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Case Studies

A Conceptual Paper on Major Defects for Residential Buildings Near the Coast in Penang, Malaysia

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Abstract

Residential buildings in coastal areas are often exposed to harsh environmental conditions, leading to recurring structural defects and accelerated deterioration. This study focuses on identifying and evaluating effective strategies for defect rectification in residential buildings in Penang, Malaysia's coastal regions. The research examines common defects, their root causes, and the efficacy of existing mitigation strategies through building condition surveys, expert interviews, and case study analyses. The findings provide actionable recommendations for cost-efficient and sustainable rectification practices, addressing immediate repair needs and long-term building durability. The outcomes of this research contribute to enhancing maintenance management practices and ensuring the resilience of residential buildings in similar coastal environments.

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1. Introduction

Residential buildings in coastal regions are particularly susceptible to unique environmental challenges that can lead to structural defects and accelerated deterioration. In Penang, Malaysia, the coastal environment poses specific threats to the integrity of residential structures. Factors such as high humidity, salt-laden air, and fluctuating temperatures contribute significantly to the degradation of building materials. Wahab et al. [1] identify saltwater exposure and persistent rainfall as primary contributors to structural damage in coastal residential buildings in Malaysia.

Common defects observed in these environments include corrosion of metal components, concrete spalling, and the deterioration of finishes. The presence of chloride ions from seawater accelerates the corrosion of steel reinforcements in concrete structures, compromising their structural integrity [1]. High moisture levels can also lead to mould growth and wood rot, further affecting the habitability and safety of residential buildings. Hanafi et al. [2] emphasise that the combination of salt-laden air and high humidity levels exacerbates the deterioration of building materials in coastal areas. Effective

maintenance strategies are crucial to mitigate these issues and prolong the lifespan of coastal residential buildings. Preventive maintenance, including regular inspections and timely repairs, addresses defects before they escalate. Mydin et al. [3] highlighted the importance of selecting appropriate construction materials that can withstand the harsh coastal environment, thereby reducing the frequency of maintenance interventions.

Building maintenance management faces additional challenges in Penang due to the region's rapid urbanisation and the increasing demand for coastal living. The lack of standardised maintenance protocols and insufficient awareness among building owners about the importance of regular upkeep further exacerbate the problem. Faqih et al. [4] suggest that implementing comprehensive maintenance management systems can significantly improve the condition of public buildings in Penang. This study evaluates the effectiveness of various defect rectification strategies employed in residential buildings in Penang's coastal areas. By analysing current maintenance practices, material selection, and the frequency of defects, the research seeks to provide actionable recommendations for enhancing building durability and occupant safety. The findings are expected to contribute to developing more resilient construction practices and maintenance frameworks tailored to the unique challenges of coastal environments.

In conclusion, addressing the maintenance needs of coastal residential buildings in Penang requires a multifaceted approach that considers environmental factors, material durability, and proactive management strategies. Through comprehensive analysis and targeted interventions, the adverse effects of the coastal environment on residential structures can be mitigated, ensuring their longevity and the well-being of their occupants.

2. Literature Review

2.1. Primary causes of defects

There are several causes of building defects. Given the diversity of materials and construction methods employed, the variations in site conditions, and the diversity of occupational uses of the finished building, this may not be a surprise. According to Hanafi et al. [2] and Mydin et al. [3], mechanical, electromagnetic, thermal, chemical, biological, and natural disasters are the primary causes of building flaws. Water, wind, and wave movement are the three main elements that could cause issues for a coastal structure. These three agents, which include saltwater, powerful waves, wind, and rain (monsoon season), can result in a few faults. As previously stated, seawater is the primary cause of this agent's flaws. Saltwater, also called seawater, is the water that makes up the oceans and seas, comprising over 70% of the Earth's surface. 96.5 per cent water, 2.5 per cent salts, and trace amounts of other elements, such as dissolved organic and inorganic particles, compounds, and a few atmospheric gases, make up seawater [5].

2.2. Moisture-related defects

A defect is "a component has a shortcoming and no longer fulfils its intended function," according to Georgiou [6]. However, according to Pheng and Wee [7], a building defect is "a failure or shortcoming in the structure's function, performance, statutory or user requirements." According to Rhodes and Smallwood [8], there are two types of building defects: patent and latent. In contrast to latent problems, which will manifest once the structure is occupied, patent defects can be found during the Defect Liability Period (DLP) and construction inspection [9]. Wear and tear typically cause construction faults [10]. Moisture issues can result in various building faults, including paint discolouration and stains.

According to Flores-Colen et al. [11], the staining issues in rendered walls are caused by varying moisture contents from various sources, including the ground and rainfall. Rainwater is one of the main reasons for façade discolouration [12].

Water seepage and leaks cause paint discolouration, peeling paint, and blistering wallpaper [1]. (1) Materials such as incompatible materials and the presence of microorganisms, (2) environmental variables like pollution, direct exposure, and moisture infiltration, and (3) chemical effects were the causes of the corrosion defect that occurred at metal sheeting and AI sheet [13]. Mould requires four things to grow: moisture, warmth, nutrition sources like wood, carpet, etc., and viable spores [14]. According to WHO (2009), excessive moisture in building components leads to the growth of microorganisms such as mould, fungi, and bacteria, which can negatively impact indoor air quality and pose a health concern. Most mould issues were found on the walls, floors, and ceilings. Moisture issues have led to construction faults such as peeling paint, discoloured paint, blistering wallpaper, stains, sweating on walls, and water marks or fungus, according to a hospital research by Hanafi et al. [1].

2.3. Defects in the Coastal Area are Mostly Moisture-Related

Buildings near coastal areas are more susceptible to moisture-related defects due to persistent exposure to harsh environmental conditions such as salt-laden air, high humidity, and frequent rainfall. These factors accelerate corrosion of metal components, the degradation of concrete, and the appearance of stains, mould, and dampness on surfaces [1,5].

Salt in the air, especially when carried by wind, infiltrates building envelopes through openings and cracks. According to Kim and Lee [5], corrosion rates in metal components can be up to ten times faster in humid, salty environments than in inland conditions. Chloride ions from sea spray and airborne salts penetrate concrete, compromising its durability and reinforcing steel integrity over time [15].

Wahab et al. [1] highlighted that Malaysia's coastal environment, particularly its tropical climate and heavy monsoon seasons, leads to recurring defects such as cracking, efflorescence, and corrosion, especially in low-cost housing with limited maintenance. These environmental stressors demand more resilient materials and construction methods to reduce early-stage deterioration.

2.4. Strategies and managing defects in coastal areas

Managing building defects in coastal regions requires an integrated approach combining material selection, maintenance planning, and construction quality control. Using durable materials such as marine-grade concrete, fibre-reinforced polymers, and protective coatings is strongly recommended for environments with high chloride exposure [3,15].

Proactive strategies prolong the building's lifespan, such as routine inspections, drainage system maintenance, and scheduled recoating. Olanrewaju et al. [10] emphasised that early identification of minor issues through regular assessments can help prevent costlier repairs in the future. Additionally, incorporating preventive maintenance into the building's lifecycle planning is especially important for public or low-cost housing where budget constraints limit major overhauls.

Further, improving site supervision and ensuring proper artistry during construction are key to preventing defects related to poor detailing or improper installation. As discussed by Pheng and Wee [7] and Georgiou [8], quality assurance mechanisms are instrumental in reducing rework and ensuring long-term performance in buildings near the coast.

3. Methodology

The methodology for this research involves a combination of qualitative and quantitative approaches to achieve the study's objectives:

- *Building Condition Survey:* Conduct detailed inspections of selected residential buildings near the coastal areas of Penang to identify major defects such as cracks, corrosion, and structural deterioration.
- *Interviews with Construction Experts:* Engage with professionals to analyse the primary factors and agents contributing to the observed defects, such as environmental influences and material degradation.
- *Case Study and Comparative Analysis:* Review existing rectification works from similar coastal residential buildings and compare the outcomes of different strategies to determine the most effective and sustainable solutions.

These methods ensure a comprehensive understanding of the challenges and the development of practical rectification strategies tailored to coastal environments.

4. Analysis

The findings of this study indicate that saltwater exposure and high humidity are the primary contributors to structural defects in coastal residential buildings. The presence of chloride ions in seawater accelerates the corrosion of steel reinforcements, leading to concrete spalling and a reduction in structural integrity. Additionally, persistent moisture accumulation facilitates mould growth and wood decay, compromising building durability and habitability. These conditions align with previous research by Wahab et al. [1], highlighting the role of chloride-induced corrosion in coastal building degradation.

The building condition survey results further reveal that using corrosion-resistant materials and preventive maintenance strategies significantly mitigate defect recurrence. Case studies of coastal residential buildings in Langkawi, Malaysia, demonstrate that structures incorporating marine-grade coatings and high-performance concrete exhibit lower deterioration rates than those using conventional materials. In contrast, buildings in Penang that lack standardised maintenance protocols display higher incidences of defect recurrence, suggesting a gap in maintenance awareness and implementation.

Expert interviews highlight cost constraints and limited awareness among property owners as key barriers to adopting sustainable maintenance practices. Many stakeholders opt for short-term remedial measures rather than long-term defect prevention, resulting in repeated structural issues. The comparative analysis of defect rectification strategies underscores the importance of material durability, scheduled maintenance, and reinforcement techniques in enhancing the resilience of coastal buildings.

5. Discussion

The findings underscore the critical need for comprehensive defect rectification strategies tailored to the coastal residential sector. Without proactive intervention, accelerated structural deterioration will lead to increased maintenance costs and potential safety hazards for occupants. This aligns with studies conducted by Mydin et al. [2], which emphasised the necessity of using corrosion-resistant materials and advanced protective coatings in coastal environments.

A preventive maintenance framework should be prioritised, incorporating regular building inspections, protective surface treatments, and waterproofing applications. However, the study identifies financial constraints and regulatory gaps as significant challenges hindering effective

maintenance implementation. Given this, policy intervention is required, including government subsidies or incentives to promote the use of high-durability construction materials. Additionally, enforcing stricter building maintenance regulations is essential to ensure property owners comply with standardised upkeep procedures.

Furthermore, adopting smart monitoring technologies, such as IoT-based structural health monitoring systems, could enhance early defect detection and support predictive maintenance approaches. This would enable property managers to track deterioration trends in real-time and implement timely rectification measures, optimising maintenance costs and prolonging building lifespan. Future research should focus on conducting a life-cycle cost analysis of defect rectification methods to provide data-driven recommendations for policymakers and industry stakeholders.

6. Results

The building condition surveys and expert interviews revealed that the primary defects in coastal residential buildings in Penang are corrosion of metal components, concrete spalling, and deterioration of finishes. Saltwater exposure was identified as the major contributing factor to these issues, with chloride ions accelerating the corrosion of steel reinforcements. High humidity also contributed to mould growth and wood rot, further degrading building materials.

Case studies of existing defect rectifications showed that a combination of preventive maintenance practices and the selection of durable materials can reduce the frequency of defects. Several strategies, including using corrosion-resistant materials, applying protective coatings, and regular inspections, effectively mitigate the effects of the harsh coastal environment.

The study also highlighted the challenges faced by building owners and managers, such as a lack of awareness of the importance of regular maintenance and insufficient standardised protocols for maintenance practices. However, buildings that adhered to a comprehensive maintenance management system exhibited fewer defects and better overall durability.

7. Conclusions

The findings of this research underscore the critical need for effective and sustainable defect rectification strategies for residential buildings located in coastal areas. The harsh environmental conditions in Penang, including saltwater exposure and high humidity, significantly impact the integrity of building structures. By adopting proactive maintenance strategies, selecting appropriate materials, and ensuring regular inspections, the longevity of coastal residential buildings can be significantly improved.

Furthermore, the research emphasises the importance of raising awareness among building owners and establishing standardised maintenance protocols to enhance building durability. With the right combination of strategic planning and expert guidance, mitigating the adverse effects of the coastal environment and ensuring the safety and well-being of occupants is possible.

The study's results and recommendations provide insights for Penang's policymakers, construction professionals, and building managers. They can serve as a model for other coastal regions facing similar environmental challenges.

Declaration of Conflict of Interest

The authors declared no conflict of interest with any other party in the publication of the current work.

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