Chapter

Coastal Adaptation: Past Behaviors, Contemporary Management, and Future Options

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Abstract

In the recent past, coastal public works solutions were generally designed as engineering problems. By that time, prior to the 1980s, the primary goal of coastal works projects was to maximize safety, taking into account only engineering knowledge and existing economic constraints. Today, concerns are no longer limited to safety; lifestyle and quality of life have become essential ingredients in building a successful coastal works project. Other aspects of the project are also important, such as environmental impact, attractiveness, and sustainability. These additionalcomplexities are further aggravated by other pieces of the puzzle that need to be integrated into the overall design, such as the non-engineering and non-science aspects. A synthesis of recent concerns regarding coastal public works projects has, in fact, become much more difficult for engineers to manage due to new assumptions of value, social acceptance, and sustainability of these projects. In this context, it is common knowledge that decision-making on a coastal issue should be based on criteria such as technical effectiveness, costs, benefits, implementation, and monitoring. This chapter addresses coastal issues using a dual perspective of meeting current needs and ensuring future sustainability. Contemporary adaptation measures and future accommodation options are also discussed.

Keywords: coastal issues, decision-making processes, public participation, coastal protection, adaptation strategies, future accommodation

1. Introduction

Coastal zones are interface regions between the mainland and the sea that are dominated by (1) processes that originate in the drainage basins of tributaries, (2) oceanographic and atmospheric processes, and (3) anthropogenic activities at different orders of magnitude and scales.

As recipient bodies, coastal areas not only receive the benefits of proper river basin management, but also suffer from the harm associated with or resulting from inefficient management processes. In particular, low water quality, sediment extraction, and sediment retention in structures implanted in the fluvial systems are the most evident factors that affect the use, natural resources, and activities that may occur in the coastal zones. The small amounts of sediment that flow into coastal areas are a matter of great concern to coastal managers, since this lack of sedimentation results in the disappearance or devaluation of beaches and the weakening of natural protection systems.

To take into account these concerns and other concerns resulting from ongoing and future impacts from climate change, managers must approach coastal zones management different than they did in the past. Inadequate management methodologies are still common practices today in many countries that have fewer resources or less concern about global climate change.

We may learn from the past that most defensive measures have been more reactive than proactive. In addition, the intervention procedures in the coastal zones, whether for the purposes of valuation or implementation of protection measures, should be improved.

Until recently, much of the coastal engineering projects were almost exclusively based on experience. As discussed in Kamphuis [1], it was in this context that many of the coastal defense works were carried out and resulted in kilometers of breakwaters, sea walls, and groyne fields for defenses against flooding and urban fronts, recovery of degraded areas, and protection of heritage of great historical and cultural value.

It is common knowledge that hard engineering structures can be effective when properly designed and installed. However, because they are continuously subjected to events that in many cases exceed their design capacity, such structures require adequate and costly maintenance. On the other hand, it is also known that these structures tend to reduce erosion and the risk of flooding in one location, but increasing the risk in another.

Meanwhile, with the evolution of the numerical methods and the computational means, it has become possible to use increasingly sophisticated mathematical models to solve complex coastal engineering problems. The use of ever more powerful, less restrictive and more user-friendly computational models, along with physical modeling, is today a common practice in coastal engineering.

On the other hand, it is of utmost importance to involve interdisciplinary groups that cover different perspectives (such as policy makers, civil and environmental engineers, geologists, biologists, economists, sociologists, lawyers, etc.). These interdisciplinary groups should include local communities and stakeholders at different stages of project development, including design, building, and monitoring.

Indeed, public participation, including stakeholders, is considered as a key principle when planning and implementing conservation projects. The same view is shared by Hedelin et al. [2] and Barceló [3], who clarifies in an Elsevier editorial note *when people are ignored and conservation measures are put in, we see opposition, conflict and often failure. These problems require the best available evidence, and that includes having both natural and social scientists at the table*.

In this context, the guidelines on coastal defenses have changed. Contrary to the coastal defenses built in the past, contemporary adaptation measures include: artificial sand nourishments, possibly with additional sand support measures; building and rehabilitation of dunes; creation and restoration of wetlands; reinforcement or creation of submerged longitudinal bars; submerged breakwaters made of geotextile tubes; buffer zones; and land use restriction and zoning.

Other measures, which are less common, but may become essential in the near future, include: building on pilings; adaptation of drainage systems; building emergency flood shelters; and tidal houses, houseboats, and floating houses.

Reconciling current activities in the coastal zones with the maintenance of healthy ecosystems requires monitoring, systematic evaluation, and implementation of corrective measures. Indeed, it is generally understood and practice has shown that when planned, preventative adaptation will be more cost-effective and efficient in the long run than retroactive measures. Therefore, identifying and addressing needs and gaps in policies and planning will strengthen the adaptive capacity of regions and local communities.

In economic terms, coastal zones' natural wealth and the wide diversity of activities taking place make these regions the main source of revenue for many countries. In fact, coastal zones are currently (1) important areas of food production through agriculture, fishing, and aquaculture, (2) the main tourist destinations on all continents, (3) significant sources of mineral resources, including oil and natural gas, (4) foci of industrial development and transport, and (5) abundant reservoirs of biodiversity and ecosystems, on which the functioning of the planet depends.

However, some decreases in attractiveness or decreases in the demand rate have been observed. On one hand, these decreases will contribute to the maintenance and sustainability of coastal ecosystems, but such behavior can also result in socially unsustainable conditions.

In fact, unfavorable circumstances in coastal zones include: (1) large concentrations of people and services in sensitive or risk areas, leading to artificialization of certain stretches; (2) insufficient or inefficient services (housing, security, health, catering, banks, leisure, bathing, etc.) to meet more needs during high-demand seasons; (3) scarcity (in quantity and quality) of water resources in seasons of increased demand and consumption; (4) great specialization of some economic activities, directed to very specific users and in very restricted periods of the year; (5) a poorly designed, non-existent, or very permissive arrangement of spaces with unbridled/abusive and uncontrolled occupations; (6) greater speculation, with uncontrolled costs and often incompatible with the quality of the services provided; (7) numerous situations of stress/confusion incompatible with rest (e.g., physical and mental recovery) that are sought; and (8) of least concern, the interests and well-being of the residents throughout different times of the year.

It is indispensable to ensure the availability of the amount and quality of water resources needed. However, excessive consumption of water beyond sustainable availability can lead to irreversible degradation. Particularly worrying is the contamination of groundwater due to excess of water consumption from coastal aquifers, leading to exaggerated lowering of groundwater levels and the salinization of these waters. For example, **Figure 1** shows stains of the wells and boreholes that exist in the Algarve coastal zone (southern Portugal) and 17 aquifers (M1, M2,..., M17) with regional expression [4].

The impact of saline intrusion on freshwater aquifers and the penetration of salt water in the estuaries will be substantially aggravated by global warming and the consequent rise in mean sea level. Due to excessive water consumption, coastal aquifers contamination by saltwater intrusion is already a reality in some southern European countries. Portugal is an example, particularly in the southern coastal region of the Algarve (**Figure 1**).

To cope with water scarcity in the months of greater tourist influx, in which the population reaches at least three times the resident population, two dams were built in the mid-twentieth century (Arade and Bravura). Subsequently, a third dam was built in the 1980s (Beliche), which was followed by the building of two more dams in the 1990s (Funcho and Odeleite), and more recently a sixth (Odelouca).

The heights of these dams vary between 41 and over 90 m and with maximum storage capacities between 2.7×10^7 and 13.5×10^7 m^3 [4]. However, these dams also suffer the effects of water shortages in the hottest months of the year, which coincide with periods of higher consumption.

In addition, high pollutant loads discharged directly into the sea without any treatment or with an inadequate level of treatment contaminate or pollute the sea, thereby excluding these waters from bathing uses and natural resources conservation, with considerable environmental impacts. Often, changes in environmental factors give rise to qualitative changes in established ecosystems (e.g., specific composition, biodiversity, etc.).

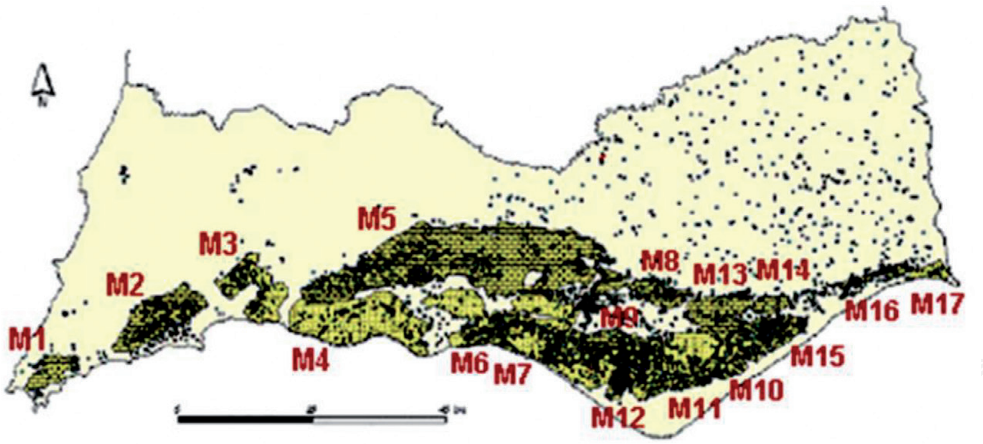


Figure 1.
Well and borehole stains (blue points) and 17 aquifer systems (Mx) that exist with regional expression in Algarve, Portugal (Adapted from [4]).

2. Traditional and contemporary decision-making procedures in coastal management processes

From the procedural point of view, the implementation of works in the coastal zone followed a very simple procedure in a not too distant past. All interventions were focused on the project, which was entirely managed by an engineer. This engineer was responsible for everything and only had contacts with the entity responsible for coastal works. The contribution of experts from disciplinary areas with different perspectives did not exist or was very limited. In fact, until the 1980s, the construction of works in coastal zones essentially followed the schematic diagram shown in **Figure 2**.

At that time, the coastal public works were contracted and overseen by the project owner, usually a government entity or a construction/business company, who alone was responsible for project decisions, coastal work implementation, and monitoring of its behavior [1]. Coastal science at that time was essentially physical (hydrodynamics—waves, currents, tides, etc.).

In Portugal, some coastal public works projects that were executed in this context are noteworthy. Until the 1980s, the entire process was carried out in accordance with the procedures shown in **Figure 2**. The interventions were usually based

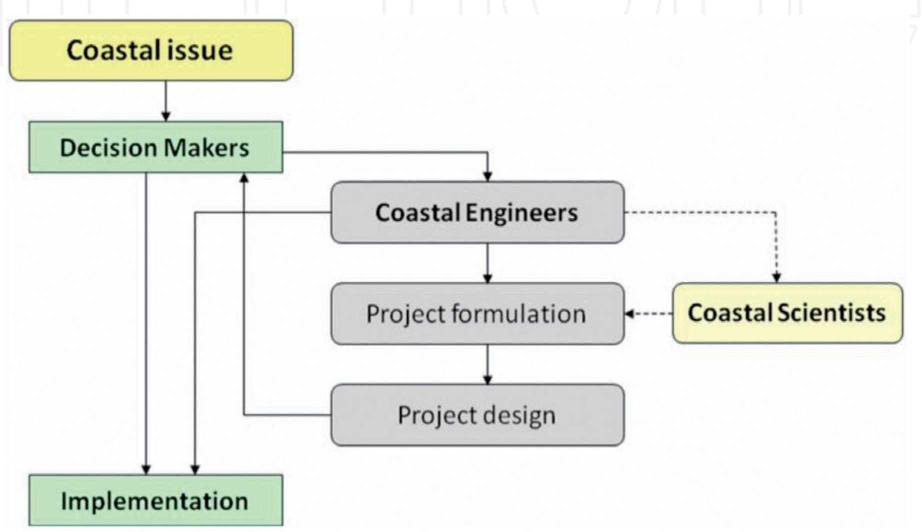


Figure 2.
Traditional decision-making process in coastal zone issues (Adapted from [1]).

on a structural project and lacked impact studies, environmental concerns, public consultation, and intervention/incorporation of the input from local communities and stakeholders.

Figure 3 shows some of the interventions undertaken on the west coast of Portugal in the 1970s and 1980s and with subsequent structural reinforcement. Currently, the urban centers shown in this figure are residential areas at high vulnerability and risk, only maintained at the expense of hard engineering projects.

It should be noted that the option for hard engineering projects was motivated by the general erosion trend of the Portuguese Atlantic coast and, in particular, by the defense of urban fronts. However, in general, these hard structures have had negative consequences along the Portuguese coast, as they have increased coastal erosion in remote areas by impeding the normal circulation of sediments. These projects also led to negative consequences locally as they led to urban expansions often occupying marginal areas as a result of false safety sensations provided by such structures (**Figure 3**).

In the 1980s, the development of more in-depth theoretical knowledge and the evolution of numerical methods and computer hardware occurred. These developments allowed engineers to develop and apply numerical models capable of describing the physical processes with greater accuracy.

It was in this context that the field of hydroinformatics emerged in the 1990s, which is a new scientific branch that links informatics tools, hydraulics, environmental concepts, and models with the overall objective of solving environmental problems in coastal waters. Examples of hydroinformatic environments created for this purpose are the modular structures described in Pinho et al. [6] and Deltares [7–9] (DELFT3D), which are capable of simulating hydrodynamic, morphodynamic, and water quality processes.

These modular structures and other highly complex two- and three-dimensional computational structures are now commonly used to solve real-world problems, particularly in coastal areas. Among the most common are: MIKE21 (https://www.mikepoweredbydhi.com/products/mike-21), POM (http://www.ccpo.odu.edu/POMWEB/), ADCIRC (http://adcirc.org/), TELEMAC3D (http://www.opentelemac.org/), DELFT3D (https://oss.deltares.nl/web/delft3d), and CCHE3D (https://www.ncche.olemiss.edu/cche3d).

Meanwhile, as addressed in [1], concerns in coastal areas are no longer limited to safety issues: lifestyle and quality of life have become essential ingredients. Other aspects of the project have also become important, such as environmental impact, esthetics, and sustainability. The additional complexities were further aggravated by other aspects that needed to be integrated into the overall design, such as

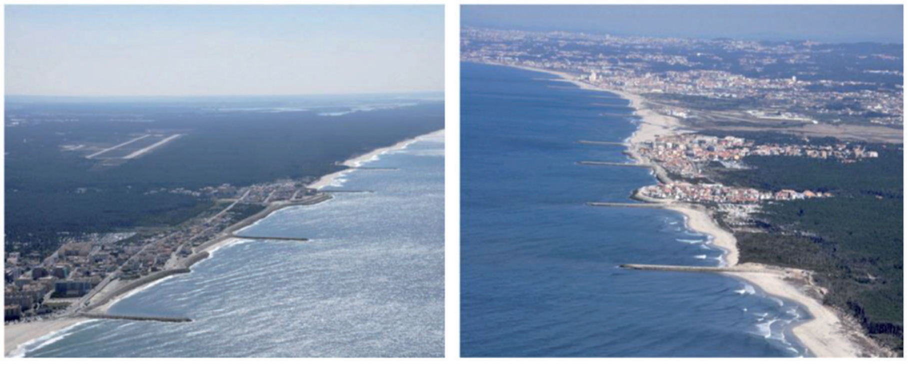


Figure 3.
Urban seafronts protected by sea walls and groins. These residential areas are located at the western Portuguese coast (Mira on left and Esmoriz-Cortegaça on right) and are only maintained at the expense of hard engineering projects (Courtesy of Lopes [5]).

non-engineering and non-science concerns. Examples of these concerns include socio-economic aspects and quality of life, involving leisure, tourism, sporting practices, fishing industries, water quality, etc.

These emerging sociological realities needed to be addressed, as well as the voices of actors and interest groups that would like their input incorporated into the project design. In fact, a synthesis of these recent concerns has become much more difficult to manage since this new reality is based on assumptions of value, social acceptance, and sustainability. The interrelationships presented in **Figure 4** show the current complexity inherent to the contemporary management process of the coastal zone.

The organizational chart shown in **Figure 4** shows that to integrate all social and technical requirements and to facilitate an optimum solution, coastal managers must organize and maintain clear communication between the various actors.

As is clear from preceding discussion, two distinct realities stand out from the traditional and contemporary approaches to the coastal planning and management issues. On one hand, the need to utilize more scientific and technological knowledge into addressing coastal issues is recognized. Therefore, specialists from different disciplines enrich the structural component of engineering design. On the other hand, the need to involve public agents, entities, interest groups, and local communities is recognized in order to ensure the necessary support and social component of the structural component.

These concepts synthesize the current manner of addressing with the coastal issues. The interactivity between both the physical-environmental and socio-economic systems is at the interface of the well-known concept of Integrated Coastal Zone Management, which requires the integration of different disciplinary expertise from local, societal, and practical knowledge within coastal planning and decision-making processes.

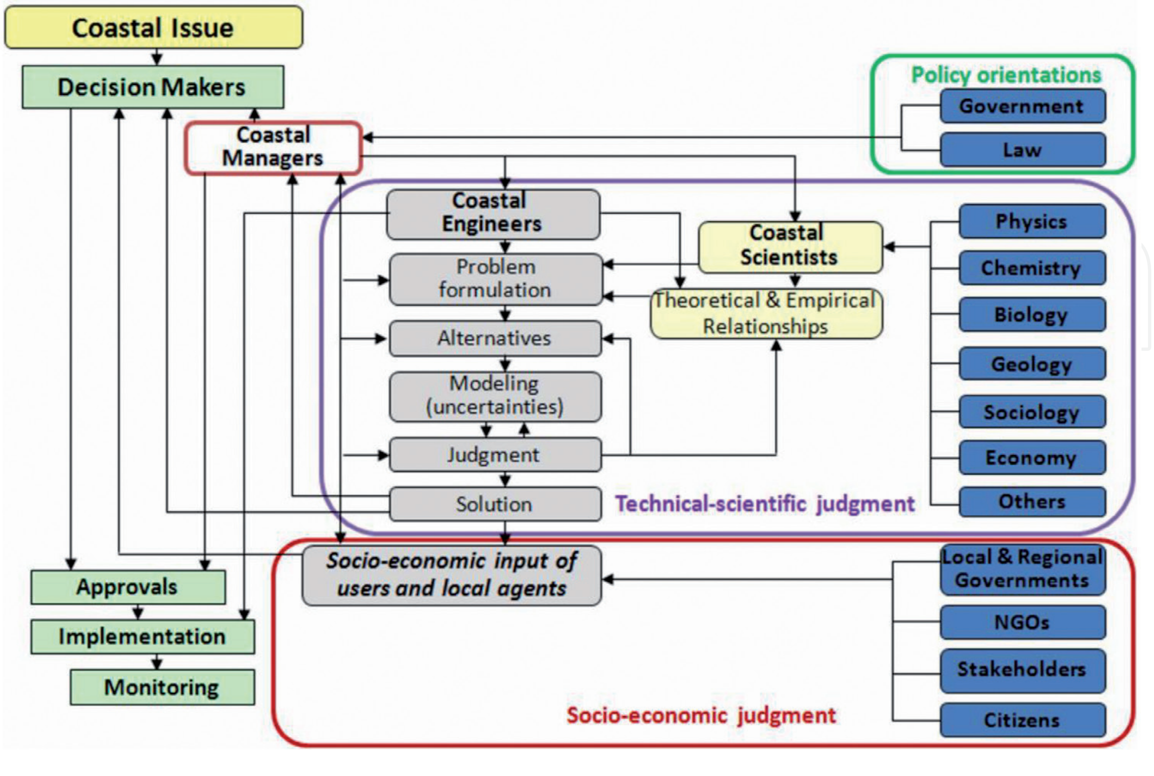


Figure 4.
Contemporary decision-making process in coastal zone issues (Adapted from [1]).

Figure 5 shows how these systems complement each other for the success of an intervention located in the coastal zone. The structural component (or resistant structure) suffers the physical effects of the processes and is fundamentally of the technical-scientific and environmental domain (PES). The socio-economic component (SES) forms the base of support of the resistant structure and is the domain of institutions, stakeholders, and citizens.

The need to involve researchers from different disciplinary areas in the conceptualization and development phases of an intervention program in the coastal zone has been recognized in several coastal interventions carried out on the Portuguese coast. The same has occurred with the need to involve public institutions, local communities, users, and citizens in general in the process of socio-economic consultation.

In this context, the intervention carried out at Costa da Caparica [11], which is an extensive well-attended bathing area, located near Lisbon, Portugal, shown in **Figure 6**, was particularly relevant.

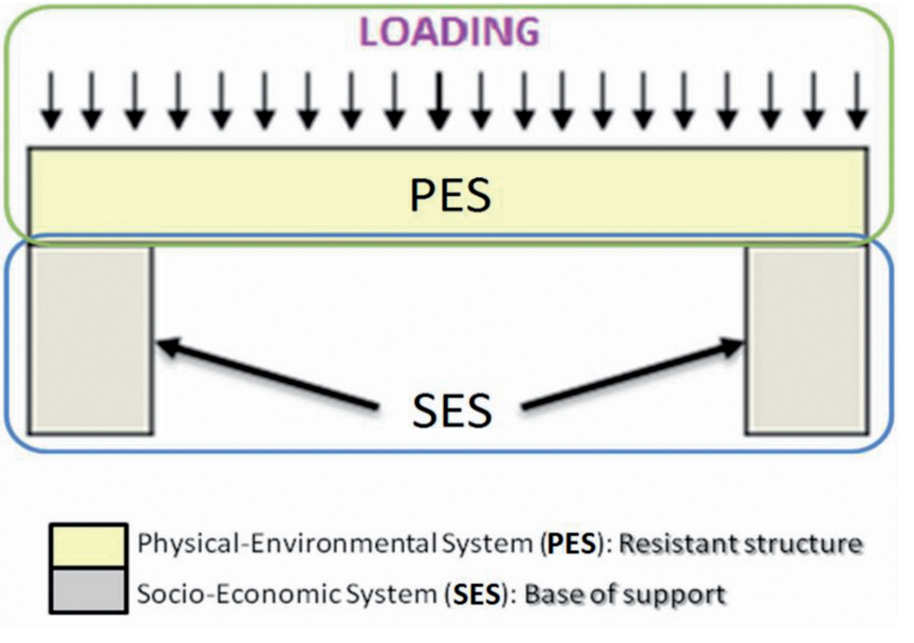


Figure 5.
Typical coastal system composed of a resistant structure and its base of support (Adapted from [10]).

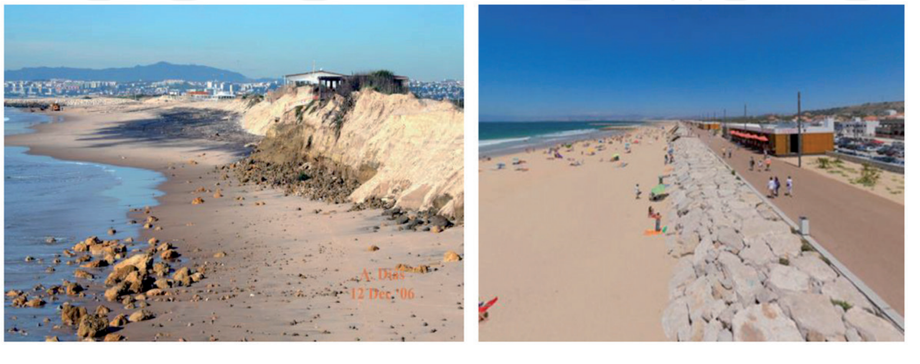


Figure 6.
Views of Costa da Caparica beach, close to Lisbon, Portugal, deprived of sand in 2006 (Courtesy of Alveirinho Dias), and the beach and its marginal strip after the last major intervention in 2014, on the left and right, respectively (Adapted from [12]).

3. Levels of operation and public participation in coastal issues decisions

As is clear from the foregoing considerations, the inclusion of different disciplinary groups is of the utmost importance for the success of any intervention program in the coastal zone. In fact, contemporary assessment processes are based on vulnerability indexes or coastal sensitivity, which are functions of several variables or physical parameters that require a diversified knowledge base that has a depth that goes beyond the pure domain of engineering.

In order to be successful, managers must consider not only physical processes and economic interests, but also the opinions and participation of citizens, stakeholders, and local communities in any planning process, conservation project, and coastal development. Public participation is paramount to ensure the development and sustainability of any coastal zone. The use of management strategies that address and consider public perception of the environmental risks, erosion effects, cyclones, tidal surges, and floods is appropriate.

However, the inclusion of entities and people to have a passive attitude is not enough. Managers must also reflect on the level of participation of the agents involved. As is reported in Guimarães et al. [13], seven levels of participation can be defined: passive, in which participants are informed of what will happen; informatory, which provides answers to participants' questions; consultation, where the participants are consulted and their perspectives are heard; incentives, in which people participate for incentives; functional, in which groups are formed that aim to achieve defined objectives; interactive, in which people participate in joint analyses to define actions; and finally, mobilizing participation, in which people participate by taking initiatives independently of external institutions. These levels of participation correspond to different levels of interaction and can be considered distinct stages of the decision-making process.

This brief analysis highlights the need to involve many actors when implementing procedures in order to produce well-accepted and sufficiently credible decision-making vulnerability and risk assessment projects in the coastal zone. However, these procedures will only succeed with as much consensus as possible, which should be useful for integrated planning and management of the coastal zone; thus, these procedures serve to establish priorities for intervention.

Truly shared management corresponds to the levels of involvement with a high degree of interaction, which encourages various types of participation, simultaneously functional, interactive, and mobilizing. For this reason, it is essential to establish trusting relationships that must be supported with dialog and a discourse among the different groups involved in the decision-making process. This relational procedure is primarily based on three dimensions: integrate, interact, and inform, as is schematically shown in **Figure 7**.

The process begins by identifying the intervention needs, which are accomplished by defining the type and design of the project. The intervention needs are noted during the implementation period of the coastal work and continue with the monitoring of the structure and surrounding space.

In all of the stages, various stakeholders should be involved and heard in the decision-making process. Decision makers should consider stakeholders an integral part of the plan to remain informed, motivated, and active during the various phases of definition, implementation, and monitoring of the proposed project.

The creation and maintenance of a healthy, multi-functional system requires strong collaboration between broadly skilled technicians, public and private entities, local authorities, residents, non-governmental organizations (NGOs), stakeholders, and citizens (**Figure 4**).

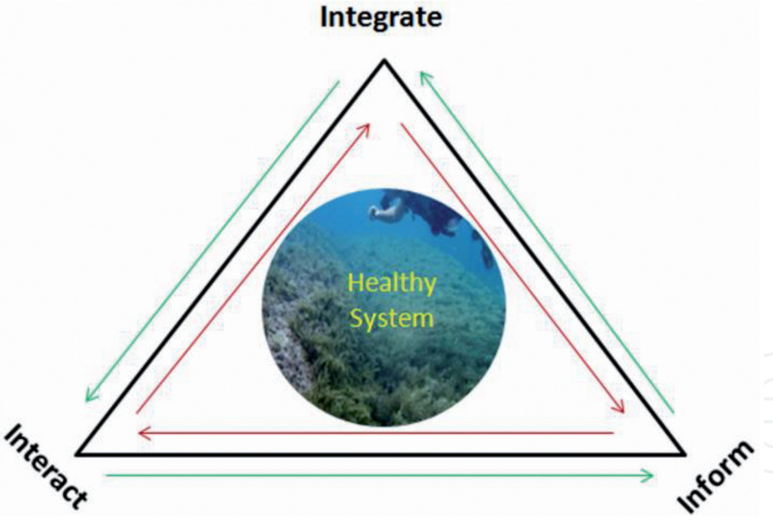


Figure 7.
Three key-dimensions for the success of the Integrated Coastal Zone Management.

In the process of developing a coastal intervention, setting commitments that result in the integration and involvement of all potential stakeholders is essential for a manager to be successful in the decision-making process. With this same goal, sensitizing the agents involved to the opportunities, potential failures, and lower individual gains in favor of the collective benefit is also important.

A permanent interaction is also essential to establish a framework for reciprocal cooperation between all parties. This interaction will provide clear and transparent information on the possible options, in order to ensure that all parties equally accept, share, and assume the expected benefits, costs, and risks involved with the project.

4. Prospects for future accommodation in coastal areas

Contemporary coastal managers are concerned with the preservation and enjoyment of coastal zones. Proper use, assessment, and monitoring of natural resources are important goals for preservation. However, to what extent will the current tourist densification in coastal zones be compatible with the sustainability of coastal zones? Will the complementary effects of global climate change lead to significant changes in the current demand for the coastal zones?

In fact, the following facts are true: (1) two-thirds of the world's megacities are located on the coast, and more than half of the population of the 22 European Member States (that have a coastline) live less than 50 km from the sea [14] and (2) these narrow coastal strips correspond to only approximately 10% of the living space on Earth. According to Berger [15], one billion people could live along the coasts, at or below 10-m elevations, by the year 2060.

Population growth and economic development are critical factors for change in coastal zones, which generate high pressure on ecosystems and natural resources due to increased use and proliferation of services. According to European Environment Agency [16], between 1995 and 2025, the projected urbanization of the coastal zone on some coasts of the Mediterranean shows a built occupation increasing from 55 to 73% in Spain, 24 to 34% in France, and 38 to 45% in Italy.

Failure to reverse this situation will inevitably lead to ecosystem collapse, which will occur more or less rapidly depending on the evolution/intensification of the following factors: (1) lack of pleasant spaces, leading to unbridled/abusive and uncontrolled occupations; (2) depletion of water resources (in quantity and quality); (3) inefficiency of services (security, health, catering, leisure, socializing, etc.); (4) increased speculation, with unbearable costs, and (5) aggravation of conflicts and insecurity.

In the meantime, maintaining coastal zone esthetics and sustainability in areas of increasing risk will only be possible through regular interventions, in accordance with the guidelines expressed in the previous points. Long-lasting sustainability can be achieved by implementing interventions that effectively reduce wave energy prior to reaching the coastline.

In fact, it is possible to guide the waves propagation by acting on the bathymetry in areas of the continental shelf, where the waves propagate in intermediate- and shallow-water conditions, forcing waves to rotate (refraction effect) and to break in positions away from the coastline; thus, preventing all of the wave energy from being discharged on the beach and/or in other natural defense systems, such as dunes. To preserve coastal dunes and stabilize the coastal foundation properly, one strategy recommends the use of artificial nourishments, possibly complemented by additional protections to prevent sand losses, such as longitudinal detached submerged breakwaters made of geotextile material. The goal of this strategy is to protect the coast in an environmentally friendly and esthetically pleasing manner. Examples of effective actions that protect the coast in this manner are presented in Oh and Shin [17] and Taal et al. [18].

It is important to note that coastal zone defense programs should adopt protection principles based on preventive actions of wave behavior, that is, interventions must be carried out from the ocean to the coast.

On this issue, the Leirosa case study has been an example of learning. This sand dune system has been the scene of three major dune rehabilitation interventions in the past 15 years. The first involved the reconstruction of the sand dunes followed by re-vegetation [19]; see **Figure 8**.

The second intervention consisted of installing geotextile containers filled with sand [20, 21], and the last one was implemented to stabilize the existing geotextile-reinforced sand dune system in the area where some encapsulated sand layers, mainly the bottom three, had partially opened up [22, 23]; see **Figure 9**.

This protection strategy allowed this stretch of the coast to remain more or less stable until 2014. However, the Hercules and Stephanie storms that struck the Portuguese coast in 2014 caused deep damages in this dune system, thus increasing the weaknesses that existed.

These events have taught us that the measures taken to protect the beach and dune system of Leirosa would not be sufficient, so we put forward a proposal to install a multi-functional submerged structure with characteristics to (1) protect

Figure 8.
Rehabilitated stretch of the Leirosa sand dunes system, from May to September 2000 (Adapted from [12]).

Figure 9.
General aspect of some bottom geotextile layers after the high tides late in the winter of 2006, in April (Adapted from [12]).

the coastal zone, dissipating energy of waves, (2) create a calmer sea on the lee side of the structure, and (3) increase the surfing possibilities in the Leirosa area of Portugal. In addition, it should be noted that coastal defense structures incorporating multi-functionalities are, in general, well-accepted by stakeholders [24]. Still according to Evans et al. [24], stakeholders recognize that the benefits to society provided by such structures could attract public and private funding.

The proposed structure for Leirosa was tested for two reef geometries with different reef angles (45 and 66°) [25, 26]. Wave data were obtained from a DATAWELL directional wave buoy located about 5 km off the coastline, position 40° 03′ 22″ N 8° 57′ 22″ W, at 25 m water depth. Average significant heights (HS) and wave peak directions (TZ) for 3-h intervals were recorded over a period of 9 months. Values of the peak period and wave direction distributions for different wave heights are shown in **Figure 10**.

Since these data series are very short, the records shown in **Figure 10** were compared to longer series (12 years) of average wave heights and peak periods obtained at a station located in Figueira da Foz, about 15 km to the north of Leirosa. These data were transposed to the wave buoy installed near Leirosa using the coastal wave model SWAN. Comparisons of frequency histograms for significant wave heights and peak periods obtained by both methods are shown in **Figure 11**.

Taking into account the results shown in **Figure 11**, where pronounced differences are noted especially in the wave periods, two design wave conditions were tested: typical storm conditions on the Portuguese west coast (wave height H = 4:0 m, period T = 15 s), and common conditions on this coast (H = 1:5 m, T = 9 s). Accordingly, the four scenarios C1–C4 shown in **Table 1** were simulated.

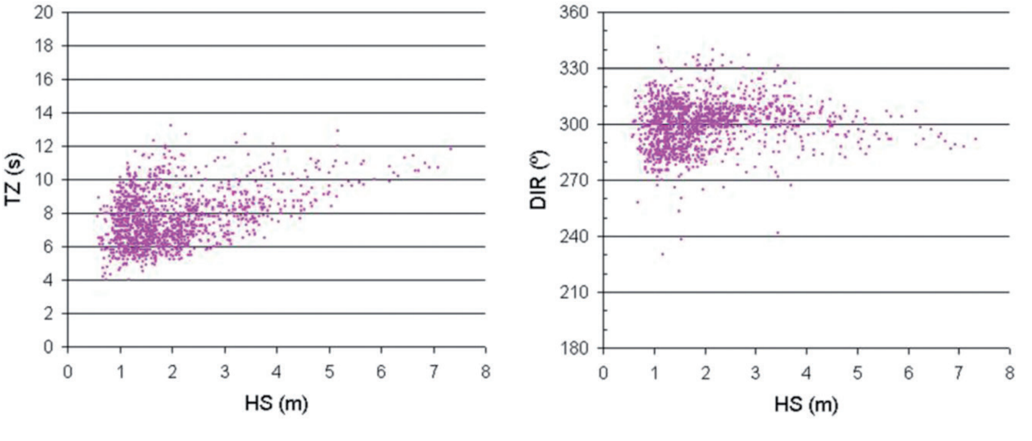
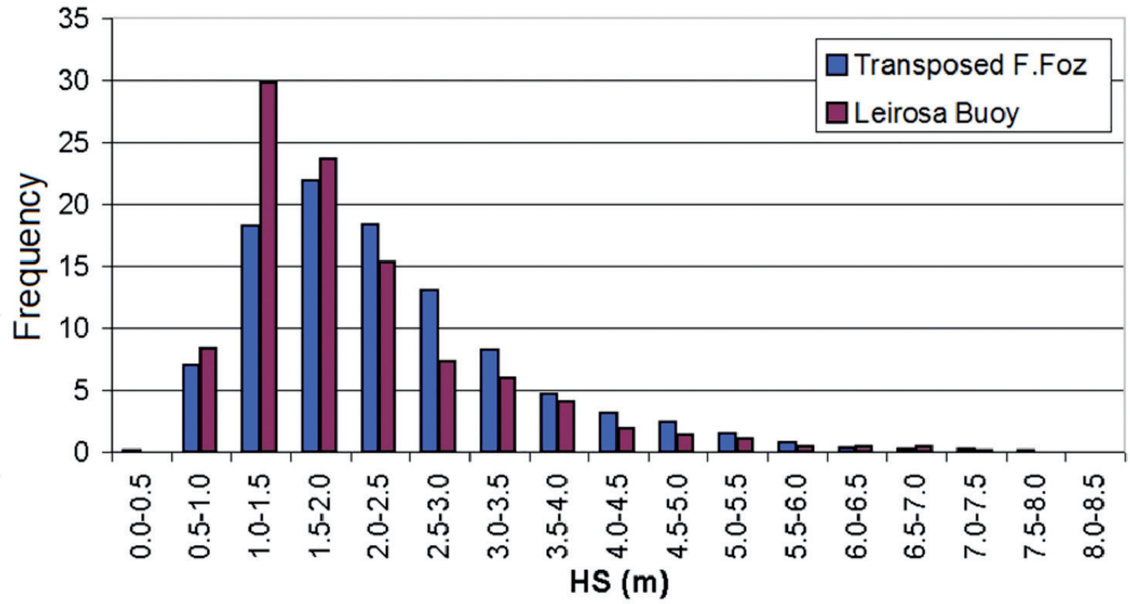
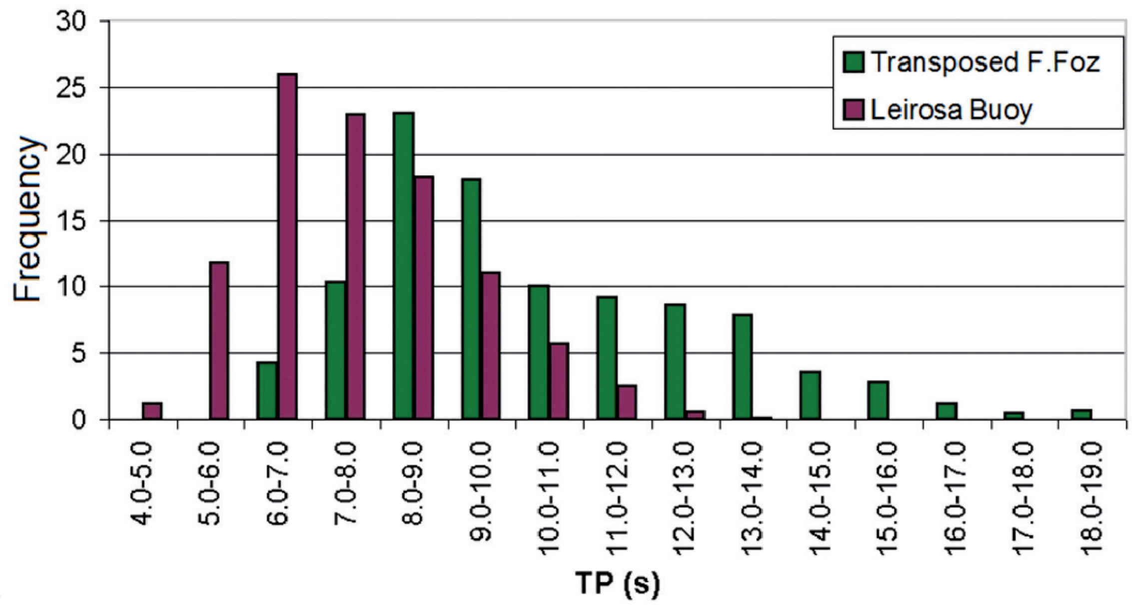


Figure 10.
Local wave data obtained from a DATAWELL directional wave buoy, at 25 m water depth: TZ-HS and DIR-HS relationships, on the left and right, respectively.



a)



b)

Figure 11.
Frequency histograms for significant wave heights and peak periods. (a) Significant height, HS. (b) Peek period, TP.

In order to propagate the incident wave, a Boussinesq type model, COULWAVE [27] was used. **Figure 12** shows numerical results of wave heights and the wave breaking line for the common wave conditions and a reef angle = 45° (C1 test, **Table 1**).

Figure 12 shows the good performance of an artificial submerged reef taking advantage of the wave refraction effect. This structure also causes wave to break in the water mass (away from the coastline). Therefore, it is possible not only to increase the width of the beach (new position of the breaker line), but also take advantage of the generated wave characteristics (shoaling effects) for sports practices. This structure can be designed to meet current conditions and, if necessary, be further strengthened to take into account possible changes in coastal dynamics.

At a later stage, earlier actions will no longer be effective, possibly as the result of ongoing climate change. This change may lead to an increased demand for accommodation alternatives in coastal areas. In areas of greater scarcity and risk,

Scenario	Reef angle (°)	H (m)	T (s)	Points per wavelength	Grid size (m)	Time step (s)
C1	45	1.5	9	43	2.14	0.09288
C2	45	4.0	13	60	2.77	0.11999
C3	66	1.5	9	43	2.14	0.09288
C4	66	4.0	13	70	2.37	0.10285

Table 1.
Reef, wave, and mesh characteristics used for the four simulated scenarios [26].

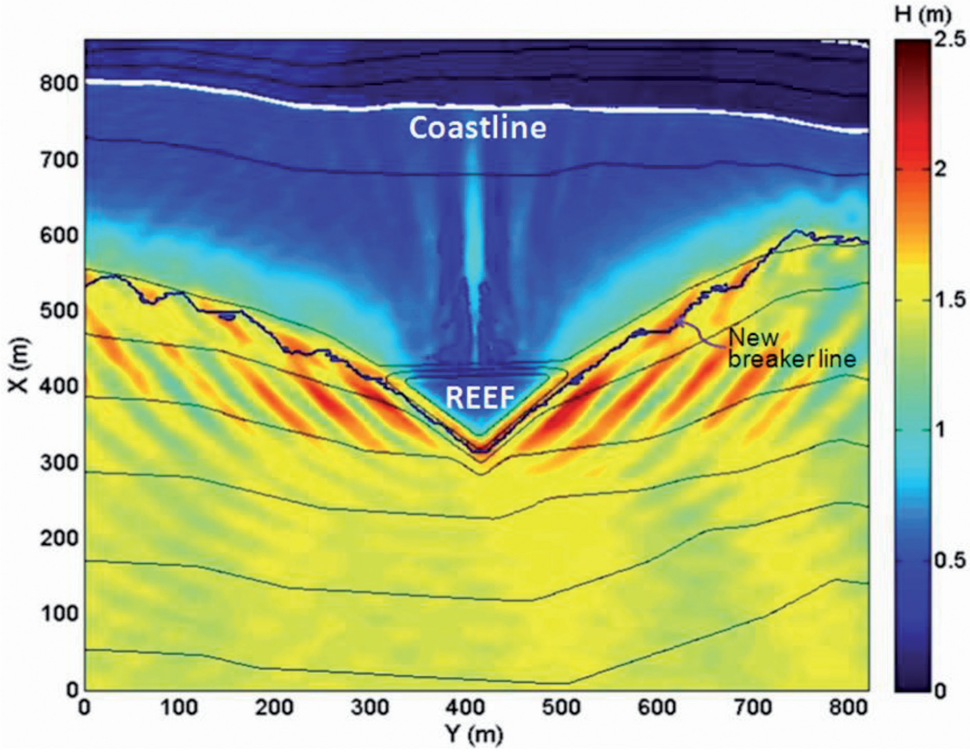


Figure 12.
Wave heights and wave breaking line around the reef area (reef angle = 45°; wave height H = 1.5 m, and period T = 9.0 s, as C1 test, ***Table*** *1) (Adapted from [26]).*

countries such as the USA, the UK, India, Indonesia, Philippines, Thailand, and many others already have elevated constructions on pilings.

In essence, it is the resumption of very old defense principles (e.g., stilts), although with potentially different motivations; however, these same flood defense purposes constructions are not new. As shown in **Figure 13**, the coastal areas of countries with extensive lowlands, such as Portugal, have constructions that were already adopted as flood defense options in the second half of the nineteenth century.

With the same goal of flood defense, demand and housing construction has grown significantly in several coastal regions of the world. For example, many houses are built on pilings along the west coast of the USA. **Figure 14** shows a set of houses of this type built on Malibu beach, California, USA, with waves crashing underneath the houses. **Figure 15** shows two luxurious waterfront homes built on pilings over the water, also in the USA coast.

More examples, among many others, are shown in https://www.homestratosphere.com/houses-built-on-stilts/. However, these structures require some care because, as noted in Park et al. [29], the structure elevation is a critical variable

Figure 13.
Flood-proof piling houses built on the coast of Tocha-Mira, Portugal, in the mid-nineteenth century (Adapted from [28]).

Figure 14.
Houses on Malibu beach built on pilings with waves crashing underneath the houses (https://www.homestratosphere.com/houses-built-on-stilts/).

Figure 15.
Two luxurious waterfront homes built on pilings over the water in the USA (https://www.homestratosphere.com/houses-built-on-stilts/).

affecting property damage and loss; they show that vertical or horizontal force caused by a given set of wave conditions may increase or decrease depending on the structure's elevation above the water level. Guidelines on how to design and build safer and less vulnerable housing to reduce the risk of life and property in coastal areas can be found in Coulbourne et al. [30].

More recently, a significant increase of floating houses and houseboats has been noted. Facilities of this kind are multiplying throughout the world, including

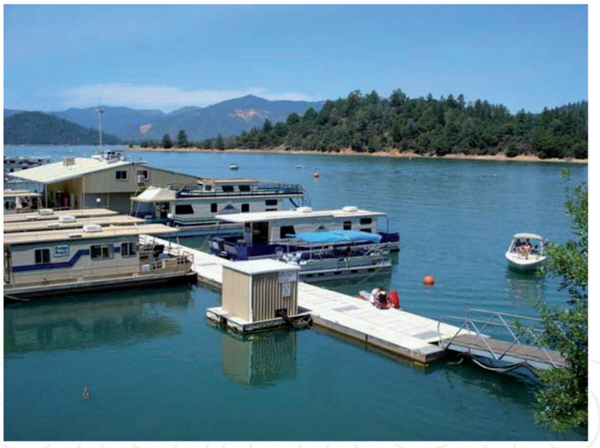


Figure 16.
Types of floating houses, as future widespread adaptation measure to address coastal hazards and climate change (Google, unknown author and date).

the sets of houseboats at De Omval, Amsterdam, on the river Amstel (just downstream from De Omval), the 60 houseboats situated on the north side of the River Thames, on Battersea Reach, and the harbor at Bembridge, with approximately 25 houseboats [12].

An increasing demand for this type of housing and a reduction of current living conditions in coastal areas are foreseeable, especially from the middle of the present century. As a consequence of global climate change, it is also foreseeable that an increase of integrated neighborhoods (including houseboats) in the coastal cities may occur. Alternatively, independent urban poles exclusively composed of houseboats, tidal houses, and floating houses like those shown in **Figure 16** may increase.

5. Conclusions

Coastal areas are now places of attraction for large masses. Coastal managers have a growing interest in implementing effective management that meets current needs, while also taking into account the need to sustainably manage natural resources for future generations. To satisfy these requirements, alternative solutions that safeguard the sustainability of the environment, tourism social resources, and services in the coastal zones will have to be considered.

Contemporary coastal management relies on the basis of integration and accountability of all stakeholders, including local communities, investors, technicians, specialists (from different disciplinary areas), and managers in the processes of conceptualization, decision-making, implementation, and monitoring of any intervention program in the coastal zone. Coastal management should aim to sensitize all stakeholders to the intervention needs, hazards, and inherent risks. Stakeholders and managers should discuss collegially the possible solutions and corresponding costs and participate in decision-making processes, accepting in this way a potential failure.

The phases of implementation and monitoring should be shared in such a way that everyone is proud of the success of the intervention or be motivated to accept and correct failure. However, if multiple interest groups are involved and these groups have conflicting interests, complexities can manifest themselves even in the acceptance and approval of processes, often resulting in conflicting voices [31]. These conflicts may be an additional problem, which may lead to only some of the stakeholders supporting the process.

Several factors will contribute to the need for adapting management procedures: global warming, consequent rise in mean sea levels, increased frequency, and intensification of storms, especially beginning in the middle of the present century [32]. These impacts from global warming will require other forms of accommodation in coastal areas.

At some point, it will no longer be possible to maintain the effectiveness of the protection measures in the high-risk areas. The effort to continue living in vulnerable areas, possibly even with high loss rates, will remain for some time, but there will come a time when the risk will no longer be acceptable and much of the effort will focus on retreating from these areas. At that time, local communities will eventually accept that retreat to a safer place is necessary. The question of "How long will the location where we retreated be a safer place?" will always remain. The costs involved in maintaining the effectiveness of protection measures in high-risk areas may also be an additional problem.

Measures of protection and accommodation will be adapted to the circumstances. The need to model the seabed on the continental shelf (at depths of 5–10 m), by redirecting the propagation of waves and forcing them to break onto the water mass (away from the coastline) is increasingly recognized. Consequently, by preventing waves from discharging much of their energy onto beaches and dune systems, natural protection systems will be less exposed.

Possible solutions to erosion include artificial sand nourishments with installation of submerged coastal control structures, such as submerged longitudinal bars, using sand-filled geotextile tubes as sand containment supports, as in Oh and Shin [17]. Another possible solution consists in the installation of submerged multi-functional artificial reefs equally with the use of geotextiles in tubular form, of which is example the Narrowneck reef installed in the Gold Coast, Australia, in response to the increasing occurrences of beach erosion [33].

Accommodation measures that use aquatic environments have long been a reality. More recently, the number tidal houses, houseboats, and floating houses are increasing. A wide variety of houseboat options are available, both in terms of features and dimensions.

The contemporary reality still allows resistance to adverse conditions with relatively soft adaptation solutions; however, most forecasts point to significant changes within a few decades [32]. High concentrations of population and services in coastal areas, increasing difficulties in finding safe and pleasant spaces and the expected flooding of many lowlands as a result of global climate change are favorable conditions for the search and installation of accommodation alternatives.

As endnotes, it is recommended the involvement of people (residents, citizens, stakeholders, and others), technical support and government in the actions to be developed under the following guidelines:

- Multi-functional flood defense infrastructures can be developed and should be implemented for the benefit of local people and businesses.

- Barriers are not enough as flood defenses—existing and new houses can become more resilient and flood resistant, and should be part of an integrated community or a city's entire strategy.

- The planning systems should encourage integrated solutions and innovative long-term local strategies.

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