# ENVIRONMENTAL DESIGN OF COASTAL CITIES. COASTAL ENGINEERING, NATURAL INFRASTRUCTURE AND HYBRID APPROACHES FOR THE WATERFRONT

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## ABSTRACT

This research aims at discussing the role of environmental planning, its progress to date and the challenges that arise, all while focusing on coastal cities. In the context of the integrated environmental planning on the coastal front of the cities, it is considered necessary to adopt the protect - accommodate - retreat target. For this purpose, various alternative protective methods and projects are examined, as well as their applicability and degree of acceptance today. The exploitation of natural infrastructure is presented as a relevant alternative to the traditional methods of engineered solutions and mechanical shielding of the coastal front, as protective measures. Currently, there is scientific consensus on the use of natural infrastructure for coastal protection as an innovative and flexible method, easily adaptable to the local conditions, securing additional environmental benefits for the city. In coastal cities, these methods are also employed to tackle challenges and weaknesses resulting from their nature, as ecosystems face additional pressures due to their location within an urban environment. Most coastal cities using natural infrastructure are in the regions of Southeast Asia and the USA. Regarding hybrid approaches of coastal protection, New York appears to be the first city to have developed and implemented such hybrid methods. The research concludes that although natural infrastructure appears to be the desired and more sustainable solution for the protection of cities' coastal front, the implementation of hybrid systems, i.e. the combination of engineered projects and natural infrastructure, is considered more feasible. When choosing hybrid systems, already constructed engineered projects are utilized, benefits of both methods are exploited, while the existence of a "double line" of defense increases the levels of protection of the coastal front and integrates smoothly the water element within the city.

## KEYWORDS

Coastal cities; Coastal engineering, Environmental design; Natural infrastructure; Resilience

## 1. INTRODUCTION

Humanity's inextricable connection with coasts throughout history, has always been an attractive field for scientific research. Especially when studying coastal cities, the interest is growing due to the complexity of interactions, as well as the challenges that arise. When it comes to pressures that affect

the coastal waterfront of a city, geological, geomorphological, climate and anthropogenic impacts are the most observed. However, no matter the origin of these pressures, natural and anthropogenic factors should be examined comprehensively and not in isolation.

Environmental planning, especially when a holistic approach is adopted, offers the appropriate directions and tools. Focusing on the coastal waterfront and on account of its dynamic shape and the constant changes that occur, this system needs to be planned sustainably [1]. Integrated coastal management is the means of organizing urban systems, which generate pressures but are at the same time on the receiving end. The process of environmental planning is continual, and the policies adopted should be examined in terms of their success and their ability to meet the challenges [2].

The coastal waterfront needs to be resilient and this can be achieved through the strategies: protect – accommodate – retreat [3-4]. Protection is accomplished by the traditional method of grey infrastructure and mechanical works, or alternatively by innovative methods such as natural infrastructure and hybrid systems.

Accommodate refers to the strategy of adaptation. Regarding to the relationship between water and the city, adaptation measures must not necessarily call for alienating it from the inner city. On the contrary the strategy of accommodation works towards smoothly integrating water within the city. Natural infrastructure as well as hybrid approaches give solutions in this direction. In many cases, the structure of the city and the level of vulnerability do not allow for adaptation measures.

The strategy of retreat entails the relocation of built environment and infrastructure to safer places. Accepting and implementing this strategy may be controversial, but where deemed appropriate, it must be adopted.

## 2. METHODOLOGY

The methodology of this work is based on the review and comparative analysis of bibliographic data and on the assessment and drawing of relevant conclusions through the study of current applications and case studies, as mentioned in the next chapter.

## 3. RESULTS AND DISCUSSION

### *3.1 Grey infrastructure*

When pinpointing the engineered methods which are more often used to shield the city's coastal front, seawalls, breakwaters, groins, dikes, and floodgates are mostly preferred [5-6]. Land reclamation, though a soft type of infrastructure, nevertheless it is considered as a mechanical work causing similar impact to the neighboring physical and anthropogenic environment. Barrier islands can be constructed by using the technique of land reclamation for the purposes of protection. However international practice proves that most of the times land reclamation technique is used to create added space in favor of the city.

Grey infrastructure remains the most popular and commonly used method for the protection of the urban coastal waterfront due to the credibility and effectiveness of engineered methods [7]. This method is also advantageous in terms of limited space demand, quick construction and application and immediate operation. Additionally, having expertise in the construction of grey infrastructure proven by the multiple successful applications internationally, makes them a preferable choice for the coastal waterfront.

At the same time, the weaknesses of grey infrastructure are increasingly observed. Limited flexibility, maladjustment and high constructive and maintenance costs are most frequently highlighted. From an environmental perspective, engineered works cause serious disturbances to the coastal ecosystems and limit the levels of biodiversity. In addition, in some cases this

type of shielding initiates hydrologic changes which lead to events of erosion.

Moreover, engineered solutions frequently cause degradation of the water quality and pollution, when they facilitate the entrapment of waste. In recent years, the ever changing conditions as well as extreme events can lead to exceeding the carrying capacity of engineered infrastructure [8-9]. As a result, designers turn to alternative methods for the protection of the urban coastal waterfront.

### *3.2 Natural infrastructure*

Natural environments and ecosystems such as mangrove forests, wetlands, salt marshes, seagrass, coral and oyster reefs contribute to the protection of coasts [8]. The importance of these ecosystems as habitats, for providing resources and maintaining high air and water quality, has already been established.

Lately, researchers study another aspect of these ecosystems, as a means of protection. Their positioning at the waterfront of the city can act as a barrier, buffering and weakening wave energy and height, as well as absorb and store large amounts of water before it reaches the inner city [9-10].

Concerning their installation, it is important to note that in many coastal cities these ecosystems preexisted the urban expansion and were gradually degraded or converted to built environment. In these cases, designers should primarily examine the possibility of restoring the ecosystem, as it happened in Hong Kong and Shenzhen, where large areas of wetlands and mangrove forests were successfully restored [11-12]. But, even if there is no ecosystem as a basis, or restoration is impossible, it can be created from the beginning. When cities are located in estuaries, deltas or bays, installation of natural infrastructure is favored, but they can also survive at more exposed waterfronts.

Regarding the evaluation of natural infrastructure, scientific studies increasingly prove that ecosystems can work to meet the objective of protection, even if it is not always possible to accurately quantify the contribution. It is a fact that the wider the area they occupy, the more effective they are. Simultaneously they do not stand as a barrier to the natural process of sediment transportation; on the contrary they work on the enrichment of the coast, giving a solution to erosion phenomena [13-14]. The ecosystems' ability of self-preservation reflects their adaptability and flexibility which is contrasted to the grey infrastructure's inflexibility.

The cost of restoration or creation of natural infrastructure is by far lower than the cost of engineered shielding [8, 15-16]. Moreover, self-sufficient ecosystems demand the least of human intervention. Except for the ability to protect, natural infrastructure provides multiple environmental benefits to the city; and ecosystems can also form a leisure space for the community to the extent possible.

As an innovative and not well-established method, there are also some weaknesses to examine. The uncertainty of effectiveness as well as the lack of expertise are noted as the main reasons why hesitation is observed and limited applications of natural infrastructure as a means of protection have been tracked to date. There is also great uncertainty about their response to extreme weather events. At the same time, other barriers can be the limitation of space as well as the time needed for the ecosystem to reach mature period in order to achieve its utmost contribution.

Except for the weaknesses resulting from their nature, ecosystems face additional pressures due to their location within an urban environment, which alters the conditions and erodes their effectiveness. All kinds of pollution, acidification, eutrophication and invasive species are only a few of these pressures.


*Figure 1. Coastal Cities using Natural Infrastructure*

### *3.3 Hybrid approaches*

Hybrid approaches constitute empirical combinations of grey and natural infrastructure. Hybrid systems can be defined as a synergy of two or more types of infrastructure, in order to obtain combined benefits and eliminate their respective weaknesses [17]. In some cases, grey infrastructure works as the first line of defense, ensuring suitable conditions for the natural infrastructure to grow. Lately, designers study the opposite form, where natural infrastructure grows seawards [18]. Regarding the effectiveness of hybrid systems, it must be noted that establishing a double line of defense can contribute importantly to achieving the aim of protection.

At the same time and besides the defensive orientation, hybrid approaches can offer the environmental benefits of the natural infrastructure, provided that they are not degraded due to the existence of grey infrastructure. The strategy of protection in this case can be seen as a cooperation with nature. Including grey infrastructure in these innovative systems, provides a feeling of security until natural infrastructure becomes recognized as an effective method of protecting the coastal waterfront [19]. Additionally, grey infrastructure gives the time needed for the ecosystems to reach their maturity by bridging the gap of protection in the meantime.

When designing a hybrid system, planners should take into consideration the interactions between different types of infrastructure, in order to avoid undermining one another. It has been noted that not all combinations are sustainable. Grey infrastructure, when installed as a first line of defense can help ecosystems grow, but on the other hand there is a possibility to stem the flow of sediments, which is essential for the ecosystems. Scientific knowledge is lacking in this area and the applications are limited. New York is one of the first cities worldwide to incorporate hybrid approaches to its plan [20].

In recent literature, ecological design of grey infrastructure is often described as a hybrid approach [21-22]. Regarding this argument, it must be noted that this kind of interventions should not be expected to provide the benefits of natural infrastructure. Incorporating natural characteristics to grey infrastructure is successful in eliminating some of the weaknesses of engineered solutions, making them more environmentally friendly. Ecological designing in terms of adjustments to already existing infrastructure turns out as an easy to take decision and many cities are taking this into consideration. However, until today the applications of ecological design are small scale and mostly in the cities of Canada, Australia, USA, in Scandinavian Countries and the Netherlands [23].

## 4. CONCLUSIONS

The research concludes that although natural infrastructure looks initially like the desired and more sustainable solution for the protection of the cities' coastal front, the adoption of hybrid systems, i.e. the combination of engineered methods and

physical infrastructure, is considered more feasible.

Grey infrastructure has gained the approval of the vast majority and remains the most popular method of shielding the coastal waterfront. The target of this method is exclusively the protection of the city. In cities where engineered methods are applied for its protection, excessive feeling of safety is observed which is misinterpreted as an opportunity for further urban expansion. The expansion in these cases may lead to increased vulnerability of the waterfront. Environmental planning should not be trapped in a vicious cycle of creating even bigger and taller mechanical works.

Natural infrastructure, as an alternative method, can change the way the coastal waterfront is designed, as it combines protection and adaptation. They work as a natural barrier protecting the city, while enriching biodiversity, capturing carbon dioxide and improving water quality. Regarding the natural infrastructure's weaknesses, the demand of space is a common difficulty in coastal cities and the demand of time may cause insecurity in cities that need urgent protection. Limited applications evidence the hesitation to accept alternative methods. To this contributes, inter alia, the difficulty to quantify protection and environmental benefits.

Most coastal cities using natural infrastructure are in northern America and southeast Asia. Developing countries and Small Island Developing States show an interest in natural infrastructure due to the low costs and the fact that in many cities' ecosystems preexisted and restoration is a feasible target. Generally, in European cities, even though there is enough space for natural infrastructures to grow, grey infrastructure is promoted for the protection of the waterfront.

Hybrid approaches, i.e. the combination of engineered methods and natural infrastructure, seem to provide multiple benefits and eliminate the weaknesses of both methods, if/when they are applied independently.

When natural infrastructure in hybrid systems grows seawards, it offers a solution to the lack of space. This also provides the advantage of making use of grey infrastructure that has been already placed in most coastal cities. Moreover, hybrid approaches allow for innovative planning and design, customized to the needs of coastal cities.

In conclusion, infrastructure at the coastal waterfront should form a barrier, but not necessarily with a defensive orientation, which often leads to dead ends. Progressively even more cities show an interest in gentrifying environmental planning towards more sustainable and resilient paths. This means that planning should re-evaluate the relationship between water and the city. Natural infrastructure can accommodate this change through the smooth integration of water within the city.

Natural infrastructure remains the most desirable choice, however hybrid approaches qualify as the most feasible method for coastal cities. Hybrid systems are making use of already existing infrastructure and facilitate the incorporation of natural infrastructure.

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