Adaptation of the shoreline of urban development to special environment conditions

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Abstract. This article discusses the need for an in-depth approach to studying the adaptation of the coastline of urban development to special natural conditions. In particular, to periodic repeated flooding and floods in areas of contact with the terrain. As well as the types of technologies and materials that are used to form a protective buffer territory of coastal urban development. The importance vector of water management evolves and shifts from barrier structures against floods and underground pipeline drainage to the natural habitat. Retention pools, wetlands, rain gardens and filter trenches are forming within the city. This has a beneficial effect on the state of the coastline itself and on the attractiveness of this recreational park feature of the city for recreation. In studies based on a factor and comparative analysis of the studied projects in tabular form, it was revealed that in the floodplain relief there are carefully options for barrier fencing. The coastline of the urban development as a buffer zone of land and water should meet the safety and comfort requirements of all inhabitants and be attractive in appearance on both sides.

Keywords: natural dam, floodplain biodiversity, park zone, adaptation to floods, urban planning, coastline.

1 Introduction

In the history of mankind, the adaptation of people to natural conditions took place in various ways. Departure from the coastline was the safest option for the forming of large settlements. Currently, given modern technology, there is an engineering and technical possibility to protect the coastline of urban settlements from the threat of flooding from the sea, ocean, lakes and large river systems [1].

The master plans of historically formed cities are inextricably linked with water flows that crossing, envelop, and fragment the city space into segments. The water environment in its diversity is one of the most important elements of the urban landscape [2-5].

Currently, there is a tendency to increase population near the coasts, increase the potential development of water areas of rivers and lakes [1]. The reason for this phenomenon lies in the social, economic opportunities for life and the implementation of the needs of individuals and communities. An extremely important desire to live on the coast is the desire of people to contemplate the natural beauty of the water space and coastline [6-11].

A few decades ago, scientists involved in landforms and habitats, people were considered as aberration or overlay on the natural environment. At the moment, it is increasingly recognized that people are part of the coastal system. The problem remains the loss of a stable eco-system and the difficulty to form and restore the disturbed habitat and landforms [1].

The coastal zones are assessed as very important for environmental activities, exceeding the usual recreational use [12]. The value of the pristine coastal zone as a protection against storm waves is...
currently recognized as a well-known part of the scientific community [13]. However, this area must meet safety conditions.

The concept of water management is gradually evolving in the context of flood risks for coastal urban development. The significance vector shifts from barrier structures from floods, underground pipeline drainage, called «gray» infrastructure, to its combination with Blue – Green infrastructure (BGI) and Urban drainage systems that incorporate elements of green infrastructure (SuDS / GI) [14-19].

Research by previous authors has shown that along with the protective functions against flooding of the territory, the coastline is an important socio-cultural place. In the considered articles, the need of residents of coastal cities for the availability of recreation, walking, active sports is noted [2, 7, 8, 14, 20, 21]. The development of such places is an important aspect of urban improvement for different age and social groups [7].

In society, there is an increasing need for the formation of the coastline of urban buildings, as a natural, very close to the natural habitat. To solve this problem, there are opportunities to create protective structures and elements that fit into the natural Park space with competent design solutions. Retention pools, swamps, rain gardens and filter trenches [5, 18] are used within the city to weaken land runoff. Various forms of flora, fauna, reptiles, insects, birds, participate in the cycle of this environment and are directly dependent on each other [11, 14, 17].

The width of the coastline and its vegetation have a significant impact on the degree of destructive or regenerative impact of floods in relation to this territory [1].

There are high-quality practical guidelines for the design of coastal buildings and recommendations for their use [22, 23]. However, these coastal protection solutions are diverse in their approaches and degree of ecologization.

The objectives of our research are to study and classify the degree of influence of various factors on the ability to adapt the coastline of urban development to special nature conditions. Special nature conditions mean periodically repeated floods in areas of contact with the topography. And also the types of technologies and materials that are used to form a protective buffer zone of coastal urban development.

Studying international literature and collecting data on actually implemented and conceptual projects gave us the opportunity to summarize and classify the data, and then refine the results and generalize the direction of ways to solve this problem.

2 Materials and Methods
The research methodology was to identify the most characteristic common signs of the considered examples. The research methods we used were factor analysis, comparative analysis and a method for comparing the data studied.

Sources to implemented and conceptual projects of sea and ocean coastlines of cities and large settlements [2, 13, 20, 24, 25, 26], coastlines of cities of large river systems [3, 8, 10, 11, 17, 21] were considered.

A total of 27 projects and concepts of the urban coastline were analyzed. All analyzed examples were generalized classified and presented in tabular data. Based on these results, a comparative analysis was performed. For some provisions of the data, a more detailed indentation has been made. This allowed us to draw a number of additional conclusions.

3 Results
3.1 Classification by the territorial signs
The results of our studies can be presented in the form of classifications for a number of common and distinctive features of the formation of coastlines of cities and large settlements.

Table 1 considers factor classification in relation to the three most common landforms of the coastline: hilly, mixed, floodplain. We did not consider the rocky foundations of the coastal territory,
since, by default, they have sufficient protection and are rare for large urban agglomerations and it was not advisable to include them in the study.

Table 1. Protective and recreational activities depending on the terrain.

| Classification                                                                 | Hilly | Mixed | Floodplain |
|--------------------------------------------------------------------------------|-------|-------|------------|
| 1. Ways to adapt the territory:                                                |       |       |            |
| 1.1. Active:                                                                 |       |       |            |
| 1.1.1. Construction of protective structures                                  | -     | +     | +          |
| 1.1.2. Changing the shape of the terrain:                                     |       |       |            |
| 1.2.1.1 Natural coastline                                                     | +     | +     | +          |
| 1.2.1.2 Restore disturbed coastline                                            | -     | +     | +          |
| 1.2. Passive:                                                                |       |       |            |
| 1.2.1. Removal of buildings from the coastline                                | -     | +     | +          |
| 1.2.2. Coastal emergency evacuation                                           | -     | +     | +          |
| 1.3. Combined                                                                |       |       |            |
| 2. By the degree of inclusion in the natural processes of the biosphere:      |       |       |            |
| 2.1. Maintaining the natural environment                                     | +     | +     | +          |
| 2.2. Environmental disturbance                                               | -     | +     | +          |
| 3. According to the need for watering the territory:                          |       |       |            |
| 3.1. Waterlogging                                                            | -     | +     | +          |
| 3.2. Draining                                                                | +     | +/-  | -          |
| 4. On water systems flowing into the water from the coast:                    |       |       |            |
| 4.1. Natural:                                                                |       |       |            |
| 4.1.1. Rivers                                                                | -     | +     | +          |
| 4.1.2. Groundwater                                                           | +     | +     | +          |
| 4.2. Artificial:                                                             |       |       |            |
| 4.2.1. Storm drains                                                          | +     | +     | +          |
| 4.2.2. Production waste                                                       | +     | +     | +          |
| 4.2.3. Domestic drains                                                        | +     | +     | +          |
| 5. On physical access to the water surface                                   | +/-   | +/+   | +          |
| 6. On visual access to the water surface                                     | +     | +     | +/-        |

Note: + has a significant impact; - inconsequential

According to the ways of adapting the territory of coastlines to special climatic manifestations, they were divided into: active (1.1), passive (1.2), combined (1.3). Active methods (1.1) are: construction of flood control facilities; change in the natural shape of the relief of the coastline; restoration of the disturbed ecosystem of the coastal territory. The results of Table 1 showed that active methods of erecting protective structures (1.1.1) are presented in two reliefs, except for hilly. The natural coastline (1.2.1.1) was preserved in hilly and mixed reliefs. However, to restore the disturbed coastline (1.2.1.2), the floodplain relief was represented in the largest number of investigated projects. These decisions were due to the fact that floodplain wetlands are maximally rich in biodiversity of flora and fauna [15, 19, 20, 21, 23].

Passive (1.2) methods of adaptation to natural catastrophic manifestations are determined by the removal of buildings from the coastline (1.2.1) and the evacuation of the population from the coastal zone in anticipation of emergency situations (1.2.2). These measures are characteristic of floodplain and mixed terrain types.

There is also a combined method (1.3), characterized in that the paramount part of the work is done with the help of human efforts. The subsequent work is will polished by nature itself in the direction
specified by the designers. This approach was implemented in projects with floodplain and mixed relief types.

According to the degree of involvement in the natural processes of the biosphere (2), both opposite criteria for maintaining (2.1) and disturbing (2.2) the natural environment showed positive results. Despite the fact that in all the projects considered, there was a violation of biosphere processes. A number of solutions made it possible to adapt the reclaimed coastline in accordance with the natural environment.

According to the need to water the coastal area (3), the criterion for waterlogging the area (3.1) was obtained. This circumstance finds a positive application in floodplain and mixed terrain, where it was originally predetermined by natural processes. Desiccation (3.2) of the floodplain area is considered as an extremely undesirable event, although it is practiced in mixed terrain.

We divided the criterion of water systems flowing into the water from the coast (4) into two groups: artificial and natural. Natural (4.1) fed the coastal waters with rivers (4.1.1) and groundwater (4.1.2). Artificial systems (4.2), in the form of storm (4.2.1), production (4.2.2) and domestic (4.2.3) drains, were also found in some projects. The design of the coastline as a protective border against flooding of urban development and issues related to artificial flows must be considered in conjunction with natural processes.

When classifying according to physical (5) and visual (6) access to the water surface, a number of important observations attracted attention. For hilly terrain, physical access to the water surface is limited, due to the steepness of the cliffs and the complexity of the terrain, due to natural causes. And for the floodplain and mixed relief, access, in the part of the considered projects, was blocked by embankments, protective walls, armored dams [26]. And, in aggregate, with limited visual access to the water surface for the floodplain relief, of course, not to the same extent as for the mixed one, this decision was negative. Negative for aesthetic, emotional, physiological feelings of visitors, and very negatively, the suppressing majority of biological processes, the interconnected border zone of the coast and water.

However, some projects of coastal park zones managed to exclude the construction of a protective wall in their idea and implementation, or to dismantle a previously available solution, trying to restore the coastline degraded from previous interference [13, 25, 26].

### 3.2 Classification by type of materials and technologies

In table 2 the classification of protective and recreational activities for the formation of the coastline is carried out depending on the degree of belonging to natural technologies and materials. Evaluation criteria were divided into three types: natural, combined, artificial.

The designated purpose classification (1) included shore protection objects (1.1) and moisture absorbing materials (1.2). The results of generalization showed that these functions are inherent in natural, combined and artificial materials and technologies. Only artificial ones with absorption (1.2) did not withstand the competition of natural ones.

The most commonly used artificial shore protection objects, in turn, included dams, walls, sea shafts and breakwaters, concrete walls and metal dowels. Natural coastal protection objects were ledges, stones, boulders, coral reefs, mangroves, logs and snag thrown ashore.

Interestingly, some of the natural objects and materials simultaneously met the characteristics of bank protection (1.1) and moisture absorption (1.2). So, for example, the root system of coniferous forest stands and other larch species of trees that adhere the soil to a solid array with its root system is also a natural «sponge» that absorbs excess moisture. Plants and shrubs also play the role of strengthening the coastline [13, 25, 26]. Combined objects and materials were brought and installed in the form of embankments, boulders, gabion blocks and logs of firewood and other wood impregnated and purposefully laid on the coast [25].
Table 2. Classification of protective and recreational activities for the formation of the coastline depending on the type of technology and material.

| Classification                                                                 | natural | combined | artificial |
|-------------------------------------------------------------------------------|---------|----------|------------|
| 1. By designated purpose:                                                     |         |          |            |
| 6.1. Shore protection objects                                                 | +       | +        | +          |
| 6.2. Moisture absorbing materials                                             | +       | +        | -          |
| 7. By structure:                                                              |         |          |            |
| 7.1. Monolithic                                                               | +       | +        | +          |
| 7.2. Modular                                                                  | +       | +        | +          |
| 8. By shape:                                                                  |         |          |            |
| 8.1. Rectangular                                                             | -       | +        | +          |
| 8.2. Polygonal                                                               | +       | +        | +          |
| 8.3. Bionic                                                                  | +       | +        | -          |
| 9. By construction technology:                                                |         |          |            |
| 9.1. Erection on site from existing materials                               | +       | +/-      | -          |
| 9.2. Delivery and installation of finished products                          | +       | +        | +          |
| 10. Environmental friendliness                                              | +       | +        | +/-        |
| 11. By the degree of inclusion in the natural processes of the biosphere     | +       | +/-      | -          |
| 12. Financial cost                                                           | -       | +        | +          |

Note: + applied; - not applied

An important fact in the observation was that only natural materials, in comparison with artificial ones, are a desiccant and a moisture distributor. In particular, when designing vegetation zones of coastlines, it is necessary to select local species of plants that can tolerate storm waves and have reflective and regenerative ability with increasing sea level, ocean, lakes and river systems depending on the susceptibility of plants to the microclimate and salt composition of water. Remediation measures are also necessary to displace dense invasive non-native species of flora [13].

As can be seen from the results of the study, the range of objects and principles of protection against floods in nature was initially laid wide enough. Therefore, there is great potential for revising approaches in the design of the adaptive coastline of urban development in the direction of using natural materials.

Classification by naturalness of materials (2) showed positive answers for monolithic (2.1) and modular (2.2) objects, products. This suggests that during construction work, the use of natural, artificial and combined objects in prefabricated and monolithic structures was implemented.

In the classification according to the shape of objects (3), rectangular (3.1) are often found in artificial (for example, concrete slabs) and combined (for example, gabion blocks). Rectangular forms (3.1) of natural origin are not found on the coast, with rare exceptions of a special kind of rock or the remains of ancient artifacts that «fit» with the nature of the place. Polygonal forms (3.2) are found in all degrees of naturalness, as are objects of a bionic shape. However, the latter, in their artificial manifestation, as a rule, did not take part in shore protection.

As can be seen from the classification of construction technologies (4), the delivery and installation of finished (4.2) objects and products were applied to all types of natural materials. On-site erection from the available materials (4.1) was carried out only in the presence of natural materials, in other cases only delivery to the construction site was practiced.

In terms of environmental friendliness (5), natural and combined materials and building technologies have huge advantages when installed with artificial materials. Therefore, for the coastal zone it is recommended to use natural and combined.

By the degree of inclusion in the natural processes of the biosphere (6), of course, natural materials and technologies are priority. However, with a competent and creative approach to the design and
implementation of coastline projects, combined ones are quite capable of competing with natural ones. The use of fully artificial materials and technologies is more appropriate in park areas within urban space.

According to the degree of financial cost of materials and applied technologies (7), in a rather approximate understanding, the use of artificial and combined was more expensive. However, this estimate is approximate and requires a comparison of financial costs for each project.

4 Discussion
The study showed that, where possible, designers of urban spaces and coastlines tried to find a balance between the natural environment and recreational construction activities to erect a protective coastal system for urban development.

All investigated cases are unique and it is necessary to carefully approach the design of coastlines of cities and large settlements. Whereas in some projects with a hilly topography, regrouping of the slopes and partial replacement with gravel and vegetation were used, for others, the formation of a gentle slope to a more natural state and erosive soil movement was used to recreate coastal zones for fish spawning [13, 25, 26].

If for rivers flowing into the water area in the territory under consideration, it is possible to evaluate the clear direction, the strength of the current, the possible increase in its level by the results of many years of field observations, that is more difficult to determine for groundwater, since these flows move slower than surface, they are affected by surface erosive processes. It is necessary to more extensively apply existing and improving modeling methods in geomorphology and geomorphometry. This will make it possible to identify and combine groundwater runoff and groundwater flowing along the changing terrain of the landscape, water infiltration, regolith thickness and groundwater dynamics.

An analysis of these data will help prevent a cardinal interruption and restrictions of natural movement of groundwater flow in the design of urban planning and quarterly development [18, 27]. In a global sense, the available research allows us to trace the dynamic displacement and sliding of the mainland into the ocean, the topography of the seas and oceans [18].

The typology of the analyzed coastal lines of urban development indicates a branching approach to design. Namely, part of the projects is being built within the framework of the certainly reliable but outdated concept of the military engineering direction. It consists in the use of cardinally protective means of creating barriers. The other part is an innovative approach to the Blue – Green infrastructure (BGI) engineering and urban planning architecture. In the studied design approaches, the latter is welcomed.

It seems to us that the BGI design approach should prevail in the future in the formation of urban spaces, including its coastlines. An ideal theoretical model of the coastline territory visually and physically looks like a natural environment with the original, prior to human intervention, cycle of biodiversity and, most importantly, safe for people to visit. Moreover, it is adapted to special environmental conditions, expressed in seasonal climatic and extreme manifestations and dendrological features of the area.

The obtained theoretical model can be used to evaluate various scenarios of the formation of the coastline of urban development and its modernization.

5 Conclusions
After analyzing the studied data, we came to the following conclusions:

When considering the factor classification in relation to landforms of the coastline territory, it was found that the floodplain relief is most vulnerable to flooding. At the same time, it has the greatest need to preserve his natural wetland biosphere. With a special application to the design of active ways of adapting the territory of coastlines taking into account climatic features, it is possible to refrain from introducing barriers into the projects of coastlines.

A comparative analysis revealed that the use of natural forest plantations, local grasses and shrubs at the same time corresponded to the characteristics of bank protection, moisture absorption and moisture distribution.
When designing the coastline, a multifactorial approach is necessary with a preliminary study of water flows running into the water from the coast, including terrestrial natural and artificial flows, in conjunction with groundwater. The presence and proper use of such data can minimize the risk of disruption of natural water currents in urban areas and beyond.

When classifying according to physical and visual access for visitors to the water surface, it was revealed that the mixed relief is most suitable.

Discovered out that in terms of environmental friendliness and fit into the natural processes of the biosphere in the examples considered, natural materials and technologies are priority. However, with a competent and creative approach to the design and implementation of coastline projects, combined ones can compete with natural ones.

It is recommended that the creation of a biosphere space outside the logistics hubs and conjoined links of urban development coasts and water sources. This space will serve as the delimitation of densely populated residential areas and the water area.

In areas with a probability of large floods, it is recommended that protective barrier structures be shifted from the coast to the entire length of the floodplain territory, right up to the border of the city’s direct infrastructure. Such a solution is guaranteed to protect the urban area. This approach is applicable for floodplain areas with a seasonal pattern of flooding, normative for this zone.

If the coastline of the urban development is a buffer zone of land and water, then it must meet all the safety and comfort requirements for all the inhabitants of this territory and, of course, be attractive in appearance on both sides.

The range of objects and principles of protection of high water and flooding in nature was initially laid wide enough. Therefore, there is great potential for revising approaches in the design of the adaptive coastline of urban development in the direction of using natural materials and technologies.

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