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A Review of Coastal Protection Using Artificial and Natural Countermeasures—Mangrove Vegetation and Polymers

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Abstract: Any stretch of coastline requires protection when the rate of erosion exceeds a certain threshold and seasonal coastal drift fluctuations fail to restore balance. Coast erosion can be caused by natural, synthetic, or a combination of the two. Severe storm occurrences, onshore interventions liable for sedimentation, wave action on the coastlines, and rising sea levels caused by climate change are instances of natural factors. The protective methods used to counteract or prevent coastal flooding are categorized as hard and soft engineering techniques. This review paper is based on extensive reviews and analyses of scientific publications. In order to establish a foundation for the selection of appropriate adaptation measures for coastal protection, this research compiles literature on a combination of both natural and artificial models using mangrove trees and polymer-based models' configurations and their efficiency in coastal flooding. Mangrove roots occur naturally and cannot be manipulated unlike artificial model configuration which can be structurally configured with different hydrodynamic properties. Artificial models may lack the real structural features and hydrodynamic resistance of the mangrove root it depicts, and this can reduce its real-life application and accuracy. Further research is required on the integration of hybrid configuration to fully optimize the functionality of mangrove trees for coastal protection.

Keywords: hard engineering techniques; soft engineering techniques; coastal protection; hybrid configuration; hydrodynamic resistance

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1. Introduction

In the coastal region, dry land and a maritime environment (water and submerged land) coexist in a zone where terrestrial functions and land uses directly affect the marine environment, and vice versa. Physiological factors such as tides, waves, nearshore eddies, sand movement, and rivers impact coastlines. In several coastal cities worldwide, coastlines cover ecosystems and habitats that generate goods and services for the local population. Coastal areas also serve as the origin or backbone of the national economy [1].

According to Zanuttigh, erosion and flooding presently pose serious hazards to coastal communities, so developing defense mechanisms capable of dealing with the increasing sea level and more frequent storms caused by climate change is a significant challenge [2]. Different techniques are used to protect coastlines against erosion, including hard engineering and soft engineering. In hard engineering, solid structures are used to withstand erosion pressures, such as sieves, dikes, embankments, piers and revetements, and breakwaters. The use of soft engineering methods of coastal protection involves taking into consideration all aspects of preservation, including environmental, sociological, and economic aspects, and utilizing smaller structures made of natural materials. Currently, many parts of the world prefer natural coastal defenses that employ vegetation such as mangroves [3–6].

Mangroves are vegetation formations that develop on alluvial soils in coastal and estuarine locations which are frequently inundated by ocean tides. Researchers have extensively studied the performance of mangrove forests in reducing waves caused by erosion, including [7–9] who conducted laboratory experiments on mangroves as coastal protection. Mangrove trees have been proven and used in several locations as a solid structure capable of shielding coastlines against erosion. For decades, this has led to problems in establishing natural coastal protection, for example, mangrove-seedling-trees being destroyed by waves or tides before they have a chance to grow firmly, which requires at least two years of plantation. Planting them requires temporary structures, according to Verhagen [10]. As a result of this challenge, a natural coastal protection system combining natural and temporary artificial structures is recommended [11].

Mangroves grow in tidal zones along estuaries and coastal areas. While considering mangrove regeneration, it is crucial to consider the appropriate habitat and planting strategy. Their species are selected based on the existing species in the surrounding region as well as their access to seed. Yuanita et al. conducted a physical modelling experiment on different configurations using four different types of model settings without mangroves and with the presence of mangroves. A modelled mangrove seedling was carried out in a wave flume made of iron bars [12].

Several studies currently indicate that floods attenuate differently but they fail to address the role of major factors such as slope bathymetry, forest area, forest channelization, plant density, flood amplitudes and durations, etc. in determining those variations. More research is needed to understand how forest and storm features impact flood attenuation rates in mangrove forests so that informed decisions can be made about mangrove management. Natural resources necessary for human survival and growth have historically been found in coastal areas [13]. Today, coastal areas remain attractive due to their abundant ecological benefits. The majority of big cities being located near coastal regions, such as New York, Tokyo, Shanghai, and London, as argued by Nicholls [14], and the population density in coastal regions being three times the global mean, are indicative of society's desire to live near the shore [15]. The socioeconomic status of coastal communities in the UK makes this particularly important due to the UK's diverse coastal areas.

Natural erosion and flooding caused by coastal storms, such as flooding and coastal erosion threats, are becoming more common as a consequence of climate change due to tidal marshes and mangrove [16]. The researchers argue, however, that tidal wetlands are not able to reduce all risks equally, and that hazard reduction is governed by specific conditions. As a result of severe weather conditions, wetland qualities, and relatively large coastal terrain geometries, long-period severe storms that raise ocean levels by several metres for about a day are less effectively attenuated. Although storm damage to vegetation (especially mangrove trees) is often severe, and recovery can take years, wetlands generally assist in reducing erosion.

Slinger and Vreugdenhil demonstrated the importance of nature-based solutions for coastal management using a critical reflection technique centered on the design process. They distinguish four axes in attempting to determine the extent to which a hydraulic infrastructure forms a nature-based solution: the degree of inclusion of ecological knowledge; the extent to which the full infrastructural lifecycle is addressed; the complexity of the actor arena considered; and the resulting form of the infrastructural artefact. They classified traditional and new sea defense facilities on the North and South Holland coasts along the axes indicating how nature-based newly implemented solutions are and how broadly society values and stakeholders are included in the design process [17].

2. Coastal Engineering Protection

The coastal zone is a sensitive area in which the balance could be disturbed by a variety of factors; therefore, engineers, planners, and government agencies must pay close attention to detail before proceeding with any engineering activities along the coastline. Coastal behavior is largely site-specific, which means that a host of different factors must be considered closely. It is important to ensure that activities near beaches are ecologically sound, particularly in metropolitan areas. In coastal protection, measures are classified as hard (gabions, seawalls, offshore detached breakwaters) and soft (artificial nourishment of beaches, bio shields/vegetation, dune stabilization, geosynthetic application) as discussed previously.

2.1. Hard Engineering Techniques

Typically, hard engineering consists of the erection of gravity infrastructure made up of dunes, concrete structures, or rubble with a trapezoidal cross-section that is designed to withstand the waves along the shoreline. When structures are built along the coast, they are often irreparably damaged. Many of the projects are usually undertaken to provide a quick solution to erosion concerns; they are most effective when they are meticulously constructed with a comprehensive understanding of the wave geography, the local bathymetry, and the sediment properties. Hard engineering structures along the coasts are groins, seawalls, breakwaters, and offshore breakwaters (emerged and submerged). Hard engineering approaches have strong impacts on the environment and are expensive to implement and maintain.

2.1.1. Seawall

This structure prevents erosion immediately along a coastal stretch, but it may not contribute to or expand beach width. It may be necessary, however, in many circumstances to regularly repair seawalls, especially those constructed of rubble mounds. Figure 1 shows a cross-section of the seawall harbor. There are several practical obstacles in transporting tonnes of rubble mound to the beach, as well as in continually fabricating concrete structures to drop along the coastlines. Hard methods and gravity systems can be efficient if the local soil structure are sustainable and construction materials are easily obtained at the construction site location. Gravity systems and hard methods can be efficient if the local soil structure is sustainable and construction materials are easily obtained on the construction site. The disadvantage of a seawall is that waves can erode the wall, defeating its purpose.

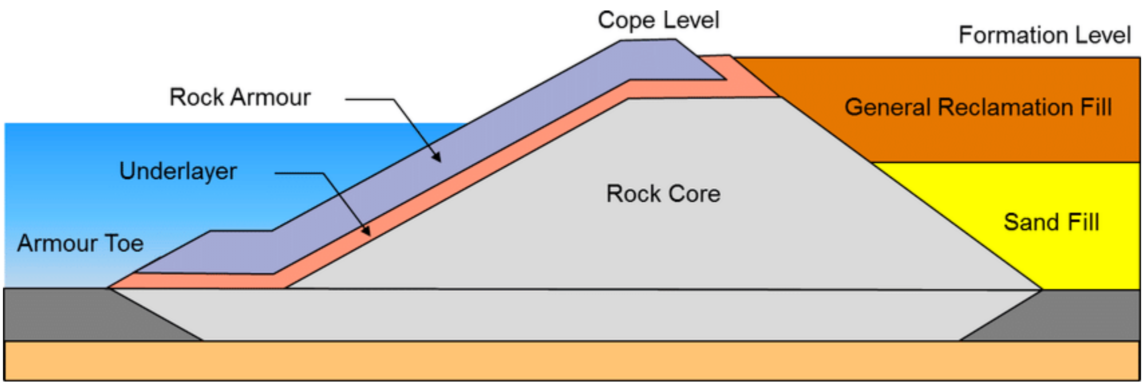

Figure 1. Cross Section of a Seawall. Adapted with permission from Ref. [16], 2013, Firth et al.". More details on "Copyright and Licensing" are available via the following link: https://www.mdpi.com/ethics#10 (accessed on 12 February 2023).

2.1.2. Gabion

According to [16], the utilization of gabion boxes as submarine reefs could be considered a soft engineering solution to counteract coastal flooding since they contribute to fostering ocean life around them. Sundar and Murali went into detail about the use of gabions around the Kerala coast. Gabion boxes are considered a hard engineering solution when used as an alternative to rubble or concrete armour layers in traditional shore-linked structures. The gabion boxes were originally used to repair a damaged seawall cross-section. Although gabions are a hard engineering structure, they are not very attractive and effective [17].

2.1.3. Offshore Detached Breakwater

Breakwaters that are disconnected offshore generate areas of low energy on their leeside, allowing for the creation of salient and, eventually, Tombolos, the details of which are described by Sukanya [18]. The cost and time involved in the construction of offshore disconnected breakwaters have prevented them from being implemented over impacted portions of Indian coastline. Waves are deflected by the breakwaters' ends, creating a quiet zone between them. Their offshore run parallel to the eroding shoreline and contribute to the formation of salient in time, which in turn leads to the formation of tombolo which enlarges the beach. Furthermore, it can also be built as part of wave energy conversion (WEC) systems, such as an oscillating water column [19].

2.2. Soft Engineering Techniques

It is a well-designed measure, which has little or no impact on the coastal environment. Opposed to hard measures, this is a lengthier process. Metrics like these require extensive knowledge. In this term, artificial beach nourishment and natural vegetation are two of the most common solutions. Over time, geo-synthetics were increasingly used in coastal protection measures, where polymer-based synthetic fibers were utilized for drainage, separation, filtration, and retention [20]. The term "soft structures" refers to structures completely or partially composed of geo-synthetic materials, such as seawalls, underwater breakwaters, and submarine reefs.

2.2.1. Coral Reef

Its' unique structures—some emerging from deep levels to the surface of the ocean, and in many cases extending parallel to coasts for tens or hundreds of kilometers—place them on the front line of coastal protection. The structural geometry and ruggedness of reef formations determine their impact on currents and waves. This complicated structure is a result of the biotic proliferation of habitat-forming organisms, particularly hard corals, and coralline algae. In addition to reducing coastline flooding, reef roughness has been found to have a substantial impact on reducing massive energy flows from underlying seas into the reef structure, greatly slowing the action of waves [21,22].

In tropical regions, coral reefs play an extremely important role in dispersing wave energy. On the other hand, fragmented reef patches and channels may be able to enhance or direct tidal energy locally [23,24]. The impact of storms on habitat and the kind of coastal protection provided by reefs must also be acknowledged [25].

Sea level rise also poses a critical threat to reef structures, including beaches and islands that are connected. As evidenced by geological data from the Great Barrier Reef, coral reefs may grow rapidly [26], although such growth is dependent on reef stability. There are many regions where land has formed from coral reef deposits that are sculpted into beaches and islands by storms and sometimes boosted by windblown sediments [27]. A massive analysis of Pacific islands found that, while some islands are shrinking in area and many have dynamic borders, all of these mechanisms could be adequate to allow sustained island expansion or maintenance under some conditions of rising sea levels: despite the slight rise in sea levels that has occurred to date, the total area of coral islands appears to have expanded [28], although coastal development and climate change, particularly ocean acidification, may alter such processes.

Psychologically, sea level rise, as well as the possibility of sea level rise associated with changes in island sediment migration, may pose serious risks even if landmasses are not substantially reduced [27,29,30]. As with coastal wetlands, reef formations have varying impacts throughout space on coastal protection. The primary sources of variability are listed in Table 1. A better understanding of these causes and their measurement is crucial to fully analyze how well a reef protects.

Table 1. Significant variation determinants in the coastal protection function of coastal wetlands and coral reefs. Coral reef data are based on [21,31–36]. Wetlands data are based on [4,35,37–39].

	Coral Reef	**Coastal Wetlands**
Ecosystem determinants	• Prevailing tides • Water depth • Exposure • Distance to shore • Slope • Wave Characteristics • Bathymetric • Topography	• Bathymetric • Topography • Wave Characteristics • Drainage System • Presence and frequency of disturbances • Slope • Distance from sediment source • Exposure • Prevailing tides • Soil characteristics • Distance to other ecosystems • Adjacent land use • Distance to shore • Water depth over plants
Abiotic Determinants	• Presence and proximity of other ecosystems (e.g., seagrass) • Reef width • Levels of bioerosion • Reef profile • Roughness • Dominant species (corals and calcareous algae)-Skeletal morphology, growth rates, disease resistance • Meso-scale structure e channels, fragmentation • Reef surface depth • Resistance and resilience (capacity to survive or recover from impacts)	• Fragmentation • Habitat width • Vegetation structure, salt marshes: plant height, vegetation stiffness • Plant density • Vegetation structure, mangroves: canopy height, aerial root physiognomy, age class distribution, sub-canopy elements • Dominant species • Resistance and resilience (capacity to survive or recover from impacts)

2.2.2. Mangrove Forest

Mangrove trees have been proven and used in several locations as a solid structure capable of shielding coastlines against erosion. This has caused problems for decades in establishing natural coastal protection, for example mangrove-seedling-trees being destroyed by waves or tides before they have a chance to grow firmly, which requires at least two years of plantation. Planting them requires temporary structures, according to Verhagen [10]. As a result of this challenge, a natural coastal protection system combining natural and temporary artificial structures is recommended [12]. Mangrove species are selected based on the existing species in the surrounding region as well as their access to seed. Figure 2 illustrates a natural coastal protection system.

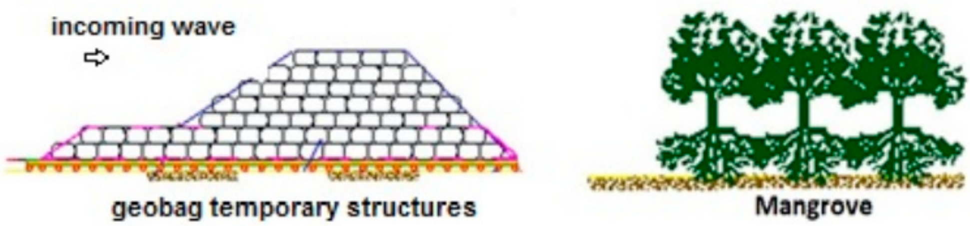

Figure 2. Temporary Structures and Natural Coastal Protection [12]. Reprinted/adapted with permission from Ref. [12]. 2019, Yuanita et al. More details on "Copyright and Licensing" are available via the following link: https://www.mdpi.com/ethics#10 (accessed on 12 February 2023).

A mangrove ecosystem is a tropical or subtropical wetland forest located between the land and the ocean composed of saltwater-adapted trees, shrubs, palms, and ferns. As mangroves grow at or above mean sea level, floods vary from near-constant to irregular [40–44]. Giri et al. estimate that mangrove ecosystems cover 152,400 square kilometres worldwide, distributed across 123 nations, and account for 30–35% of tropical wetland forests [43–45]. They are not one morphological group, but rather a variety of plant species with special adaptations that allow them to survive in the severe intertidal environment [40,42,46].

Traits and Adaptation

With both physiological and morphological adaptations, mangrove plant species are uniquely adapted to frequently waterlogged, salines, and turbulence intertidal environments, including:

- Extensive aerial rooting systems.
- Mechanisms for salt exclusion, tolerance, or secretion.
- Conservative resource-capture and growth strategies, including investments in buoyant, viviparous propagules for several species [47].

Rhizophora species have tall lateral prop roots (or stilt roots). In some cases, as well as in *Avicennia* spp. [e.g., *officinalis*]), shallow but far-reaching aerial roots producing surface-penetrating pneumatophores in *Avicennia*, *Laguncularia*, *Lumnitzera*, *Sonneratia*, and *Xylocarpus* spp., surface-penetrating knee roots in *Bruguiera*, *Ceriops* and *Xylocarpus* spp., plank roots in *Camptostemon* and *Xylocarpus* spp., and buttress-forming stems in *Heritiera* and *Kandelia* spp. assist in stabilising mangrove stems (Figure 3; [41,43,46,47]). In the saline intertidal zone, high root:shoot ratios are a key factor for absorbing water [47], as well as tolerance of strong intertidal disturbances [48]. The presence of lenticels allows root aeration in anaerobic, water-logged sediments with surface-penetrating aerial roots [46,47]. Mangrove roots such as *Aegialitis*, *Aegiceras*, *Avicennia*, *Bruguiera*, *Ceriops*, *Excoecaria*, *Osbornia*, *Rhizophora*, and *Xylocarpus* spp. are also capable of excluding salt from tissues by ultrafiltration; other species actively secrete salt from tissues such as *Acanthus*, *Aegialitis*, *Aegiceras*, *Avicennia*, *Laguncularia* and *Sonneratia* species or from senescent leaves such as *Excoecaria* and *Xylocarpus* spp. [46,47].

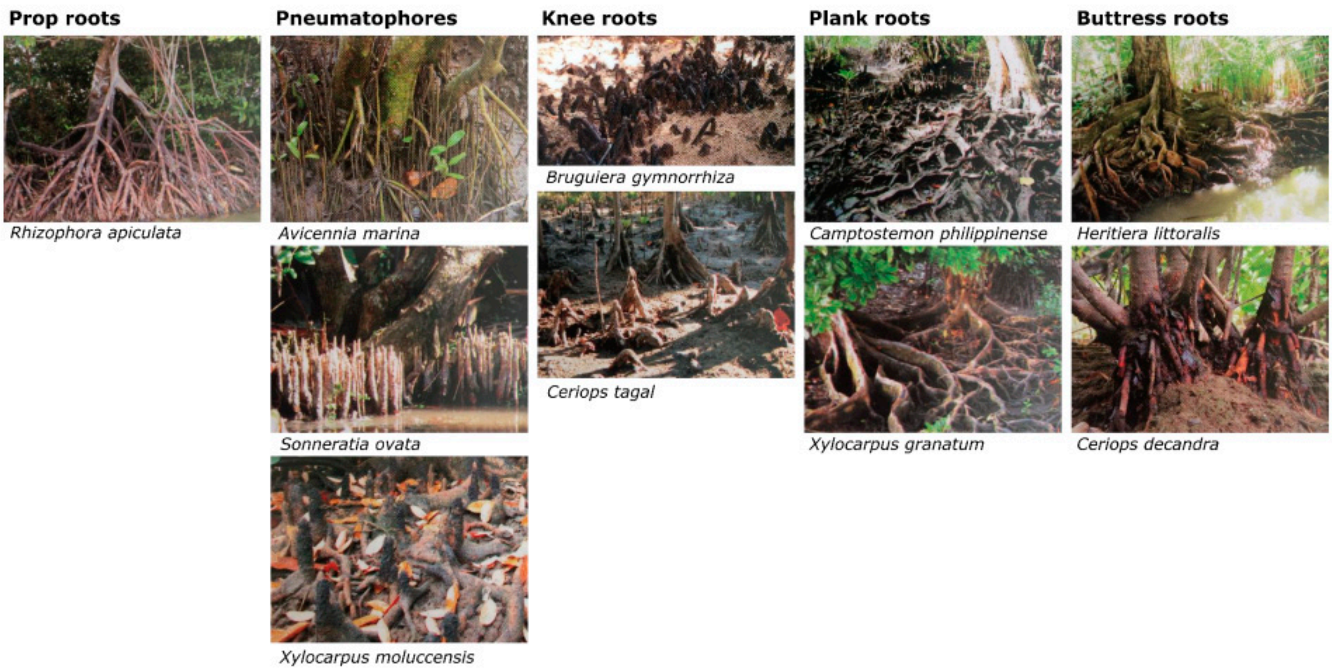

Figure 3. Mangrove Species. Reprinted/adapted with permission from Ref. [41], 2010, Polidoro et al. More details on "Copyright and Licensing" are available via the following link: https://www.mdpi.com/ethics#10 (accessed on 12 February 2023).

Mangrove species make significant investments in leaf production, often producing lengthy, fleshy leaves with tough outer layers of the epidermis and specialised salt excretory glands that reduce transpiration losses at the expense of reduced number of leaves and photosynthetic activity [41,46,49]. *Rhizophora apiculata* mangrove seedlings can be planted on the shore when they are more than 30 cm tall and have four leaves. Seedlings of *Rhizophora mucronata* can be planted when they are at least 55 cm tall and have at least four–six leaves. As mangroves cannot thrive in either wet or dry conditions, they should be planted in places where both wet and dry conditions exist daily.

Experimental Models of Coastal Protection

Models are conducted using a physical modelling experiment on different configurations using four distinct types of model settings without mangroves and with the presence of mangroves [12]. A modelled mangrove seedling was carried out in a wave flume made of iron bars. Different types of configurations are illustrated in Figure 4.

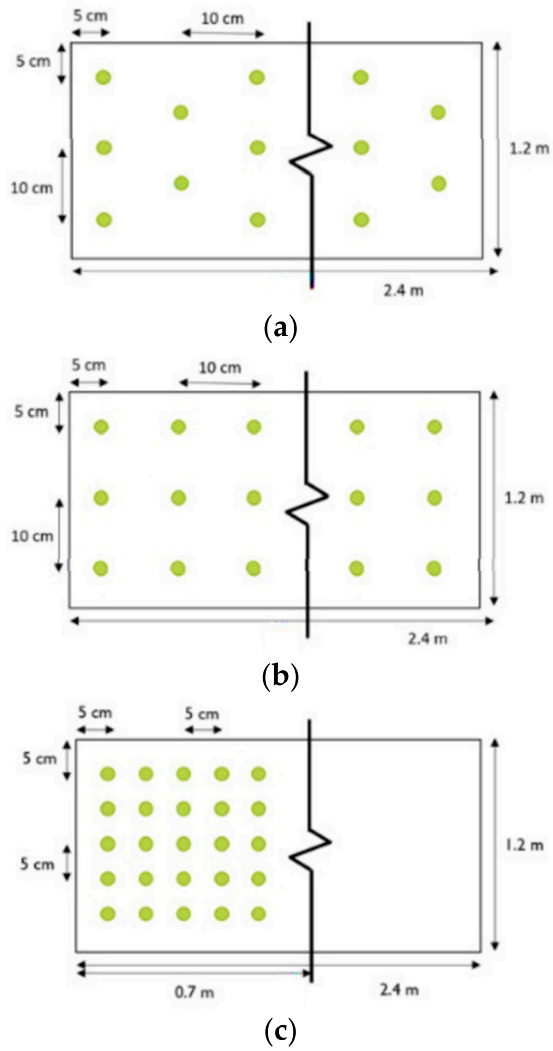

Figure 4. Types of Configuration (**a**) staggered arrangement 10 cm; (**b**) tandem arrangement 10 cm; (**c**) tandem arrangement 5 cm. Reprinted/adapted with permission from Ref. [12]. 2019, Yuanita et al. More details on "Copyright and Licensing" are available via the following link: https://www.mdpi.com/ethics#10 (accessed on 12 February 2023).

In this study, the influence of the mangroves model was examined using the wave transmission coefficient (K_t). A transmission coefficient is the ratio of the transmitted wave height (H_t) to the starting wave height (H_i). To determine the transmitted wave height (H_t), data from wave gauge CH_3 was used, while the initial wave height (H_i) was determined by data from wave gauge CH_2.

$$K_t = \frac{Transmiited\ Wave\ Height}{Incident\ Wave\ Height} = \frac{H_{t\ (CH_3)}}{H_{i\ (CH_2)}} \quad (1)$$

The research objective was to examine the wave height reduction with different mangrove densities, and to investigate the effect of mangrove seedling tree patterns on wave attenuation. The experimental testing was carried out in a narrow wave flume with a mangrove model as the primary natural barrier and geotextile geo-bag models as a temporary constructed construction. During this laboratory experiment, several wave scenarios were established. The study focused on the wave propagation findings over mangrove seedling trees in order to discover the most effective configuration of mangrove tree planting against wave. The results revealed that the wave height reduction in areas with mangroves was twice as big as that in bare land [12].

During the research it was also discovered that the variation in wave attenuation comparing tandem and staggered tree configurations was 20% lesser and that the temporary structure considerably reduces wave height and protects the growth of mangrove seedlings against wave action.

Safari et al. in their study computed the transmission coefficient (K_t) as the ratio of the residual wave height after models to the incident wave height before models in Equation (2) [50,51]. To overcome the limitations of the previously described armour blocs, Hogue et al. investigated the newly designed armour unit, called 'The Starbloc®,' which is made up of a centralized hexagonal core, three legs, and two noses. Its structural characteristics facilitate simplified mobility, much better positioning, and much better hydraulic stability [52].

$$K_t = \frac{Wave\ Height\ after\ Models}{Wave\ Height\ before\ Models} = \frac{H_{aft}}{H_{bfr}} \quad (2)$$

An experimental investigation of the efficiency of artificial Xbloc walls made of hybrid polymer and mangrove root models for water wave defense was conducted by Safari et al., as shown in Figure 5, Ref. [51].

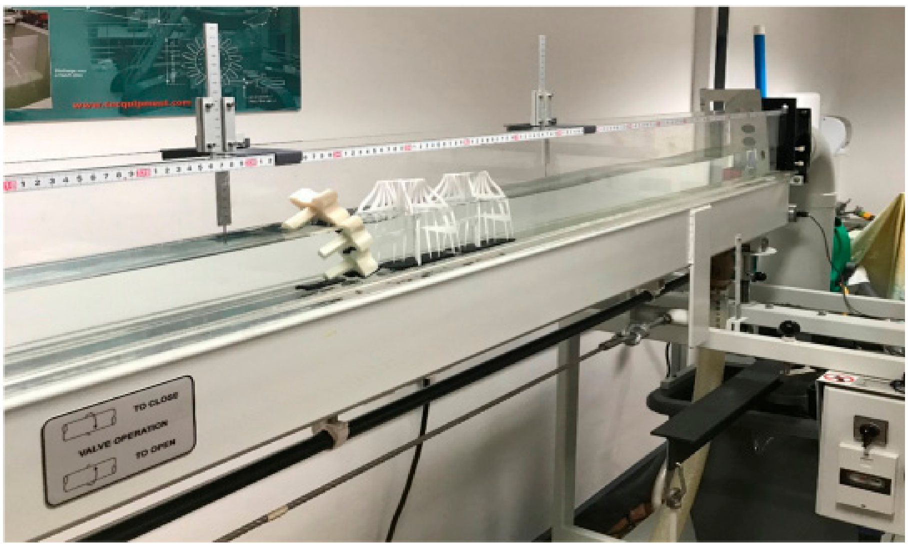

Figure 5. Hybrid Configuration using one Xbloc wall with two mangrove roots in a 5 m flume tank. Reprinted/adapted with permission from Ref. [51]. 2018, Safari et al. More details on "Copyright and Licensing" are available via the following link: https://www.mdpi.com/ethics#10 (accessed on 12 February 2023).

Three Xbloc pieces were placed on each other and bonded with water-resistant adhesive to form one Xbloc wall. Software such as SolidWorks and AutoCAD were used to create fake models, which were 3D printed, laser cut, and superglued. The test was carried out using a variety of single and multiple Xbloc barriers and mangrove root simulations. For six alternative model setups, changes in wavelength, height, celerity, and period were found. The results showed that the celerity, height, and wavelength were successfully reduced, as well as the wave period being lengthened (one cycle time).

In the research carried out, it was discovered that the hybrid configuration of one Xbloc wall and two mangrove roots gave the best protection, lowering the wavelength, celerity, and height by 5.50%, 26.46%, and 58.97%, respectively, and delaying the wave duration by 28.34%. The configuration with only one set of mangrove roots model had the lowest attenuation. As a result, wave reduction utilizing the hybrid action of artificial polymer made Xbloc walls and mangrove roots was superior since it permitted wave energy dissipation to a larger extent than using just Xbloc walls or mangrove roots alone.

As shown in Equation (3), Zwicht computed the transmission coefficient in consideration of wave height and wave energy [53]. Their studies specify the reflection and dissipation coefficients as two additional wave attenuation analysis factors. Their linking method involves the energy balance among the three factors.

$$K_t = \frac{Transmitted\ Wave\ Energy\ (after\ forests)}{Incident\ Wave\ Energy\ (before\ forests)} = \frac{E_{m0,t}}{E_{m0,i}} \tag{3}$$

Hogue et al. investigated the uneven wave attenuation performance of mangrove forests in terms of wave dissipation, reflection, and transmission coefficients. The experiment was carried out in a Twin Wave Flume (TWF), with the bigger flume containing quantified *Rhizopora* sp. mangrove trees and the smaller flume not. *Rhizophira* sp. was extremely efficient in minimising tsunami-induced flow due to the complexity and thickness of its rhizome. The wave energy diminished exponentially throughout the flume forest area, and the amount of the energy dissipated decreased from the front of the vegetation to the end having more wave attenuation at the mangrove forest Ref. [52].

Artificial coastal protection measures were examined by Zwicht, who analyzed the effect of concrete unit weight on the hydraulic stability along with our ability to establish the appropriate computational model of the stability number (Ns) [53]. Based on the model testing, it was evident that as the specific weight increases, so does the hydraulic stability; however, when factoring in the impact of varied gradients, relevant data were obtained. For gradients of 2:3 and greater, stability was observed to be higher than predicted from the previous Ns equation, whereas stability was lower for gradients of 1:2. During coastal protection, the stability of armour bloc units depends on their structure, packing density, and deployment pattern (random or organized). Acropode® and Xbloc®, which are single layer interlocking armour block units, can be damaged by oscillations. As a result of a weak foundation or inadequate interconnections, blocks wobble during this phase of destruction, causing variations in their optimum state.

A laboratory experiment of wave attenuation through cylinder arrays, mimicking wave attenuation processes through a coastal man-grove forest, was conducted in a flume of the Fluid Mechanics Laboratory at Delft University of Technology by Phan et al. The effective length, height, and width of the flume is 40 m, 1 m, and 0.8 m, respectively. Numerical modeling was constructed based on SWASH model using Morrison's equation shown in Equation (4) [54].

$$F_x = \frac{1}{2}\rho C_D h_v b_v N_v U\ |U| \tag{4}$$

The physical model was constructed in a way that the numerical results can be directly compared with the experimental results. A wide variety of wave characteristics, such as regular, irregular, broken, and non-broken waves, were used in the experiment to obtain additional information. The findings support the idea that vegetation can reduce wave heights. Furthermore, the vegetation influenced the set-down of the waves rather than the set-up of the waves. Data from the experiment were used to assess the effect of wave nonlinearity on wave reduction techniques.

Maza et al. investigated the physical processes involved in flow-mangrove interaction, wave attenuation, and drag forces along a 1:6 scale fringe Rhizophora mangrove forest. A 26 m long forest composed of 135 models built reproducing mature Rhizophora mangrove trees with 24 prop roots were used for the experiment. Using both experimental and numerical approach, it was observed that water depth, the accompanying mangrove frontal area, as well as wave height were shown to be the major variables causing wave attenuation for short waves. Wave shoaling was caused by the forest's seaward slope, which increases the wave steepness. Therefore, the pressures imposed on the mangroves began to rise after 3–4 m. Wave decay models that match wave heights well produce smaller pressures farther into the forest [55].

3. Conclusions

Models are critical for forecasting and monitoring mangrove functioning and sustainability. Classification techniques are necessary to characterize mangroves for use in coastal flood risk mitigation. Secondly, experimental and numerical mangrove models may be used to replicate severe flooding circumstances (functionality) and anticipate long term development (persistence) in order to analyze the impacts of climatic and human induced alteration. While mangrove model configuration has been extensively used, the creation of experimental and numerical methods with predictive validity is an ongoing area of study.

Globally, coastal areas suffer endemic problems of human induced problems associated with increase in population growth while dealing with the effect of naturally occurring climate change and increased susceptibility to coastal flooding. Mangrove forests can aid flood mitigation and help adapt to climate change. Mangroves are suitable for minimizing coastal flooding when combined with artificial structures. Many researchers are experimenting with different methods of coastal protection measures using a combination of hard and soft engineering structures as hybrid coastal defense strategies. In order to reduce coastal flooding using mangrove forests, there is need to study, analyze, and simulate the essential processes, patterns, and limitations to mangrove efficiencies.

This review provides an overview of the existing literature on experimental modeling and numerical approaches for the effective use of mangrove trees and artificial polymers in coastal protection. Mangrove roots occur naturally and cannot be manipulated unlike artificial model configuration which can be structurally configured with different hydrodynamic properties. Artificial models may lack the real structural features and hydrodynamic resistance of the mangrove root it depicts, and this can reduce its real-life application and accuracy.

4. Innovation and Future Research Direction

This research is limited to finding the influence of using natural and artificial countermeasures considering different reviews of past literatures on the use of hybrid polymer and mangrove trees. The study is to examine the effectiveness of using the combined polymer and mangrove roots in comparison with each model being used separately for coastal protection. This study recommends the following:

- The artificial models may lack the actual structural features and hydrodynamic resistance of the natural mangrove tree species it depicts, reducing accuracy when used in real-world applications. Further research should be undertaken to model the real-life properties of mangroves so that greater adaptability and resistance can be validated to real life applications.
- The use of digital devices should be adopted for future research to reduce human errors when taking the reading during the process of collecting data.
- The application of Artificial Intelligence and Machine Learning could be applied to predict the future wave reduction in using structural measure and nature based solution.

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