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"Implementation Of Constructed Wetlands Landscape Design"

"A Resilient Application"

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ABSTRACT

Cities are centers of economic activities and opportunities, and according to recent United Nations' reports half of the world's population are currently living in cities, resulting in a phenomenon often referred to as the "Urban Turn". However, cities are also places that face accumulated stresses and sudden shocks, resulting in social, physical, or economic breakdowns. That is unless a city is resilient.

The concept of urban resilience has increasingly gained the interests of governments, urban designers, and various practitioners worldwide due to the unprecedented urbanization and the rising impacts of climate change, natural and man-made disasters, as well as other chronic stresses. As defined by the United Nations " resilience is the capacity of a certain system subjected to potential hazards or stresses to adapt, resist, or change in order to maintain its functions and structure, through learning from past experiences to inform future risk management measures". Consequently the main goal of resilient landscape is to prepare, retrofit, and adapt urban systems and communities to bounce back and recover more quickly from disruptive events and chronic stresses, either now or in the future.

Constructed wetland are considered an artificial mimic of natural wetlands, one of the most biologically diverse natural ecosystems which offer a number of resilient and sustainable functions, some of which are management of water flow of rivers, mitigation of floods, climate regulations, conservation of water sources, water purification, as well as maintaining biological diversity.

The main scope of this research is to study the potential benefits of constructed wetlands landscape design as a resilient approach to achieve water management, stormwater and flood control, improving water and air quality, in addition to aesthetic, recreational, and socio-economic functions.

KEYWORDS

Resilience, multifunction landscape, constructed wetlands, ecosystem management.

INTRODUCTION

Cities worldwide are facing a wide range of hazards and pressures, among which are flood risks, air and water pollution, droughts, heat island effects, resource scarcity, and endangered natural habitats. Urban resilience is achieved when urban settlements are able to prepare for, mitigate, respond to, and adapt to such disruption without affecting the basic functions of the city, or threatening the life of its inhabitants.

Many attempts have been made to deal with disruptive events and chronic stresses in cities, but recently there is an increasing interest in urban resilience as a new research venue. Resilient measures offer efficient solutions and work as an alternative for hard-engineering measurers since eco-engineering resilient measures are relatively cheap and have the potential of combining multiple urban functions in one comprehensive urban landscape. Constructed wetlands represent an effective example of such eco-engineering resilient approaches being a low cost, easily operated alternative for conventional urban management systems (Ezeah, C.,et al 2015).

1. RESEARCH METHODOLOGY

The study is the part of a series of researches to analyze the potential benefits of constructed wetlands projects through an ongoing research project of a multifunction constructed wetland project to be implemented in 10th of Ramadan city. The project is a joint coooperation between different academic institutions including MTI University, Cairo University, MSA University and The National Water Research Center.

The study is divided into two main parts; the first part is a theoretical study of the concept, importance and main parameters of urban resilience, as well as the main concept, benefits and types of constructed wetlands to point out the correlation between urban resilience and constructed wetlands as a resilient, multifunction, low impact design solution to various urban hazards and stresses.

The second part of the study follows an analytical approach, where a number of constructed wetlands mega-projects from different locations worldwide are analyzed pointing out their main challenges and threats, design criteria and outcomes to present a reflective learning experience on the application of constructed wetlands. In conclusion, a set of design considerations of constructed wetlands as a resilient application is proposed. Moreover, the potential role of constructed wetlands as a resilient solution to prominent climate change hazards facing Egyptian cities is pointed out to inform future researches on constructed wetlands application to mitigate climate change impacts and thus enhance urban resilience in Egypt.

2. URBAN RESILIENCE DEFINED

The word “Resilience” comes from the Latin word “Reselio” meaning to bounce back after a disruption. (P. Longstaff et al, 2010). The concept of resilience has been initially introduced as a unifying concept related to the field of ecology and sustainability sciences (Curtin & Parker 2014). However, resilience is a multi-disciplinary concept that could be attributed to different domains; physical, social, ecological, urban....etc.

Although the concept of urban resilience has emerged relatively late after engineering and ecological resilience, it has rapidly gained interest as an important research venue in urban studies (Sharifi and Yamagata, 2014).

The goals of resilience vary accordingly from the preservation of ecosystems, mitigating impacts of climate change, disaster risk reduction, to preservation of cultural heritage as well as social and psychological resilience goals. This adds to the complexity of resilience conceptualization. Over the past years, definitions of resilience have proliferated according to different domains and perspectives.

Until the early 2000s, most of the literature restricted resilience to resisting shocks and withstanding disruptive events. However, more recent literature has stated that merely resisting shocks is no longer sufficient and that systems must have the ability to bounce forward better than before the shock (Chandra et al., 2011). The increasing impacts of climate change along with the rapid urbanization added a new range of hazards, thus affecting the definition of resilience. Resilience therefore must work to enhance the system's performance and adaptive capacity to face multiple forms of hazards and accumulated stresses, rather than merely resisting or mitigating losses due to disruptive events. (Shaikh Muhammad Mehedi Ahsan, 2013).

3. IMPORTANCE OF URBAN RESILIENCE

Several hazards are continuously pressuring people living in cities and threatening development strategies and prosperity. Urban resilience is based on multi-level strategic plans to encounter such hazards.

Among the most significant risk drivers in cities are:

- The increase in urban populations resulting in turn in the increased density of urban areas. This adds pressure on land, institutions, and services, as well as the increase of settlements in unsafe, hazard-prone areas.
- Health breakdowns, floods and landslides due to inefficient management of water resources and lack of solid waste management and drainage systems.
- Unsustainable human activities, increasing pollution, abusive use of resources which threaten the balance of ecosystems.
- Negative impacts of climate change resulting in a change in temperature and precipitation levels leading to sea-level rise, floods, and other climate-related disasters.
- Lack of preparedness, fast response to disasters and effective coordination of emergency strategies (UNISDR, 2012).

4. CONSTRUCTED WETLANDS AS A RESILIENT APPLICATION

Natural wetlands are considered an extremely rich ecosystem, offering various ecological functions, some of which are: enhancing biodiversity, controlling natural floods, maintaining habitats for wildlife, water treatment, preserving shorelines, and air purification (Hamilton, S.K. et al, 1997). Constructed wetlands are man-made urban systems that mimic the functions of natural wetlands but in a more controlled environment, providing a range of sustainable and resilient urban functions.

The benefits of constructed wetlands are not merely limited to water management and purification. Other benefits include environmental benefits such as energy generation from biogas, reducing heat island effect, air purification, and erosion control. Economical, recreational, and social aspects are also major assets that could be achieved through the implementation of constructed wetlands (The Nature Conservancy, 2015).

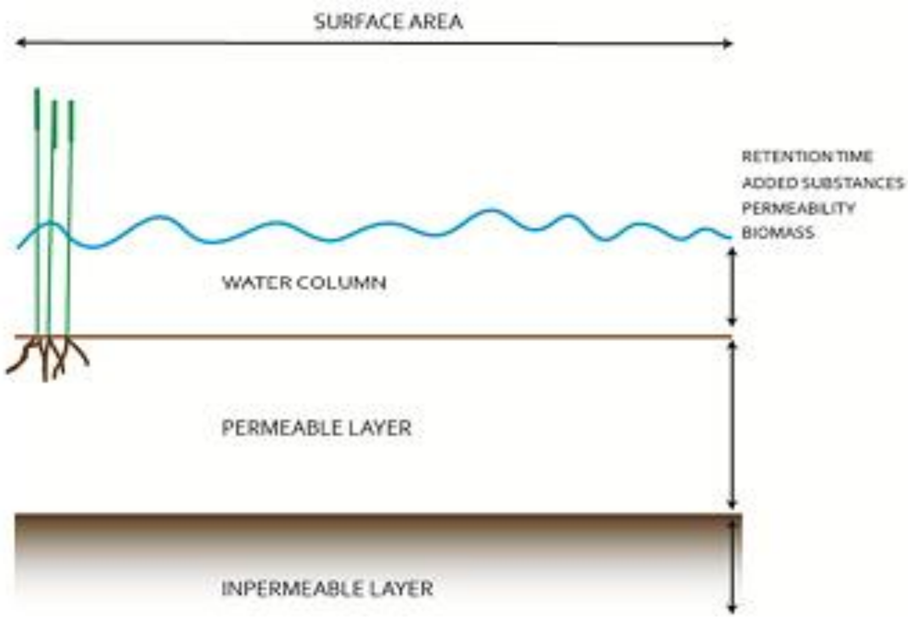
Moreover, compared to other conventional grey infrastructure systems, constructed wetlands are considered more preferable due to:

- Lower operating expenses due to minimal energy costs, low maintenance costs, no bio solids or waste disposal.
- Lower environmental impacts due to reduced constructions and dependence on natural processes.
- Reduced labor costs since constructed wetlands generally require minimal operational support as opposed to conventional grey systems (ASLA,2018).

4.1 Types Of Constructed Wetlands

Constructed wetlands are engineered controlled urban systems that exploit the natural processes such as natural vegetation, soil, and micro-organisms to achieve the required functions (Fig. 1). They are classified either according to the type of natural plantations or microphytes employed or according to their hydrological system and water flow (Vymazal, 2010). Constructed wetlands employ two types of water flow either surface water flow, or subsurface water flow according to different factors such as the rate of water flow needed, or other aesthetic or landscape design factors (Fig.2).

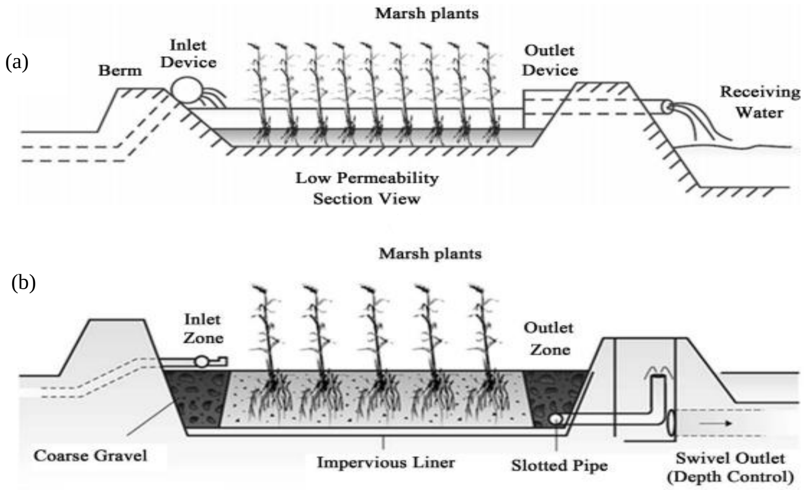
Figure (1) An illustration of the basic idea and main layers of constructed wetlands



Source: Ezeah, C., et al 2015

Figure (2) Types of constructed wetland according to the type of water flow

(a)Surface water flow, (b) Sub-surface water flow



Source: Ezeah, C., et al 2015.

4.2 How Constructed Wetlands Contribute To Urban Resilience?

Constructed wetlands offer a range of resilience functions in various areas as follows (Greenway, M., 2010, Altor, A.E., Mitsch, W.J., 2006-Balderas-Guzman, Celina. 2013- Gobster, P.H., Westphal, L.M., 2004 - Wong, T.H.F. 2006):

4.2.1 Improved water quality

Wastewater resulting from stormwater runoffs, agricultural, or municipal discharges are efficiently treated by various elements of constructed wetlands, such as vegetation uptake, bacteria and algae, soil absorption, and gravitational settling effect. In addition, some chemical reactions and volatilization activities may also occur, thus eliminating other water contaminants such as hydrocarbons.

4.2.2 Water storage and hydrology

Constructed wetlands can be used as temporary water storage bodies to manage stormwater runoffs and provide protection against over banks flooding. They are used as a water sponge to mitigate the effect of flood disasters and regulate water quantities.

4.2.3 Improved air quality

Air quality is highly improved due to reduced levels of carbon dioxide and other pollutants.

4.2.4 Energy conservation

Wastewater management using constructed wetlands require no or minimal energy thus resulting in energy conservation, while grey wastewater treatment systems, on the contrary, have elevated energy consumption rates. In addition, some constructed wetlands are used to generate energy from biogas.

4.2.5 Climate change resilience

Constructed wetlands have proved to contribute to ecosystem management, avoiding water shortages through recycling and reuse, flood protection, reduced levels of carbon accumulation in soil, and urban heat island effect mitigation.

4.2.6 Habitat and biodiversity enhancement

Due to the permanent water retention property associated with constructed wetlands design, it is considered as an excellent habitat for wildlife. Different species find suitable habitats in constructed wetlands such as different types of birds, reptiles, and amphibians.

4.2.7 Quality of life enhancement

The aesthetic value of constructed wetlands is manifested through the landscape design integrating water bodies with various types of plants and vegetation, along with different hardscape features. Constructed wetland urban landscapes play a distinctive role in increasing community livability by creating recreational areas.

4.2.8 Physical and psychological health benefits

Constructed wetlands provide physical health benefits through better water and air quality. Moreover, the large areas of water bodies and green spaces also contribute to better mental health and lower crime rates among community residents.

5. INTERNATIONAL EXAMPLES OF CONSTRUCTED WETLANDS PROJECTS AS A RESILIENT APPLICATION

During the past years, a number of constructed wetland parks projects have set obvious evidence on the resilient role of constructed wetland parks in encountering climate, urban, social and economic problems, some of which will be illustrated in the following section.

5.1 Qunli Stormwater Park (2009-2010)

Located in Qunli, Haerbin City in China with an area of 300,000 m2, Qunli wetland park is designed to work as a green sponge in the city (ASLA, 2012).

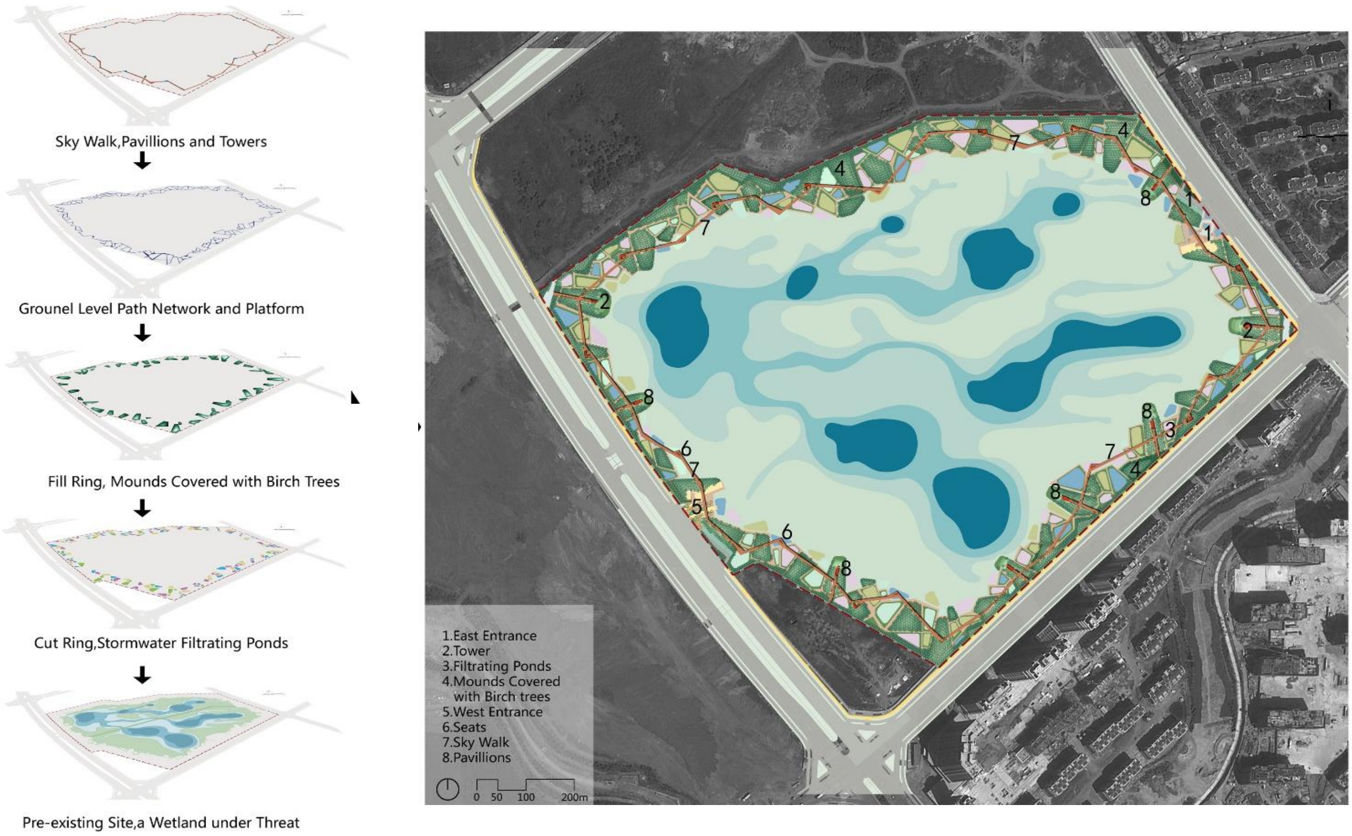
5.1.1 Challenges and threats

- Urbanization threats since Qunli is a town in a city populated by 3.8 million pressuring the natural ecosystem.
- A degraded natural wetland with endangered natural habitats.
- High levels of annual rainfall reaching 60-70% during summer resulting in flood hazards
- An overflow of stormwater which is in due course wasted and recharged into the river.
- A percentage of 83.6 of the town area is covered by impervious surfaces.
- A decline in groundwater levels due to excessive exploitation.

5.1.2 Design concept

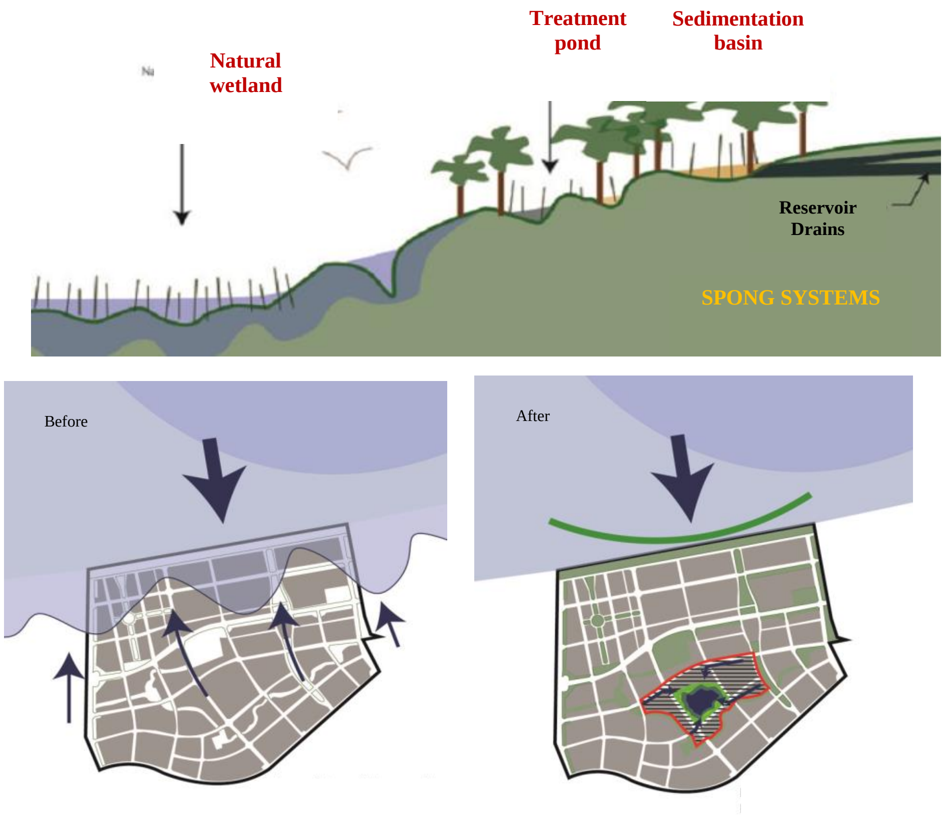
- Encircle the existing natural wetland to preserve the natural ecosystem.
- Minimum earthwork through using cut and fill technique to create a network of ponds and mounds around the circumference of the wetland forming a buffer zone.
- The network of ponds is used as a water sponge for storing and regulation of stormwater.
- Using the natural filtration processes of wetland grasses found in the ponds of various sizes and depths.
- The park provides a number of aesthetic and recreational values through an interlinked network of paths, sidewalks, pavilions, skywalks and seating areas to support the community's social activities.

Figure (3) Design concept of Qunli wetland park



Source: ASLA, 2012

Figure (4) An illustration of the sponge system and the monsoonal rain conditions before and after the implementation of the park design



Source: ASLA, 2012

5.1.3. Project outcomes

- Preservation of the previously degraded natural wetland.
- Restoration of native biodiversity of fauna and flora.
- Stormwater management through collection, storage, and purification of stormwater, therefore mitigating stormwater floods.
- The amount of treated water has reached 500000 m^3.
- Increasing water levels in underground aquifers by recharging them with excessive stormwater.
- The innovative multifunction landscape design has allowed the park to be nominated for the Energy Globe Award in 2015 for achieving stormwater treatment and retaining while mitigating flood hazards.

Figure (5) The final images of the project showing the aesthetic and social aspects of the landscape design

Source: ASLA, 2012

5.2. Mill River Park And Greenway (2013)

The Mill River Park is located in Stamford, Connecticut, USA. Its area is around 33 acres (Nia Rhodes Jackson, 2014).

5.2.1 Challenges and threats

- A neglected, highly polluted riverfront.
- A high level of silt accumulations throughout the river banks.
- The natural flow of the river has been obstructed by dams since the 1600s.
- The dams restricting the river flow have resulted in a considerable loss of biodiversity including various types of fish.
- The tidal effect of the river poses a high risk of flooding to central Stamford city.
- The local community's need for a public park to join the city with its historic riverfront.

Figure (6) The Mill River condition prior to the project

Source: ASLA, 2015

5.2.2 Design concept

The design was a collaborative design by civil engineers, ecologists, and landscape architects along with local community participation.

- The final master plan consisted of a 28 acres park along with a 3miles long greenway.
- Mill River Park is designed to act as a revitalization project for the historic riverfront.
- The project design plays an important role in sustaining natural habitats and connecting the city to nature.

Figure (7) The project's master plan

Source: ASLA, 2015

Figure (8) Images of the site before and after the project implementation

Before After

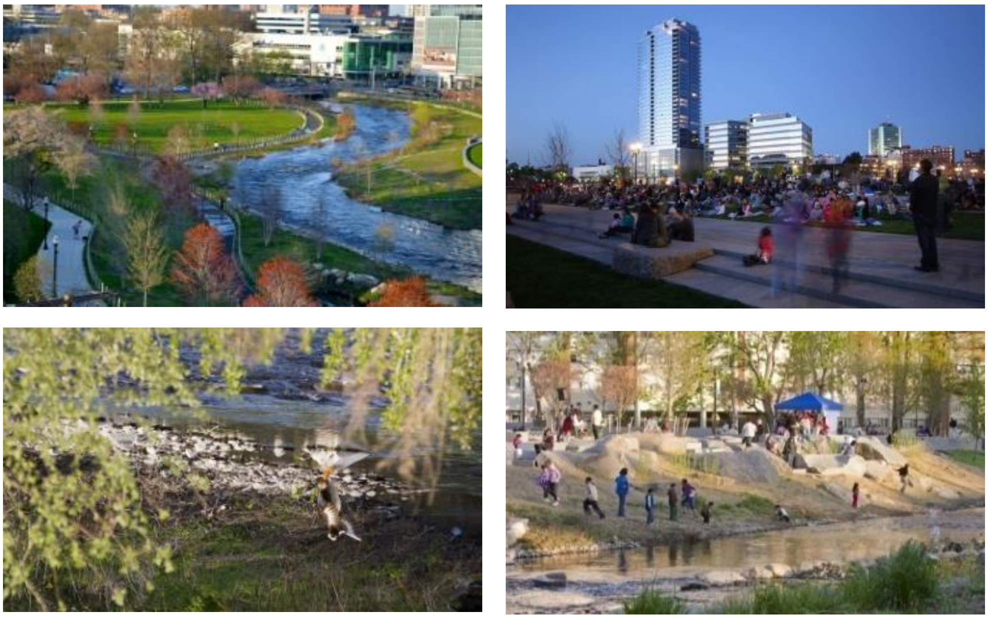
Source: ASLA, 2015

5.2.3 Project outcomes

- The project won the 2015 American Society for Landscape Architects (ASLA) Design Honor Award.
- The Mill River Park has become Stamford's main recreational, economic, and social hub.
- The project generated a set of environmental benefits including restoration of terrestrial and aquatic ecosystems, stream temperature moderation, riverbanks, and flood plain management.
- Biodiversity enhancement through the integration of new bird species such as ground-nesting birds, river otters, and mallards.
- The design also contributed to a significant reduction in pollution levels.
- The number of trees planted reached 400 trees in addition to thousands of shrubs.

- The Park raised the economic revenue of Stamford through $4 million more municipal tax revenue annually.

Figure (9) Final images of the Mill River Park landscape design



Source: ASLA, 2015

5.3 Albufera Constructed Wetlands Park (2013)

Albufera of Valencia is a natural wetland of great ecological value in Spain. However, the area has witnessed severe degradation which affected its natural ecosystem. Dramatic measures had to be taken in order to restore the area's ecosystem balance. The Albufera national park project offered a suitable solution in the form of 3 constructed wetlands covering an area of 90 hectares (Medwet, 2015).

5.3.1 Challenges and threats

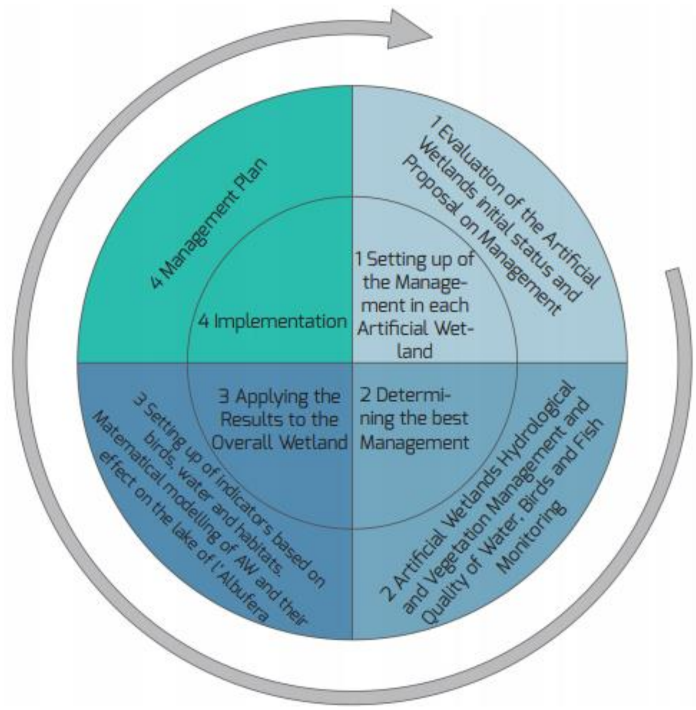
- Increasing urbanization and industrialization around the borders of the lake.
- Illegal farming practices due to the intensive usage of fertilizers and pesticides resulting in high levels of pollutant contamination in the lake.
- Environmental problems due to illegal fishing and hunting.
- The area is home to a number of endemic and endangered species of plants and animals.

5.3.2. Design Concept

- The design aims to accomplish high ecological values to meet the requirements of the Water Framework Directive.
- Restoration of 3 existing rice fields by converting them into constructed wetlands.
- Management of hydraulic rates, water flow, and vegetation within the 3 constructed wetlands.
- Improve the quality of the urban area surrounding the lake.
- Reducing levels of pollution and contamination in the Albufera Lake.

- Create natural habitats for fauna and flora.
- Implementing monitoring and assessment tools to evaluate water quality, turbidity, alkalinity levels as well as sedimentation and dissolved oxygen.
- Establishing a set of indicators to assess the conservation of bird species to be applied in other wetland projects.

Figure (10) The project's 4 phases



Source: Medwet, 2015

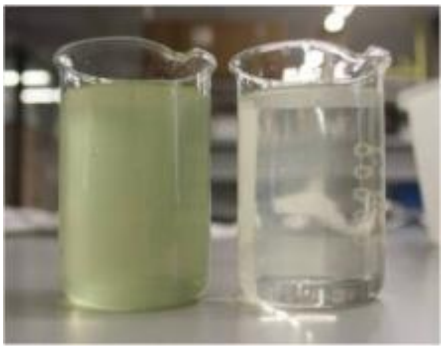
5.3.3 Project outcomes

- During the 1st year of the project, a percentage of 15% of the lake water was introduced to the wetlands.
- Mitigation of climate change impacts and heat island effect.
- Mitigation of carbon sequestration.
- Increase of waterfowl breeding

Figure (11) The 3 constructed wetlands of Albufera

Source: Medwet, 2015

Figure (12) A visual illustration comparing the input water on the left to the water treated by the constructed wetland on the right



Source: Medwet, 2015

6. CONSTRUCTED WETLANDS MAIN DESIGN CONSIDERATIONS

In order to achieve the above-mentioned potential benefits out of a constructed wetland park, the design ought to incorporate multi-function landscape features. A set of design criteria and consideration regarding various urban functions are listed in Table 1:

Table (1) Design criteria for constructed wetlands

Design Theme	Criteria
Water quality	- Design to ensure the maximum time of water retention to enable efficient purification. - Promote the systematic distribution of watersheds to form an integrated water treatment network. - Support water exposure to various conditions for different purification processes. - Design water basins of different depths, since shallow basins provide direct contact with plant roots and microphytes, while deeper depths promote anaerobic processes. - Maintain a ratio of 1:20 between width and length of water bodies. - Design the wetland park to provide a multiplicity of wetland cells of different sizes.
Climate change resilience	- Since carbon levels are one of the main factors affecting air quality and climate-related problems such as the heat

	island effect, a dense level of vegetation must be maintained. - To minimize the release of methane from constructed wetlands, design the networks to avoid permanent inundation of wetland cells through frequent monitoring and maintenance.
Habitat and biodiversity enhancement	- Enhance plant biodiversity by planting vegetation on the banks of the wetland cells. - In order to avoid increasing populations of mosquito, allow for a diversity of predators.
Quality of life	- Ensure an appropriate area for enriching the landscape with various recreational activities such as walking, biking, hiking, fishing, and kayak riding. - Design different areas of open spaces with adequate shaded seating areas and landscape furniture to promote social interaction and community connectivity. - Engage community members in the design process through surveys and questionnaires to inform design decisions regarding recreational and social activities, and awareness programs to enhance educational activities about the benefits of constructed wetlands.
Economic benefits	- Constructed wetlands can act as a multifunction landscape that promotes economic benefits by utilizing treated water in planting flowers, productive crops, and industrial oils. Moreover, some wetland cells can be used for fish breeding.

Source: Author based on data from (Balderas-Guzman, 2013- Moore and Hunt, 2012 - Altor and Mitsch, 2006 - Greenway, 2010, - Serrano and DeLorenzo, 2008).

7. CONSTRUCTED WETLANDS AS A RESILIENT SOLUTION TO URBAN, SOCIAL AND CLIMATE CHANGE PROBLEMS IN EGYPT

The abovementioned constructed wetland projects prove the potential efficiency of constructed wetland parks in mitigating the effects of heavy rainstorms and acting as a nature-based coastal protection strategy. In addition to their role in reducing heat island effect and pollution levels in cities, as well as restoring ecosystem balance.

During the past few years, Egypt has encountered a number of climate change related incidents that have affected the functionality of different cities and caused considerable damage to public and private properties. These incidents have raised a great deal of debate about the preparedness of Egyptian cities to face climate change events, whether they are sudden events like heavy rainstorms or long term effects of climate change like sea-level rise (Figures 13,14,15).

Figure (13) Cairo during a heavy rainstorm, October 2019

Source: https://www.youm7.com/story/2019/10/22/

Figure (14) Rainstorm in Alexandria, 2015

Source: https://www.masrawy.com/news/news_regions/details/2019/10/25/1659067/

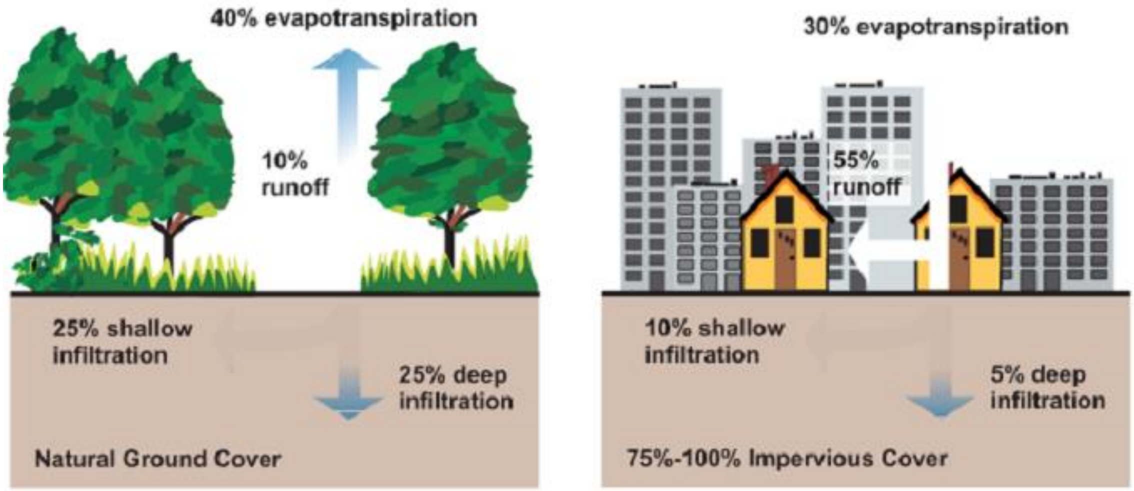
Figure (15) Scenarios of the effect of sea-level rise on the Northern coast of the Nile delta

Source: Y. Eldeberky, (2011)

7.1. The Role Of Constructed Wetlands In Mitigating Effects Of Heavy Rainstorms

Constructed wetlands act as natural rainwater sponges, reducing surface runoff of rainwater during extreme storms since the green vegetation cover absorbs large percentages of rainwater compared to impervious surfaces (Fig. 16). The absorbed water can also be collected through underground drainage systems to recharge groundwater levels. The water bodies in the landscape design of constructed wetlands also act as rainwater reservoirs, thus preventing the loss of rainwater.

Figure (16) Effect of green spaces in reducing surface runoff during rainstorms



Source: U.S. Environmental Protection Agency.

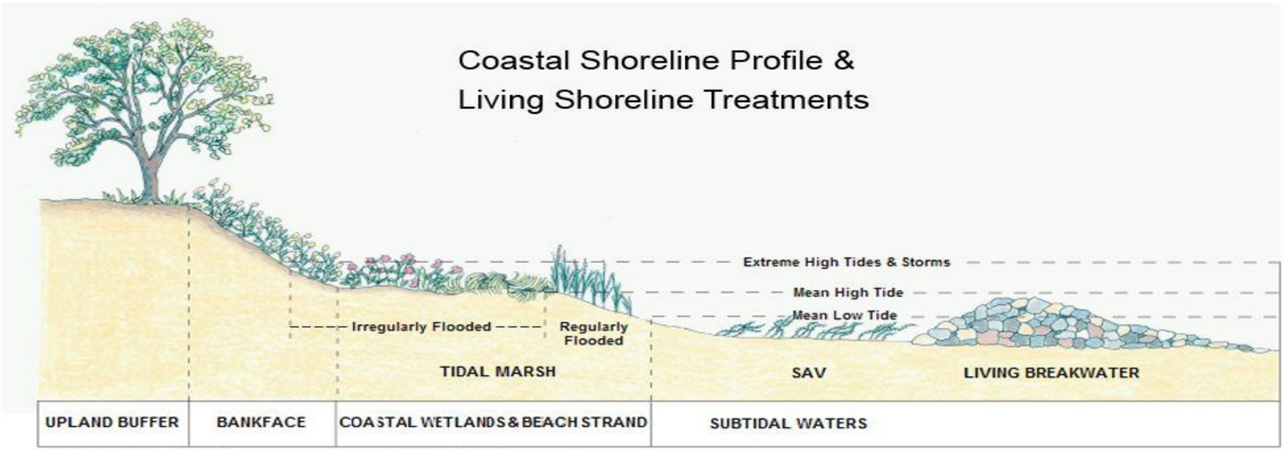
7.2 The Role Of Constructed Wetlands In Coastal Protection

Coastal constructed wetlands may act as intermediate buffer zones protecting shores and coastlines against wave surges and coastal erosion, offering a resilient solution that is less exhaustive, more productive, and aesthetically appealing compared to grey infrastructure installments (Fig.17). Coastal wetlands can be designed as a complement to an existing natural shoreline wetland or as a new urban intervention.

Figure (17) Shore protection walls in Alexandria

Source: Y. Eldeberky, (2011)

Figure (18). An illustration of the main concept of constructed wetlands for shoreline protection



Source: https://www.nationalgeographic.org/encyclopedia/living-shoreline/

8. CONCLUSION

Urban resilience has become a prominent development goal due to the increasing urbanization trends, as well as the extreme effects of climate change which threaten a greater number of people and assets every day. Governments, academics and urban planning practitioners worldwide are shifting from hard engineering infrastructure systems to nature induced, low impact designs to achieve urban resilience against different shocks and stresses and achieve ecosystem balance. Constructed wetlands are among the most resilient urban landscape approaches, representing a multifunction landscape that can be implemented to encounter various urban and climate change issues. Constructed wetlands are also low maintenance projects which require minimum operating costs, equipment, and personnel. They are economically sustainable projects that not only consume fewer resources, but can also generate economic profits through farming, fisheries, and other economic activities. Moreover, constructed wetlands contribute to increasing the quality of life of citizens through an aesthetically pleasing recreational landscape design combining green spaces and water bodies, thus increasing community connectivity.

In Egypt, constructed wetlands represent a promising solution to a number of urban and climatic problems, such as heat island effect, high pollution levels in Egyptian cities, wastewater management, rain storms runoffs, and coastal zones management.

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