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Orginal Article

Systematisation of techniques for a holistic solution to reducing the vulnerability of coastal areas to water level fluctuations

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Abstract: The article examines the issue of a holistic solution for reducing the vulnerability of coastal urban areas to water level fluctuations. Based on an analysis of examples from global, French, and Ukrainian practice, it generalises and proposes an original systematisation of defined techniques to mitigate the vulnerability of coastal urban areas to water level fluctuations. The systematisation was conducted for three identified hierarchical system levels of coastal area organisation: urban planning, object, and environmental design levels. It also incorporates four generalised strategies – prevention, control, adaptation, and resilience – aimed at addressing the risks associated with water level fluctuations. An original matrix of 24 systematised techniques is proposed, whose combinations will ensure a holistic solution to the problem. A combination of 12 systematised techniques has been identified that can effectively enhance the existing situation in Gruissan, a coastal city in the south of France, to mitigate the risks and negative impacts of flooding in its coastal areas. The implemented example of adapting flooded areas along the coast of Gruissan Pond to meet the modern needs of the city, its residents, and tourists serves as a practical illustration of the proposed theoretical studies.

Keywords: coastal areas, water fluctuations, systematisation of techniques

1. Introduction

The problem of flooding in coastal urban areas located at or near sea level is relevant to various countries, including France and Ukraine. This is evidenced by numerous international documents, such as the UN declaration “Transforming Our World: The 2030 Agenda for Sustainable Development” [1], the UN resolution “Water for Sustainable Development” [2], the decisions and resolutions of the UNESCO Intergovernmental Oceanographic Commission [3], as well as the Resolution of the Cabinet of Ministers of Ukraine on flood risk management and land use in areas at risk of flooding [4,5]. This issue affects multiple aspects of life, encompassing ecological, urban planning, architectural, functional, cultural, social, and economic dimensions, and therefore requires a holistic solution. To achieve such a holistic approach, various systemic levels must be considered.

The scientific and methodological foundation of this study is based on the work of numerous researchers worldwide. These include studies on the consequences of sea level rise, potential land flooding, and the loss of cultural world heritage, notably by K. Smith and R. Ward [6], H. Pettit [7], and B. Marzeion and A. Levermann [8]; research on the impact of water fluctuations on urban and territorial development by J-J. Terrin [9], C. Kennedy [10], and G. Wright [11]; and strategic approaches to flood risk management by P. Sayers, Y. Li, G. Galloway, E. Penning-Rowsell, F. Shen, K. Wen, Y. Chen, and T. Le Quesne [12]. Additionally, studies on the engineering protection of territories by A. Rocochynskiy [13], the ecological and economic use of flooded areas by A. Sokhnych [14], and methods for assessing changes in land conditions and decision-making for comprehensive flood protection by V. Kovalchuk and T. Matiash [15], P. Kovalchuk and S. Shevchuk [16], and M. Romashchenko [17] have contributed valuable insights. Further significant contributions include M.T.O.V. Peiris's research on assessing urban resilience to floods and spatial interactions between natural, physical, and social systems [18], as well as G. Guthrie’s work on coastal adaptation to rising sea levels and cost-minimisation policies [19].

Additionally, studies by Spanish and Italian researchers on modelling and managing flood risks in urban areas [20], British researchers on the implementation of Blue-Green flood risk management strategies [21], Chinese researchers on sustainable urban planning for coastal flood risk control [22], and Indian researchers on sustainable integrated urban flood management strategies for smart city planning [23] are particularly noteworthy.

The issue of urban flood prevention methods was also addressed in the authors’ report at this year’s international conference “Fluctuations. Water Territories” in Toulouse-Gruissan, France, which focused on the impact of water level fluctuations on coastal areas [24], as well as in research on the cumulative development of historical centres in small towns [25].

It has been established that specialists from various fields, including architecture, engineering, sociology, history, and economics, have been engaged in addressing coastal flooding challenges. However, there remains a need to consider the reduction of coastal urban areas’ vulnerability to water level fluctuations as a complex and holistic process. This necessity defines the purpose and objectives of this study. Thus, the study aims to systematise various techniques for the prevention, control, adaptation, and resilience of coastal areas to water level fluctuation risks, facilitating their effective application at different systemic levels. Recommendations for supplementing the existing situation in Gruissan, a small coastal town in the south of France, with these techniques, alongside a conceptual example of adapting its flooded areas to the current needs of the city and its residents, will serve as a practical illustration of the proposed theoretical framework.

2. Methodology

The study methodology consists of five consecutive stages, employing appropriate research methods. At the preparatory stage, an analysis of previous research was conducted to determine the study's aim.

At the analytical stage, based on an examination of global, French, and Ukrainian project practices, an original systematisation of techniques for reducing the vulnerability of coastal urban areas to water level fluctuations was proposed. Additionally, as validation of its effectiveness, examples were provided where such techniques have been implemented. The systematisation was structured across three hierarchical systemic levels of coastal urban area organisation: urban planning, object, and environmental design.

At the urban planning level, issues related to an entire city or specific location are addressed. To resolve these issues, a set of techniques – referred to in this study as urban planning techniques – was generalised.

The object level was established to focus on individual buildings. This level is hierarchically subordinate to the urban planning level, functioning as a subsystem. Here, solutions are tailored to specific urban structures, which are integral parts of the broader urban system. Accordingly, object-level techniques were generalised.

The environmental design level pertains to the surroundings of urban buildings and specific local areas. It represents an even lower hierarchical level, acting as a subsystem of both the urban planning and object levels. To address issues at this scale, environmental design techniques were generalised.

All identified techniques were further classified according to four strategic approaches: prevention, control, adaptation, and resilience in response to the risks of water level fluctuations.

At the synthesising stage, a matrix of systematised techniques was proposed. This matrix illustrates solutions to the identified problem across the four strategies – prevention, control, adaptation, and resilience – at the three system levels: urban planning, object, and environmental design. This approach ensures a holistic response to the issue.

At the final stage, the most effective combination of synthesised techniques, integrating different strategies and system levels, was identified to enhance the existing conditions in Gruissan, a coastal town in the south of France, in order to mitigate the negative impact of flooding and prevent further risks to its coastal areas.

At the experimental stage, a conceptual design was developed for adapting the Pond area in Gruissan Park, adjacent to the "old town". This case study validated the effectiveness of the proposed theoretical framework.

3. Base material: systematisation of techniques to reduce the vulnerability of coastal urban areas to water level fluctuations – matrix of systematised techniques

In global practice, a wide range of tools is available to address various challenges related to reducing the risk of coastal flooding caused by water level fluctuations. This study identifies and generalises techniques for mitigating these risks, systematising them across three levels: urban planning, object, and environmental design. These techniques provide solutions tailored to different strategies: prevention, control, adaptation, and resilience in response to the risks of water level fluctuations.

The prevention strategy primarily focuses on the creation of protective structures at different system levels to mitigate or eliminate the negative impact of coastal flooding when water levels rise. The control strategy aims to monitor conditions and regulate water flow onto land. The adaptation strategy seeks tools to modify a given location to accommodate temporary or simultaneous flooding. The resilience strategy ensures the continued functionality and structural integrity of an area, enabling it to exist, function, and develop despite fluctuations in surrounding water levels. The latter two strategies are particularly crucial for the sustainable existence and development of coastal urban areas.

Thus, in the proposed systematisation at the urban planning level, the following techniques have been identified:

- Prevention Strategy: dynamic barriers, artificial breakwaters, artificial reefs.
- Control Strategy: protective dams, automatic dam gates, drainage flow, and underground tunnels for drainage water.
- Adaptation Strategy: fish parks, oyster farms, salt lakes, artificial or restored marshes, coastal morphology modification.
- Resilience Strategy: artificial channels, artificial or natural sandspits, expansion of beach dunes, floating cities as an extension of the coastal area.

The following techniques are relevant at the object level:

- Prevention Strategy: prefabricated flood blocks, sponge shields.
- Control Strategy: relocation of buildings, use of smart airbricks.
- Adaptation Strategy: transformable houses, floating houses.
- Resilience Strategy: buildings raised on piles, fascines.

At the environmental design level, the following techniques have been identified as effective:

- Prevention Strategy: raised berms, artificial thalwegs, gabion walls.
- Control Strategy: artificial water collection ponds, drains.
- Adaptation Strategy: water absorption by greenery, shoreline reinforcement with vegetation.
- Resilience Strategy: artificial embankments, pedestrian paths perpendicular to the shoreline.

Below is a more detailed description and discussion of the synthesised techniques.

Among the techniques within the prevention strategy, three notable examples include the "dynamic barrier" (from the urban planning level), the "use of sponge shields" (from the object level), and the "raised berm" (from the environmental design level).

Dynamic Barrier (Urban Planning Level): This technique involves the creation of temporary gateway barriers consisting of a metal box structure with gates positioned on the seabed. During high tides, the gates are filled with compressed air, causing them to rise and form temporary barriers that prevent water from overflowing and protect coastal areas from flooding. This technique has been implemented as part of a complex of breakwaters and gateways near the Venice Lagoon [26].

Use of Sponge Shields (Object Level): This technique employs barrier boards that are typically installed underground in front of a building, positioned vertically within a steel or concrete gutter. When floodwaters reach a predetermined level, water enters a special technical pit and then flows through a pipe into the gutter, causing the shield to float and rise completely, creating a protective barrier. This method has been utilised in the Netherlands to protect the Van Abbemuseum – a museum of modern and contemporary art located on the eastern bank of the Dommel River in Eindhoven – from flood damage during periods of high water levels [27].

Raised Berm (Environmental Design Level): This technique involves constructing a raised earthen berm or mound around a designated area. Typically made from compacted soil, gravel, or other suitable materials, the berm can be planted with vegetation to enhance stability and aesthetics. This approach serves as a natural flood barrier or helps to redirect water flow. An example of its application can be seen in the Ragöser Dam project near the small Ragöser River along the Oder-Havel Canal in Germany [28].

From the Ukrainian experience, several techniques within the prevention strategy are particularly noteworthy, including “artificial breakwaters”, “prefabricated flood blocks”, and “gabion walls”. These techniques correspond to the urban planning, object, and environmental design levels, respectively.

Artificial Breakwaters (Urban Planning Level): These structures are typically built using concrete blocks, stones, or other durable materials and are strategically placed to dissipate wave energy effectively. By reducing wave intensity, they help protect the coastline from erosion and flooding. This technique has been implemented along the sea coast of Odesa.

Prefabricated Flood Blocks (Object Level): This technique involves assembling a modular flood barrier composed of interlocking blocks that form a continuous protective strip. When deployed, these modules automatically fill with rising floodwaters, reinforcing the barrier and protecting buildings from flooding. These modular block barriers can be customised in length and direction to fit specific openings and landscapes. This method has been applied in several Ukrainian cities, including Odesa, Dnipro, Kherson, and Vylkove.

Gabion Walls (Environmental Design Level): This technique involves constructing protective barriers using wire baskets filled with stones or other materials. The wire baskets, or gabions, are typically made of galvanized steel mesh and filled with stones of various sizes. These structures provide erosion control and flood prevention and are frequently used in park areas, near water bodies, and in coastal and mountainous regions. In Ukraine, this method is widely applied, particularly in the Carpathian region and in coastal areas of Kherson, Dnipro, and Kyiv.

Among the techniques within the control strategy, three notable methods have been identified: "drainage flow and underground tunnel for drainage water," "relocation of buildings," and "artificial water collection ponds." These techniques correspond to the urban planning, object, and environmental design levels, respectively.

Drainage Flow and Underground Tunnel for Drainage Water (Urban Planning Level): This technique was implemented in the "First Street Tunnel" project in Washington, DC [29]. Such underground tunnels enable the collection and transportation of stormwater from areas with outdated infrastructure, thereby controlling water levels and mitigating flood risks. The tunnel channels collected stormwater to a wastewater treatment plant before discharge.

Relocation of Buildings (Object Level): Although complex and costly, this technique can be employed to preserve valuable buildings, mitigate flood risks, or support urban redevelopment. It has been applied in various countries, including the United States, Japan, the Netherlands, and Australia, depending on local conditions, regulations, and priorities.

Artificial Water Collection Ponds (Environmental Design Level): This technique involves creating adaptive and dynamic spaces with catchment areas or tanks designed to collect and store rainwater, stormwater runoff, or other water sources. Once stormwater absorption capacity is restored, the collected water is gradually released back into the system, ensuring controlled water flow and preventing overload. A notable example is Waterplein Benthemplein in Rotterdam, Netherlands, where adaptive green zones integrate catchment ponds for flood control [30].

From the Ukrainian experience, several techniques have been identified within the control strategy, including "protective dams," "use of smart airbricks," and "drains." These techniques correspond to the urban planning, object, and environmental design levels, respectively.

Protective Dams (Urban Planning Level): This technique involves constructing barriers to control and redirect floodwaters away from populated areas. A notable example of its implementation is the Kyiv cascade of dams project, where spillways, gateways, and drainage systems have been incorporated depending on the design and location of each structure. Due to its complexity, this technique requires additional structural elements to ensure proper flood management.

Use of Smart Airbricks (Object Level): This technique employs modular bricks that allow air to pass through but block water infiltration. When floodwaters reach the height of these airbricks, they automatically seal to prevent water penetration into buildings. This method has been applied in various flood-prone regions of Ukraine, particularly in private homes, where residents use these bricks as a preventive measure against flooding.

Drains (Environmental Design Level): This technique refers to the installation of surface drainage systems designed to collect and channel rainwater from streets and sidewalks while also managing groundwater levels and soil aeration. These drainage systems typically consist of grated openings or channels connected to underground pipes, which transport collected water to drainage wells or nearby water bodies. This method has been implemented in multiple Ukrainian cities, including Mykolaiv, Dnipro, and Kyiv, and is particularly effective in park areas.

For the adaptation strategy, the following techniques have been identified at the urban planning, object, and environmental design levels: "coastal morphology change," "transformable houses," and "water absorption by greenery."

Coastal Morphology Change (Urban Planning Level): This technique involves adapting the shape, structure, and composition of coastal areas in response to natural changes. It includes methods such as beach nourishment, dune restoration, and the construction of coastal stabilisation structures. A notable example of its implementation is the Withernsea coastline project in the UK [31], where these measures were introduced to reduce the risks of coastal erosion and protect existing developments.

Transformable Houses (Object Level): A transformable house is designed to adjust to fluctuating water levels, making it an effective flood-resilient housing solution. The first amphibious house, built in South Buckinghamshire, on the River Thames, UK [32], is a key example of this approach. It is designed to rise up to 2.5 metres during floods while being secured by steel posts, which prevent lateral movement caused by water pressure.

Water Absorption by Greenery (Environmental Design Level): This technique allows certain areas, such as public green spaces, to function as temporary stormwater storage during extreme weather events. The planted vegetation prevents soil salinisation and supports natural recovery once water levels recede. An example of this technique can be found in the Tasinge Plads Park project in Denmark [33], where green infrastructure was utilised to enhance urban flood resilience.

Studying the Ukrainian experience, we have identified the following adaptation strategy techniques, which are also widely applied in other countries: "fish parks," "floating houses," and "shoreline reinforcement with greenery." These techniques correspond to the urban planning, object, and environmental design levels, respectively.

Fish Parks (Urban Planning Level): This technique involves the creation of designated zones within rivers, lakes, ponds, marshes, or coastal areas to protect and preserve aquatic ecosystems while allowing for sustainable human use of wetlands. In Ukraine, this method has been implemented in Mykolaiv, Kherson, and Vylkove to support environmental conservation and establish protected areas.

Floating Houses (Object Level): These houses are constructed on floating platforms or pontoons, enabling them to rise and fall with changing water levels. This approach is particularly effective in flood-prone areas, ensuring habitable and adaptable living spaces along water bodies. In Ukraine, this technique has been applied in Kyiv, along the banks of the Dnipro River, demonstrating its relevance for coastal and riverside construction.

Shoreline Reinforcement with Greenery (Environmental Design Level): This method involves planting vegetation along the shoreline, including grasses, shrubs, trees, and other native plants, to stabilise the soil and prevent erosion. Additionally, the plants serve as natural buffers, absorbing and dissipating wave energy, which helps protect the coastline from damage. This technique has been actively utilised in Vylkove, where it has contributed to shoreline stability and ecosystem preservation.

For the resilience strategy, the following techniques have been synthesised: "creating an artificial or using a natural sandspit," "buildings raised on piles," and "pedestrian paths perpendicular to the shoreline." These techniques correspond to the urban planning, object, and environmental design levels, respectively.

Creating an Artificial or Using a Natural Sandspit (Urban Planning Level): This coastal engineering technique aims to stabilise shorelines, reduce erosion, and enhance environmental resilience. Natural sandspits can be reinforced with additional sediment to strengthen their protective function. This practice is widely applied in coastal cities across France, where it contributes to long-term shoreline stability.

Buildings Raised on Piles (Object Level): This technique involves elevating building structures above ground level using vertical columns or piles made of concrete, steel, or wood, driven into the ground. It is widely used in coastal areas and flood-prone regions to protect structures from rising water levels. A notable example is the development of marine coastal areas with beach buildings on piles in Gruissan, France, where this method has been successfully implemented.

Pedestrian Paths Perpendicular to the Shoreline (Environmental Design Level): This technique serves a dual purpose – it protects the shoreline while ensuring convenient access to the waterfront. Pedestrian walkways are constructed using materials such as concrete, stone, gravel, or boardwalks, depending on site conditions and aesthetic requirements. An example of its application can be seen in Hornsbergs Strandpark, Sweden [34].

Taking into account the Ukrainian experience, the previously mentioned resilience strategy techniques can be supplemented by the following methods at the urban planning, object, and environmental design levels: "artificial channels," "fascine," and "artificial embankments and shafts." It should be noted that these techniques are relevant not only for Ukraine but also for other countries.

Artificial Channels (Urban Planning Level): This technique involves the dredging of existing waterways or the construction of new channels to enhance an area's resilience to flooding while also providing navigable routes for transportation, irrigation, drainage, and aesthetic purposes. A notable example is Vylkove, where an extensive network of interconnected water channels has been developed, ensuring the city's adaptability and long-term sustainability in the face of flood challenges.

Fascine (Object Level): A fascine is a tightly bound bundle of vines or brushwood, cylindrical in shape, used to reinforce the slopes of hydraulic structures and prevent erosion. This method provides an innovative and environmentally friendly approach to strengthening embankments and protecting hydraulic structures. In Vylkove, this technique has been widely applied, particularly in reinforcing the foundations of buildings situated along water channels.

Artificial Embankments and Shafts (Environmental Design Level): This technique enhances urban landscapes and surrounding territories by making them more resistant to flooding through the construction of barriers that hold back floodwaters. Artificial embankments and shafts are built using materials such as soil, sand, gravel, and stone, often reinforced with concrete or geotextiles and covered with vegetation to improve stability and durability. This method is particularly relevant in the Carpathian regions of Ukraine, where annual floods caused by heavy rainfall pose significant challenges.

To ensure the effectiveness of a solution for reducing the vulnerability of urban areas to water level fluctuations, it is important to apply the synthesised techniques not individually but in combination. Moreover, these combinations should encompass different system levels, ensuring a comprehensive and holistic approach to the problem. Therefore, we have compiled all 24 discussed and systematised techniques for mitigating the risks of water level fluctuations in coastal areas into a unified framework, presented as our proposed matrix of techniques at different levels for various strategies (Fig. 1).

These techniques are categorised into three groups, with eight in each, corresponding to specific system levels: urban planning, object, and environmental design. Their integrated application enables a holistic approach to the issue, addressing it simultaneously at different levels, from general to detailed. At each level, two techniques are allocated to each of the four defined strategies. This structure ensures that every level comprehensively tackles the issue, incorporating prevention, control, adaptation, and resilience techniques simultaneously. In the future, this matrix can be expanded with newly synthesised techniques, particularly within the resilience strategy, thereby further developing and enhancing this study.

4. Results: A combination of techniques to reduce the vulnerability of coastal areas in Gruissan to possible sea level rise – concept for the adaptation of the pond coastal area in the park zone of Gruissan

As a result of this study, we have proposed a combination of twelve prevention, control, adaptation, and resilience techniques from our matrix at various system levels, which we believe can be applied in the coastal city of Gruissan, in the south of France. Together, these techniques will effectively complement the existing solutions in the city to mitigate the risks associated with possible sea level rise.

Gruissan is a small resort town in the Occitanie region, located on the Mediterranean coast of France. According to forecasting studies by the Climate Central Institute, certain areas in this region, including parts of Gruissan's coastal zones, may be at risk of complete flooding [35].

Concerned about these potential threats, residents and local authorities are actively seeking solutions, engaging scientists from various fields and organising professional scientific and practical conferences dedicated to this issue. As part of this year’s architectural conference and workshop in Gruissan, we proposed a holistic solution incorporating a combination of techniques aimed at reducing potential risks. The mayor and representatives of the Commune of Gruissan were actively involved in discussions on the proposed solutions and in evaluating the conceptual strategies.

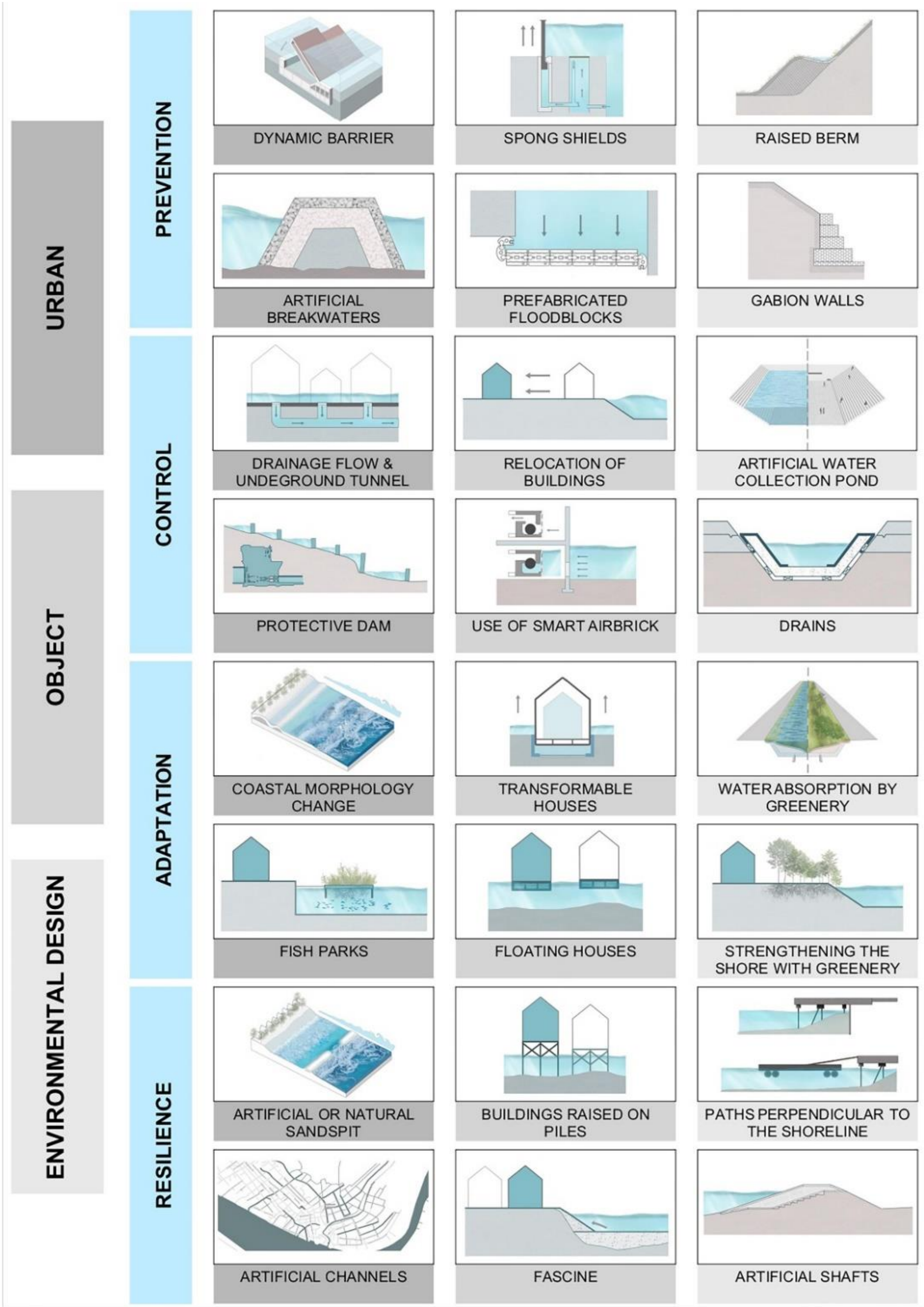

Fig. 1. Matrix of techniques. *Source:* own study

Therefore, the following combination of techniques from the author's matrix is recommended for Gruissan to mitigate the risks of coastal vulnerability due to possible water level rise: dynamic barriers, use of sponge shields, raised berms, spatial monitoring, use of smart airbricks, artificial water collection ponds, fish parks, floating houses, water absorption by greenery, creation of walking paths on restored marshes, buildings raised on piles and a single platform, artificial embankments and shafts (Fig. 2).

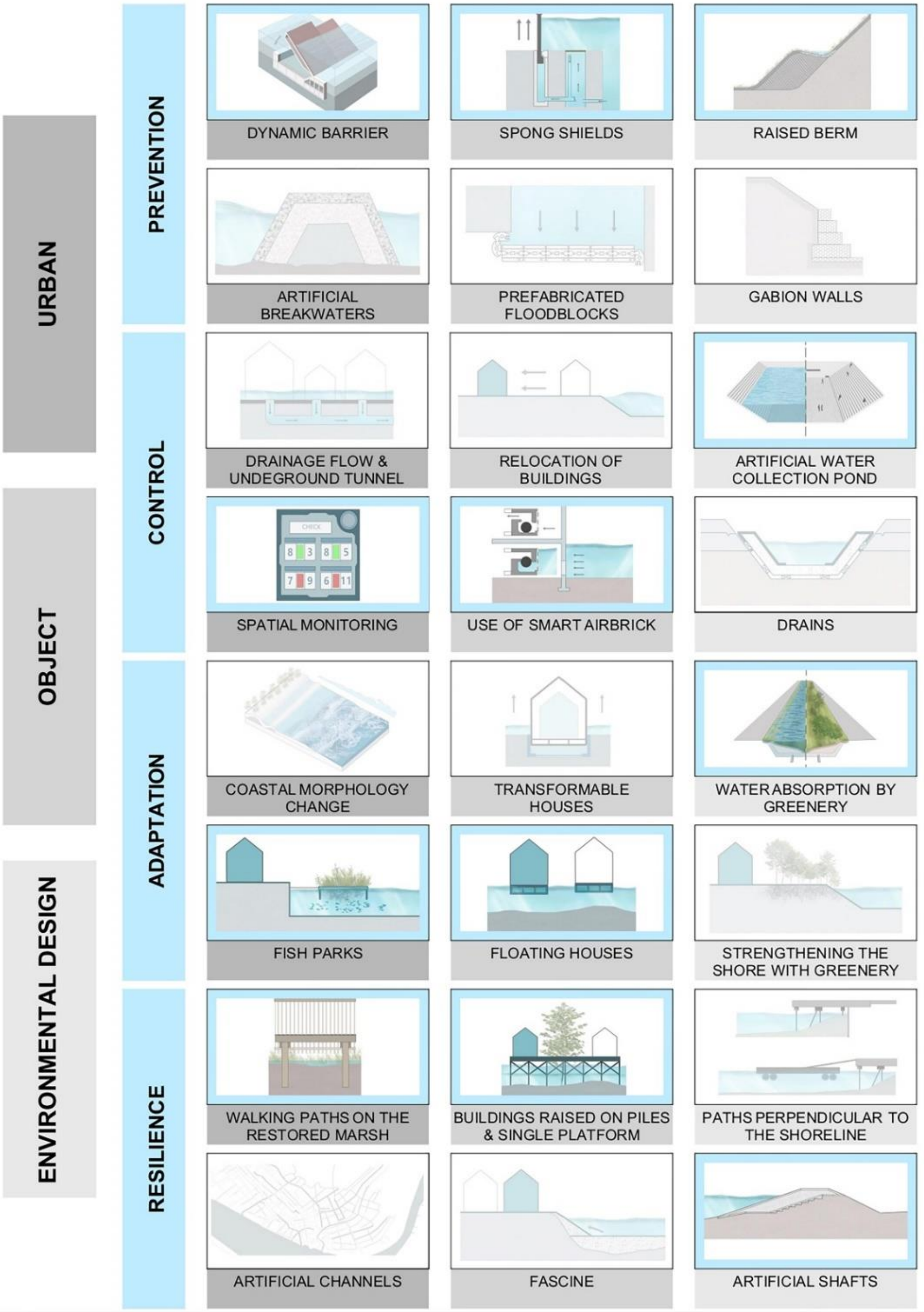

Fig. 2. A combination of 12 selected techniques from the author's matrix will be effective for Gruissan. *Source:* own study

At the urban planning level within the prevention strategy, we propose the installation of "dynamic barriers" at the entrances to bays and canals. If the water level exceeds the tidal threshold, these barriers – combined with the reinforcement of existing artificial embankments and berms, as well as the construction of new ones – can effectively prevent and mitigate flooding. As part of the general control strategy, we recommend establishing a spatial monitoring system comprising monitoring sensors, an analytical centre, and a warning system to enable real-time flood risk assessment and early intervention measures. For the adaptation strategy, new fish parks in flooded areas can be integrated with the existing salt lakes and oyster farms, contributing to biodiversity enhancement and sustainable water management. Within the resilience strategy, it would be beneficial to connect existing wetlands to the city's park area and develop pedestrian and bicycle paths, along with designated recreational spaces. This approach would preserve valuable wetlands, which play a crucial role in carbon dioxide absorption and ecological balance, while simultaneously enhancing recreational opportunities and improving the quality of life for residents and tourists.

At the object level, we propose using "sponge shields" for existing buildings and "smart airbricks" for new constructions as part of the prevention and control strategies. "Smart airbricks" function as a passive flood protection system, operating like regular airbricks that automatically close when water levels rise while also facilitating ventilation and drying of flooded spaces between flood events. For the adaptation and resilience strategies, floating houses and houses raised on piles and a single platform will be effective. The latter technique is particularly valuable as it supports the creation of a single, sustainable social and physical urban space on non-floodable, elevated structures. This raised platform design would preserve underwater ecosystems, allowing plants and animals to thrive uninterrupted, while simultaneously providing new opportunities and a comfortable environment for residents.

At the environmental design level, within the prevention and resilience strategies, we propose constructing artificial embankments and shafts along the entire coastline on the city side. These should be built using the "raised berm" technique to enhance durability and prevent rapid erosion. The embankments should be constructed from natural materials, such as stone, which is more effective at absorbing wave energy than reinforced concrete and is less prone to erosion than sand or soil.

Within the control strategy, artificial water collection ponds should be placed in front of public and administrative buildings, as well as in public gardens. During flooding, these reservoirs would capture excess water, keeping pedestrian paths and streets dry. In normal conditions, these spaces could be utilised as public gathering areas. For the adaptation strategy, the "water absorption by greenery" technique will be highly relevant. Mangroves, which are resistant to saltwater, can be planted in flooded wetlands. Their growth can be managed through selective cutting, with the harvested material repurposed as biomass fuel. Additionally, green spaces along city streets can be expanded and integrated with artificial reservoirs, creating an efficient system for water drainage from pedestrian areas.

The addition of these techniques to the existing conditions in Gruissan will not only enhance flood resilience by reducing vulnerability to potential flooding but will also improve everyday comfort in the city, ensuring a higher quality of life despite fluctuations in water levels.

The concept for adapting the pond's coastal area in the park zone of Gruissan was implemented as a project test of the proposed techniques (Figs 3–5). This proposal was developed as part of an international student workshop, conducted within the REA-24 conference, organised with the support of the Commune of Gruissan municipality [36].

The site selected for adaptation (highlighted on the map with a circle) is located on the bank of Gruissan Pond, between the “old town” and the urbanised resort built at the end of the last century (Fig. 3). It is separated from urban development by a pine urban park and serves as a pedestrian-friendly zone, offering picturesque landscapes and recreational spaces popular among both locals and tourists. The area is intended for walking, relaxation, and nature observation, particularly of migratory birds.

As per the task set by the Commune of Gruissan, the objective was to develop an adaptation strategy for the occasionally flooded area along Gruissan Pond, adjacent to the pedestrian path and the city’s pine park, by transforming it into an information and observation point for migratory birds.

To provide convenient birdwatching locations and to ensure safe and high-quality usage, the proposal includes the installation of small multifunctional wooden modules on pontoons, interconnected by pedestrian walkways raised above the marshland on wooden piles (Figs 4, 5). This practical application strongly demonstrates the relevance of the techniques identified in the theoretical part of the study, reaffirming their applicability for Gruissan.

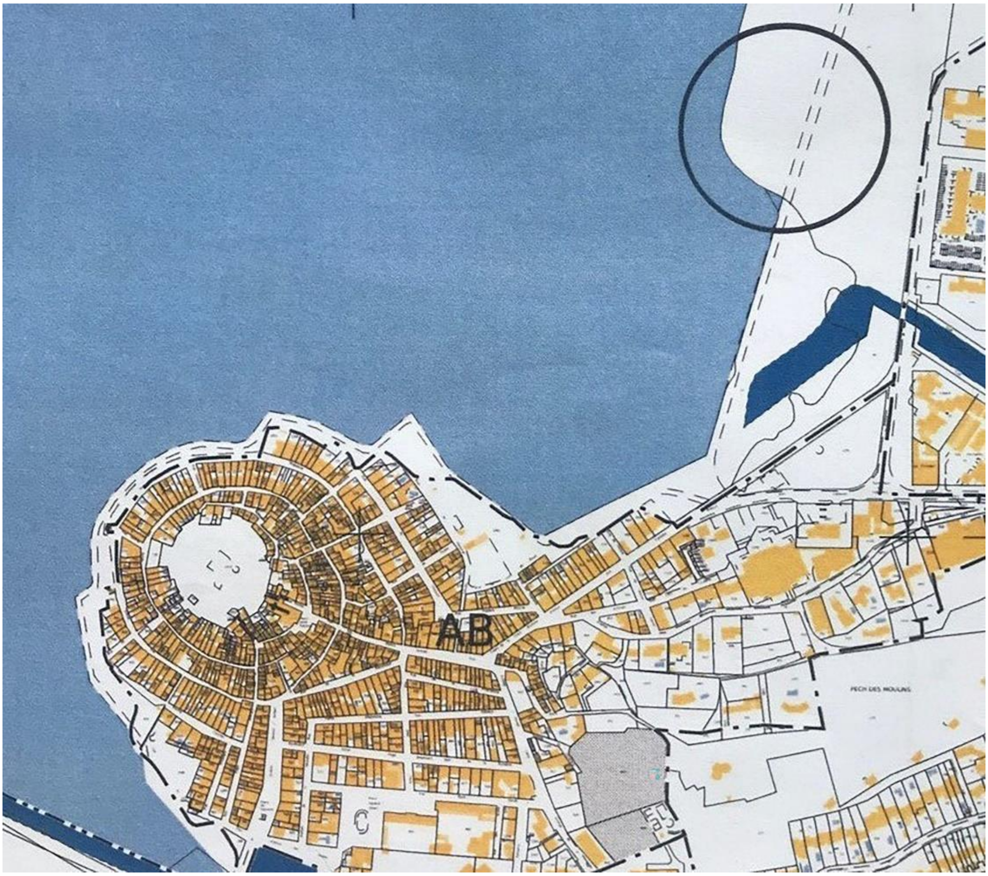

Fig. 3. The location selected for the adaptation proposal. *Source:* [36]

Fig. 4. Concept of a multifunctional wooden module. *Source:* own study based on [36]

Fig. 5. Concept for the adaptation of the pond coastal area in the park zone of Gruissan. *Source:* own study based on [36]

The image of waves touching the shoreline inspired the design of the walkway path, creating a dynamic and immersive experience. This path provides visitors with varied perspectives of the city, mountains, and water, enhancing engagement and spatial perception. Four circular wooden modules integrated along the new pedestrian path serve as bird-watching platforms, rest areas, and information/exhibition spaces. The primary bird-watching module is positioned deeper along the walkway to ensure a quiet and undisturbed observation environment. Additionally, it is slightly lowered relative to the path, allowing visitors to observe from the birds' eye level. This structure features a roof and side wall, providing protection from wind and sun. To ensure universal accessibility, ramps are incorporated for all descents, making the space fully inclusive.

The concept is modular and adaptable, allowing for the addition of walkways and circular structures as new needs emerge on-site. Their design and positioning ensure flexibility and resilience to fluctuating water levels.

The implementation of this concept confirmed the effectiveness of the theoretical framework and received high praise from the representatives of the Commune of Gruissan.

5. Conclusions

Thus, reducing the vulnerability of coastal areas to water level fluctuations requires a holistic approach. To be effective, this approach must be implemented at different systemic levels, using appropriate techniques and their combinations.

We have synthesised and systematised techniques for four key strategies – prevention, control, adaptation, and resilience – to mitigate the risks of water level fluctuations. These techniques have been structured across three hierarchical levels: urban planning, object, and environmental design. Their selection is based on examples from Ukrainian and international best practices in addressing the risks and vulnerabilities of flooded areas, reinforcing their practical relevance.

An author’s matrix of twenty-four systematised techniques has been developed. The simultaneous application of these techniques at different systemic levels for various strategies is an effective method for reducing risks and ensuring a comprehensive solution. The proposed matrix can be expanded with new techniques, particularly in adaptation and resilience strategies, which are crucial for the sustainable development of coastal areas. Additionally, exploring its adaptability to different contexts would be an interesting avenue for further research and refinement.

A combination of twelve synthesised techniques from the proposed matrix has been identified as suitable for complementing the existing conditions in Gruissan, a small coastal town in Occitanie, southern France. Recommendations for their potential implementation at various systemic levels and within different strategies have been provided. The integrated application of these techniques across all hierarchical levels will significantly reduce the vulnerability of Gruissan’s coastal areas to water level fluctuations.

As a practical demonstration of the proposed theoretical framework, an adaptation concept was developed for the occasionally flooded area along Gruissan Pond, addressing the modern needs of the city, its residents, and tourists. This case study validated the effectiveness of the theoretical assumptions, further reinforcing the practical applicability of the proposed solutions.

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