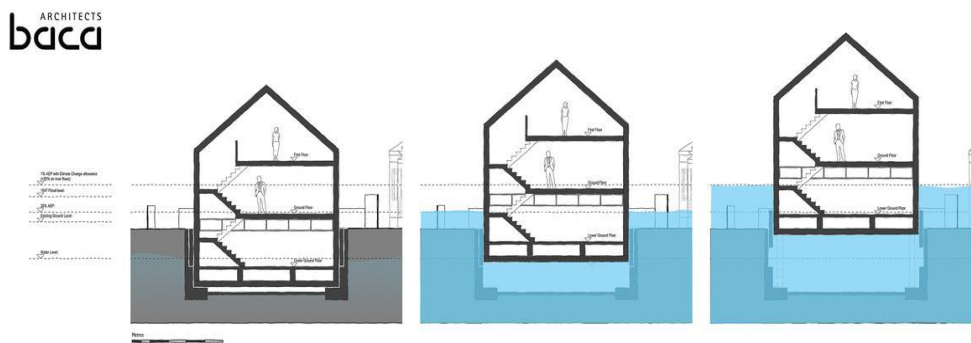


Figure 7: Diagrams illustrating the flood response of the Thames Amphibious House. Source:

The Thames Amphibious House, also known as Formosa by BACA Architects, demonstrates this adaptive approach through an engineered flood-resilient housing strategy. The house normally rests on fixed foundations but is designed to rise within a purpose-made dock when floodwater enters. Through buoyancy, guideposts and flexible service connections, the building can float safely during flood events while remaining connected to utilities. This precedent is relevant because it shifts flood design away from resisting water and toward accommodating hydrological change. However, its focus remains on a private residential building and engineered buoyancy, rather than ecological mediation, mangrove biomimicry or coastal community resilience.

Theme 3: Biodiversity Enhancement and Habitat Creation

The third theme is biodiversity enhancement, which corresponds to the habitat-forming capacity of mangrove root systems. The spaces between mangrove roots create shelter, breeding grounds and ecological niches for different organisms. Architecturally, this suggests that built structures in sensitive coastal environments should not only minimize damage to ecosystems, but may also be designed to support habitat formation and multi-species coexistence.

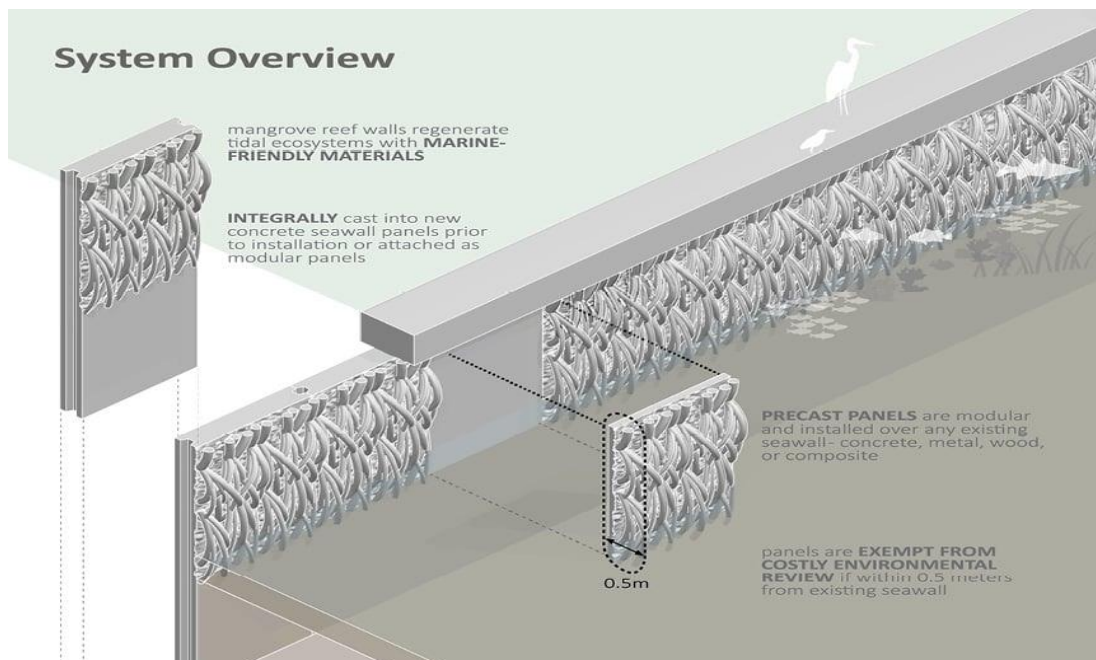


Figure 8: The Mangrove Reef Wall. Source: <https://www.theplan.it/eng/award-2022-Special-Projects/mangrove-reef-walls-parametrically-modeled-and-digittally-fabricated-seawall-panels-which-imitate-nature-keith-van-de-riet-university-of-kansas-architecture>

Mangrove Reef Walls by Keith Van de Riet explores this principle through a biomimetic seawall panel system that imitates the form and function of red mangrove roots and oyster reef habitats. The panels are parametrically modelled and digitally fabricated to produce textured, root-like surfaces that can be attached to conventional seawalls. These surfaces help dissipate wave energy, provide habitat niches, support oyster attachment and enhance the ecological value of hardened shorelines. This precedent is important because it combines erosion mitigation with habitat creation, showing how coastal infrastructure can become more ecologically productive.

Another relevant precedent is the Educan School for Dogs, Humans and Other Species, which demonstrates a multi-species architectural approach. The building incorporates nesting spaces for different bird species with each nest carefully positioned and sized according to species-specific behaviours. Kestrel hawk nests, owl nests, perches and bat habitats are integrated into the structure, allowing the building to support both human and non-human users. Although this project is not coastal or mangrove-specific, it is relevant

because it shows how architecture can deliberately accommodate biodiversity through small but intentional spatial and structural decisions. This supports the argument that coastal architecture in ecologically sensitive areas should move beyond avoiding harm and instead consider how design can actively support local habitats.

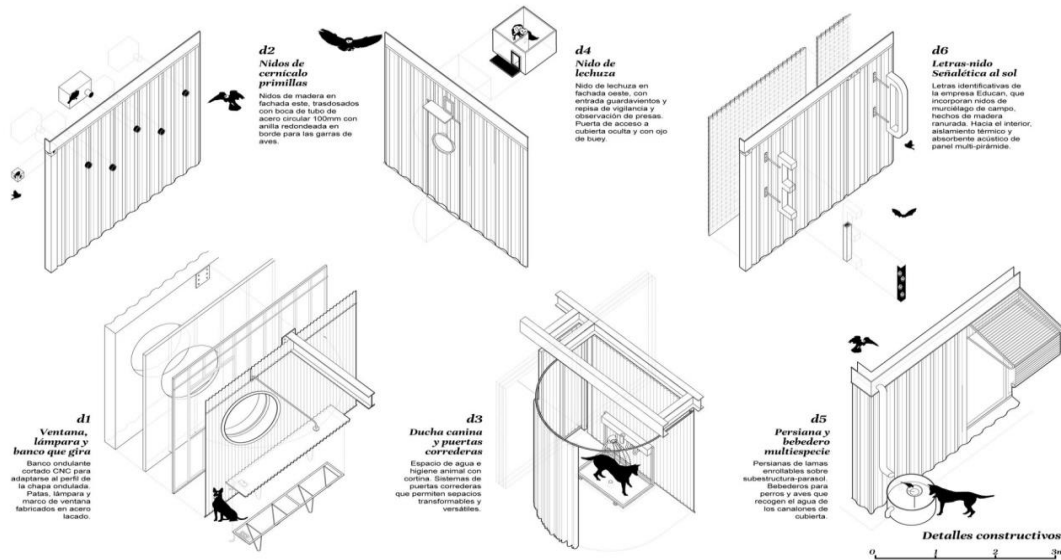


Figure 9: Educan School for Dogs, design considerations for multispecies co-existence. Source: archdaily.com

Theme 4: Desalination and Water Purification

The fourth theme relates to desalination and water purification, inspired by the mangrove's ability to survive in saline environments. Mangroves regulate salt through root filtration, water transport and salt excretion which suggests potential environmental and hydrological applications for biomimetic design.

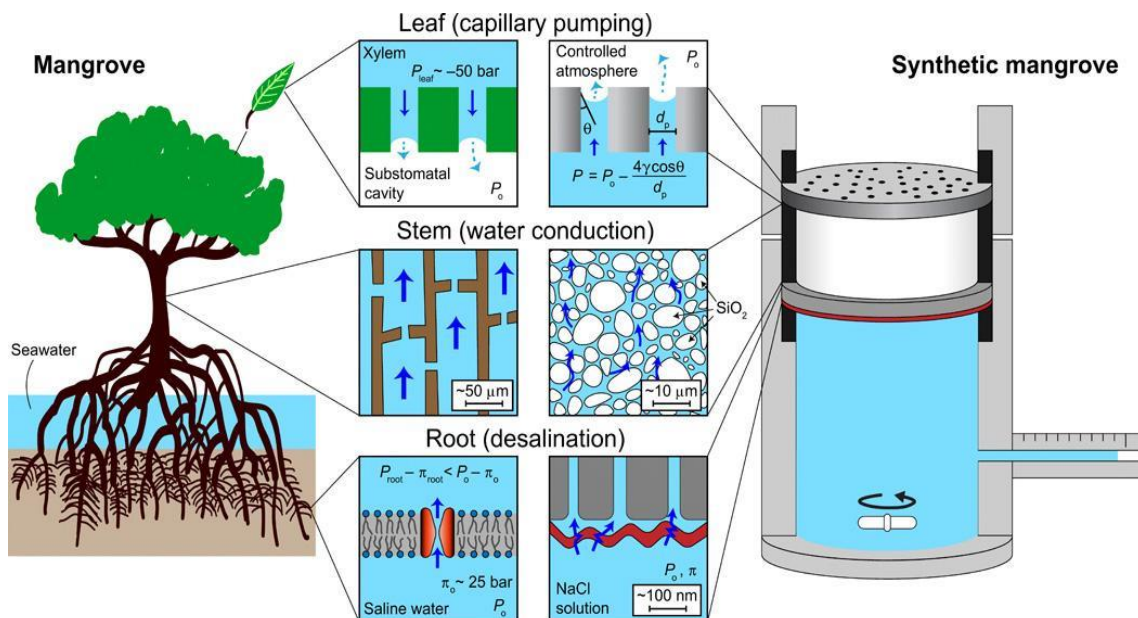


Figure 10: Diagram illustrating the capillary-driven desalination in the synthetic mangrove system. Source: Wang et al. (2020).

Wang et al. (2020) developed a synthetic mangrove system to study how mangrove trees desalinate saline water through capillary-driven negative pressure. The system mimics three main functions of natural mangroves: capillary pumping through leaves, water conduction through the stem and membrane-based desalination through the roots. Their findings demonstrate that mangrove-inspired systems can passively

drive water uptake and desalination. This expands the relevance of mangrove biomimicry beyond structural form, showing that mangrove behaviour can also inspire passive environmental systems. However, the study is primarily technological and focuses on desalination and plant hydraulics rather than architectural space, coastal community context or built-form design.

Synthesis and Research Gap

Overall, the state-of-the-art review shows that contemporary coastal and biomimetic design is gradually shifting beyond conventional hard engineering approaches toward more adaptive, regenerative and ecological strategies. The reviewed studies and precedents demonstrate that mangrove-inspired systems can support wave attenuation, amphibious adaptation, habitat formation, oyster restoration, multi-species coexistence and passive water systems. These examples are significant because they challenge a purely defensive model of coastal design and instead suggest more relational approaches that work with water, ecology and living systems.

However, the review also reveals several limitations. Many existing studies remain focused on technical performance, such as CFD simulation, seawall retrofitting, oyster restoration, material behaviour or desalination technology. While these studies are valuable, they often offer limited discussion on architectural space-making, user experience, programme integration and site-specific community context. Conversely, architectural precedents that demonstrate elevated or amphibious responses to water are not always directly informed by mangrove ecosystems or coastal ecological processes.

As a result, there remains a gap in translating mangrove ecological behaviours into a holistic architectural design approach that responds to both environmental and social conditions. This study positions itself within this gap by exploring how mangrove principles can be translated into site-specific architectural strategies for Batang Salak and Pulau Salak, Sarawak. Rather than approaching biomimicry as visual imitation or isolated technical innovation, this research interprets mangroves as systems of adaptation, porosity, attenuation, filtration, habitat creation and interdependence. These principles are then applied through a research-by-design process to inform an edutourism and research-oriented coastal development that mediates between people, water and mangrove ecology.

METHODOLOGY

The methodology employed in this research is structured as a qualitative research-by-design process, where ecological knowledge, site observation, contextual analysis, precedent studies and conceptual design exploration are used together to inform architectural decision-making. Research-by-design is appropriate because the study investigates how ecological principles can be translated into architectural thinking through iterative design exploration. In this approach, design is not treated only as the final output, but as a method of inquiry.

Site Contextualization

Batang Salak and Pulau Salak were selected as the contextual focus due to their estuarine setting, mangrove-influenced environment, water-based access, village settlement patterns, ecological tourism potential and surrounding development pressures. The site provides a relevant context for examining architecture as a mediator between people, water and ecology. Site understanding was developed through contextual mapping, photographic documentation, sensory observation and analysis of land-water relationships. The site visit and contextual analysis identified several important site conditions. These include boat-based access, river arrival, stilted village structures, mangrove edges, tourism routes, village settlement patterns and environmental pressures such as nearby quarry activity and flood bypass infrastructure. These findings were used to ground the design in local conditions rather than produce a generic biomimetic response.

LITERATURE AND PRECEDENT REVIEW

The literature review examined coastal resilience, limitations of conventional hard coastal infrastructure,

biomimicry in architecture, mangrove ecosystems and multi-species architecture. State-of-the-art precedents were reviewed to identify existing approaches to biomimetic, amphibious, nature-based and habitat-supporting design. These sources established the theoretical and design basis for translating mangrove principles into architecture.

Abstraction of Mangrove Principles

Selected mangrove behaviours were abstracted into architectural principles. Root porosity was translated into permeability and fragmented spatial organisation. Wave attenuation was translated into distributed structural resistance. Filtration were translated into water-sensitive environmental systems. Habitat creation was translated into design considerations for avian and aquatic inhabitation within the building. Interdependence was translated into mixed programmes linking education, tourism, research and community awareness.

Architectural Design Translation

The abstracted mangrove principles were then applied to the accompanying Design Thesis proposal for Batang Salak. The design proposal includes an edutourism and research-oriented coastal development consisting of a mangrove ecology and biodiversity museum, teaching laboratories, seminar spaces, wildlife observation towers, floating amphibious resort accommodations, restaurant facilities and boardwalk networks. The design is used as a conceptual prototype to test how mangrove principles may inform spatial organisation, structural logic, circulation, environmental systems and visitor experience.

Scope and Limitations of Method

The study does not claim to provide full hydrodynamic, structural or ecological validation. Its contribution is found in architectural translation and conceptual design exploration. The research uses ecological and technical literature to inform design thinking but it remains within the discipline of architecture. Community input and site observation are used to support contextual understanding rather than represent the full views of all residents or stakeholders. The outcome is therefore best understood as a site-specific research-by-design process, not a universal prototype for all coastal settlements.

RESULT AND DISCUSSION

The findings of the study show that mangrove-informed architecture is most meaningful when translated through site-specific conditions. The design does not begin with a predetermined form, but with the relationship between mangrove behaviour, Batang Salak's estuarine context and architectural programme.

Batang Salak requires a site-specific coastal response

The first finding is that Batang Salak cannot be approached as a generic coastal site. Its spatial character is shaped by estuarine water movement, boat-based access, mangrove ecology, village settlement patterns, tourism routes and surrounding development pressures. These conditions require architecture to negotiate between water and land, settlement and ecology, conservation and tourism, and human use and environmental sensitivity.

Water-based access is particularly important in this context. Pulau Salak is experienced through river movement and boat arrival rather than conventional road-based entry. This condition suggests that architecture should treat water as part of the circulation and spatial sequence. In the design proposal, this is translated into jetty arrival, pontoon access, boardwalk networks and elevated pavilions.

Existing stilted structures and lightweight village construction also show forms of local adaptation to water.

These local conditions support the use of elevated floors, pile-supported decks and floodable undercroft

spaces. The design therefore does not impose an entirely foreign architectural language, but extends existing coastal adaptation into a more formal architectural system.



Figure 11: Photograph showing the jetty for boat-based access at Kampung Salak. Source: Joanne Ho (2025).

The mangrove edge is another key condition. It operates as an ecological threshold between settlement, river, habitat and tidal processes. This informs a fragmented and porous layout, where built forms are separated into pavilions connected by boardwalks rather than arranged as a single continuous block.

Mangrove principles become design generators

The second finding is that mangrove principles can act as design generators when translated behaviourally rather than formally. The following matrix summarises the relationship between mangrove behaviour, architectural translation and Batang Salak application.

Table 2: Translation Matrix: From Mangrove Behaviour to Architectural Strategy.

Mangrove behaviour	Architectural strategy	Design application in Batang Salak
Adaptation to tidal fluctuation	Elevation, stilts and amphibious structures	Raised pavilions, pile-supported decks and amphibious floating buildings
Root porosity	Fragmented massing and permeable circulation	Clustered museum, boardwalks and open courtyards
Wave attenuation	Distributed structural resistance	Porous pile and exoskeleton system
Filtration	Water-sensitive environmental systems	Rainwater-harvesting system and oyster filtration piles
Habitat creation	Multi-species coexistence design considerations	Wildlife observation towers, birds nesting niches and aquatic habitats under structures
Interdependence	Integrated programme	Edutourism, teaching spaces, research and community integration

This matrix demonstrates that the design is not based on visual imitation of mangrove form. Instead, mangrove behaviours are abstracted into architectural principles and then applied to the specific site and programme of Batang Salak.

Porosity is the Central Architectural Principle

Amongst the identified principles, porosity is one of the most significant for the design proposal. Mangrove roots do not form a solid wall; they create a porous and distributed network that allows water to move through while slowing and redistributing flow. This principle challenges conventional coastal design that relies on rigid barriers.

Architecturally, porosity operates at multiple scales. At the site scale, porosity appears through a dispersed masterplan that allows water routes, ecological zones and pedestrian boardwalks to interweave. At the building scale, porosity appears through fragmented pavilions, open courtyards, permeable edges that allow ventilation and views to circulate and shaded transitional spaces. At the structural scale, porosity appears through repeated piles and exoskeleton elements that create a distributed support system. At the programme scale, porosity appears through the integration of education, tourism, research awareness and ecological observation.

This multi-scalar porosity allows the project to function as an interface rather than a barrier. Visitors arrive by water, move through elevated boardwalks, pass between pavilions and encounter the mangrove edge as part of the architectural experience. The building does not isolate people from coastal processes but instead, makes those processes visible and spatially meaningful.



Figure 12: Aerial view of the Design Thesis Project: Batang Salak Estuary, Edutourism and Research Centre

The edutourism programme supports ecological mediation

The fourth finding is that programme is essential to the architectural translation of mangrove principles. A purely technical coastal structure may protect land but may not change how people understand or relate to the coastal ecosystem. For this very reason, the design proposal adopts an edutourism programme that combines interpretation, public learning, observation, accommodation and research.

The mangrove ecology and biodiversity museum functions as a public interface for communicating ecological knowledge. Teaching laboratories and seminar spaces support educational activities. Wildlife

observation towers frame the wider estuarine landscape and wildlife routes. Boardwalks become learning trails rather than simple circulation paths. Accommodation and restaurant spaces support longer visitor engagement while remaining part of a controlled low-impact tourism strategy.

Through this programme, architecture becomes a mediator between people, water and mangrove ecology. The project is not only an object within the landscape, but a spatial system that encourages awareness, collaborative stewardship and ecological literacy.

DISCUSSION

From Resistance to Mediation

The findings support a shift from coastal resistance to coastal mediation. Resistance implies the separation of land and water through the usage of rigid barriers. Mediation implies the negotiation between environmental forces, human use and ecological processes. In this study, mangrove ecosystems provide a model for mediation because they do not block water completely. Instead, they slow, filter, trap, support and coexist.

This distinction is important for architectural design. A seawall may provide a clear line of defence, but it often produces a hard boundary that separates people from the coastal ecosystem. A mangrove-informed architectural system by contrast, can support elevation, permeability, ecological learning and spatial continuity. It may not replace engineering infrastructure in every context but it offers an alternative way of thinking about how architecture can participate in improving coastal resilience.

In Batang Salak, mediation is expressed through water-based arrival, elevated platforms, porous pile systems, fragmented pavilions, boardwalks and ecological observation routes. The architecture does not aim to eliminate water from the site, but to frame water as part of the spatial and educational experience.

From Visual Biomimicry to Behavioural Translation

This study also reinforces the need to move beyond visual biomimicry. Mangrove-inspired architecture can easily become superficial if it simply imitates the iconic forms of roots. This paper argues that the stronger architectural contribution lies in behavioural translation. Mangroves are valuable not because they look expressive, but because they perform within unstable coastal environments.

In the design proposal, mangrove behaviour is translated into architectural strategies. Tidal adaptation becomes elevation. Root porosity becomes fragmented spatial organisation. Wave attenuation becomes distributed structural logic. Filtration becomes environmental water systems. Habitat creation becomes designed multi-species habitats. Interdependence becomes an integrated programme of tourism, education, research and community awareness.

This approach positions biomimicry as a design method rather than a visual style. It allows ecological knowledge to inform decisions about structure, circulation, programme, water management and user experience.

From Universal Prototype to Site-Specific Process

The study does not claim that one mangrove-inspired prototype can be applied to all coastal settlements in Sarawak. Coastal villages, wetlands and estuarine landscapes differ in topography, hydrology, biodiversity, settlement patterns, access, livelihood and development pressure. Therefore, a universal architectural solution would risk oversimplifying complex local conditions and ignoring actual needs.

The contribution of this paper is instead methodological. It demonstrates a process; observe the site, identify ecological principles, study relevant precedents, abstract design strategies, apply them to a specific context and test them through design exploration. This process may be transferable, but the design outcome must remain site-specific.

For Batang Salak, this results in architecture that responds to boat access, mangrove edges, village adaptation, tourism potential and development pressures. In another coastal settlement, the same process may produce different architectural strategies. This distinction is important because it prevents biomimicry from becoming another generic design formula.

Implications for Built Environment Research

The study contributes to built environment research by positioning architecture as an active participant in coastal resilience. Rather than treating buildings as objects that must be protected by infrastructure, the paper suggests that architecture itself can become part of the mediating edge between people and water.

This has implications for architectural education and practice. Coastal architecture should not be evaluated only through formal appearance or object-based design. It should also be evaluated through how it responds to environmental change, supports ecological relationships, integrates public learning and engages with local site conditions.

The study also suggests that design-based research can play an important role in ecological architectural thinking. While scientific and engineering studies are necessary for technical validation, architectural research contributes by translating ecological knowledge into spatial experience, programme, structural logic and cultural meaning. This translation is essential if coastal resilience is to become part of everyday built environment practice rather than remain only within engineering or environmental science.

CONCLUSION

This paper examined how mangrove ecosystem principles can inform site-specific coastal architectural design in Batang Salak, Sarawak. It began by critiquing resistance-based coastal infrastructure and then explored mangroves as models of adaptive mediation. Through research-by-design, selected mangrove behaviours were abstracted into architectural strategies and applied to an edutourism and research-oriented coastal proposal.

The findings show that mangrove-informed architecture is most meaningful when understood as behavioural translation rather than visual imitation. Mangroves offer architectural lessons through adaptation, porosity, wave attenuation, filtration, habitat creation and ecological interdependence. These principles were translated into elevated pavilions, fragmented massing, boardwalk networks, porous pile and exoskeleton systems, water-sensitive environmental strategies and ecological learning routes.

The paper contributes a site-specific design process that shifts coastal architecture from hard resistance toward adaptive mediation. In the context of Batang Salak, this means designing with water rather than against it, using architecture to connect people with mangrove ecology rather than separating them from it.

The study is limited by its conceptual and qualitative scope. It does not provide full hydrodynamic, structural or ecological validation. Future research should include more detailed simulation, physical testing, ecological impact assessment and participatory engagement with local communities and stakeholders. Nevertheless, the study demonstrates how ecological intelligence can inform architectural thinking and offers a foundation for more adaptive, porous and regenerative approaches to coastal design in Sarawak.

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