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A proposed framework to measure environmental sustainability of the developed waterfronts (King Abdullah Park –Dammam)

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ABSTRACT
Sustainability is a function of society, economy and environment developed with the intention of achieving today's and future generations' needs without harming and diminishing renewable environmental resources. Environmental sustainability in designed areas requires enrichment of biodiversity and continuity of site productivity; maintenance and enhancement of natural processes; and durability of used materials and continuous use of the designed site at different times. The purpose of this paper is to develop a framework to measure environmental sustainability of the designed coastal waterfronts, using the King Abdullah Park (KAP) at the Dammam waterfront as case study to analyse the situation and apply the developed framework. The site of the KAP constitutes one of the most environmentally sensitive areas in the Eastern Province of the Kingdom of Saudi Arabia (KSA). It occupies the central part of the Tarut Bay, which has faced extensive urban expansion and has suffered associated problems of dredging and land filling since the late 1970s.
This research study of KAP applies a simple methodology that based on direct observation and analysis of the environmental natural processes in relation to the implemented proposal in the area. Through application of the framework, environmental effects on the area, users and resources/processes are examined against the environmental sustainability indicators. The research revealed that: in designed coastal waterfronts most of the natural processes are altered or imbedded leading to loss of biodiversity and site productivity; and raise of several environmental problems including accumulation of wastes, weathering of coastline and pavement materials, and damage of other structures. This will result in increase of hidden costs regarding maintenance and replacement; and abandonment of the place. The results of this study will help produce sustainable design of new waterfronts; and preserve and enhance natural processes which are of most importance for coastal areas' health and productivity.
Conference Topic: Smart Materials and/or Systems and Sustainability
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1. INTRODUCTION:

1.1 Background:

Coastal areas are considered one of the most sensitive areas to any source of alteration and/or modification, as they perform complexity of interrelated processes taking place within a variety of maritime and terrestrial ecosystems. Coastal ecosystems include near shore shallow waters, beaches, dunes, salt marshes, sabkhats and intertidal zone function in a sustainable manner to maintain the ecological integrity and balance between biotic organisms and their abiotic physical environment. Functionality of such ecosystems relates to the coastal areas' dominant processes and actions of currents, waves and tides.

Within any natural ecosystem, human settlements are considered formidable agent of change that influences fundamental ecological processes (Theobald et al, 2000). Expansion of urban areas has accelerated by growth of human populations and their needs which together act to diminish vital natural ecosystems and resources; and increase conflicts over land use (Beardsley et al, 2009).

The environment of coastal cities has suffered physical growth as a result of attraction of human activities which have stimulated driving forces for the development of nearby coastal areas. In addition to the population growth as the major driving force of coastal zones development since the middle of the twentieth century, socioeconomic (including: exploitation of coastal natural resources, urban and agricultural developments have significantly contributed to coastal environmental degradation (Haslett, 2000). These driving forces are the roots for increasing pressures on coastal ecosystems and their resources which are typically linked to the cumulative effects of diverse types of risks arising from coastal development, recreation and tourism activities, pollution and consumptive exploitation of resources.

Worldwide, modification of coastal areas to accommodate urban land uses, recreational and tourism facilities requires huge amounts of land filling on intertidal habitats and dredging of nearby shallow water areas. The Dammam Metropolitan Area (DMA) is not exceptional from that. It has experienced extensive coastal development resulting in land filling and dredging of more than 4,100 hectares of inter tidal and shallow water habitats during the last twenty years of the 20th century (Kubarrah & Al-Wakeel, 2003).

This study is an attempt to develop a framework for measuring environmental sustainability based on simple techniques of site inventory and analysis, and application on specific area to define the impacts of development on the environmental sustainability of that area. Here it is worth noting the difference between measurement and assessment. According to Brandon and Lombardi (2005) measurement involves the identification of variables related to sustainable development and the utilisation of technically appropriate data collection and analysis methods, while assessment involves the evaluation of performance against a criterion or a number of criteria.

1.2 Study Area: King Abdullah Park (KAP):

The Dammam water front occupies the southern part of the Tarut Bay (figure 1) between Seahat at the north and the King Abdulaziz Seaport at the south. King Abdullah Park (KAP) has extended on about 3.5 km at the middle of the Dammam water front; west oriented facing Al-Murjan Island. This area suffered a great deal of reclamation operations resulting in the continuous shift of coastline westward during 1994 – 2004 (Al-Sulbi, 2008) as well as huge amount of land filling that took place during the construction of the KAP in order to create series of platforms up to six metres high.

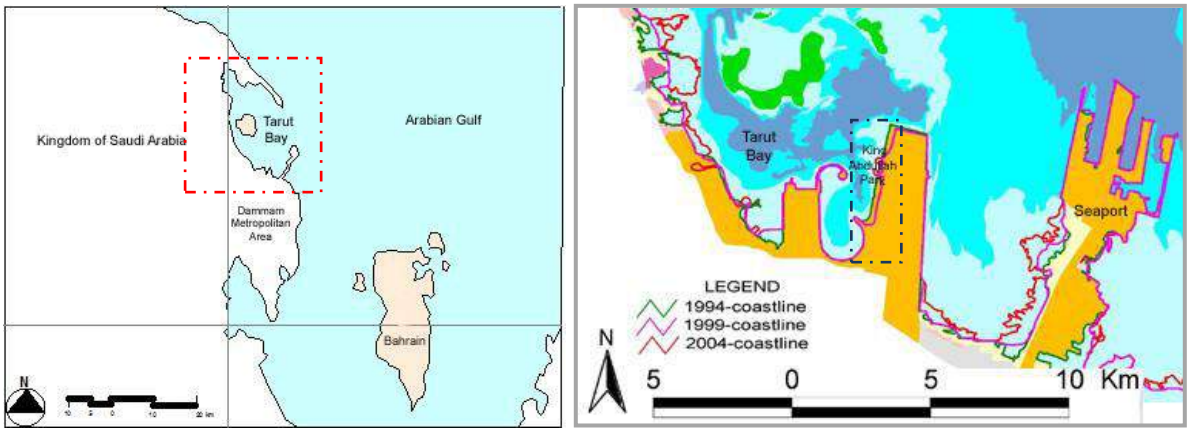

Figure 1: Location of Tarut Bay and King Abdullah Park on the Arabian Gulf.

The Park was opened for public in July 2007 on an area of 500,000 m^2 of the coast and consists of 17,000 m^2 main festival plaza rises to more than 5 m above the sea level; three other platforms up to 4 m high and of more than 15,000 m^2 each, 250,000 m^2 green areas; 14 children play areas; 8 km long jugging and training track; and car parking for 3,000 cars (figure 2). More than 500,000 m^3 of filling materials were used to reclaim and reform the site and its overlooked coastline.

The extensive land filling operations that bring the coastline to a water depth of two metres or more have reshaped the coastline and created a series of curvilinear pockets with no stagnant water but with heavy and strong wave actions. This' instead of enhancing coastal sustainability, affects number of ecological processes which lead to rubbish and litter accumulations.

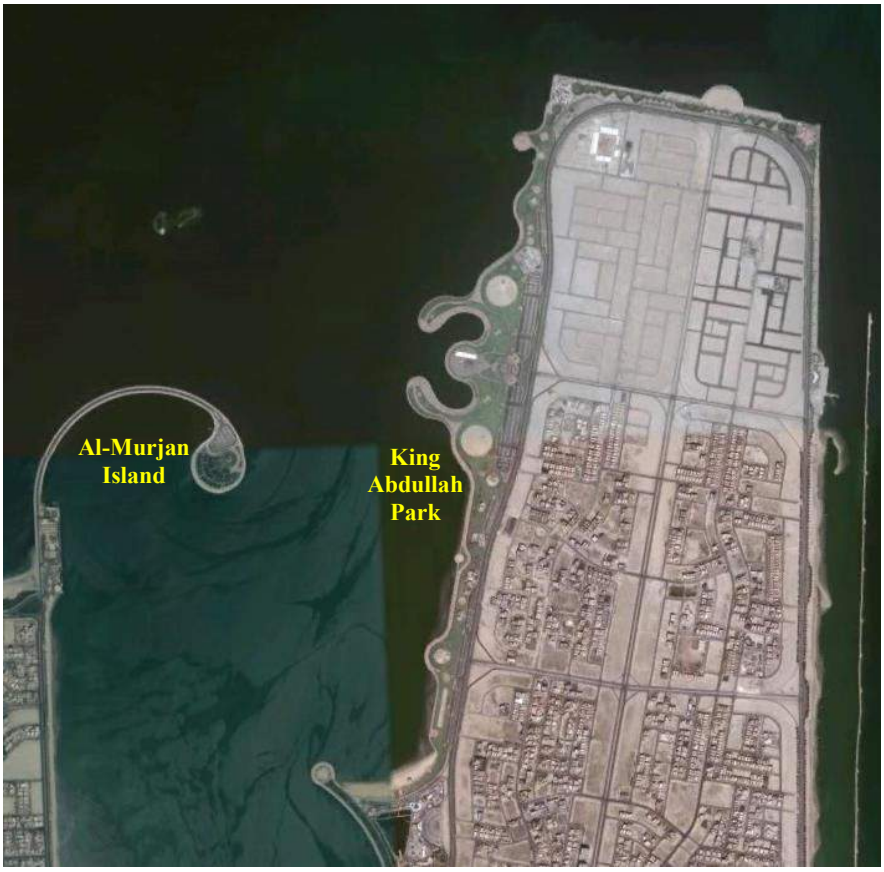

Figure 2: King Abdullah Park emphasises the reshaping of coastline and creation of small bays.

2. SUSTAINABILITY:

Sustainability, in general, refers to development that allows people to meet their present needs without compromising the ability of future generations to meet their own needs (WCED, 1987). It is a function of society, economy and environment. Thus sustainable development aims toward the achievement of economic and social development that ensures higher standards of living for existing and future generations and, at the same time, protects and enhances their physical environment (Selman, 1996). Therefore, sustainable development can maintain a delicate balance between the human need to improve their lifestyles and feeling of well-being on one hand, and preserving natural resources and ecosystems functionalities, on which present and future generations depend, on the other hand (figure 3).

Figure 3: The rule of sustainable development to maintain a balance between economic and environmental issues

The concept of sustainability has argued that maintenance of ecological integrity, sustainable use of natural resources and maintenance of genetic diversity must be incorporated into all development programmes (Middleton, 2003). Also, several studies emphasised that sustainability is achievable when environment is fully respected in development programmes. Robert (2002) confirmed that long-term sustainable development can be achieved when socio-economic development is operated within the earth's natural cycles. This briefly means that:- modification of natural ecosystems will impede some of the natural cycles, which in consequence will affect long-term environmental sustainability.

For the purpose of this paper, environmental sustainability might be defined as long-term maintenance of ecosystem components and functions for the present and future generations to meet their needs and survival with no harms to environmental resources and communities' health. This definition will be applied to develop a framework for measuring environmental sustainability in the developed coastal waterfronts.

3. METHODOLOGY AND TOOLS:

3.1 Development of an environmental sustainability measuring framework:

Natural environments are affected by human intervention in positive and negative ways as their characteristics and processes are usually modified throughout design processes and after occupancy. Coastal areas, as natural transitional buffers between terrestrial and maritime ecosystems, are considered one of the most sensitive areas to changes. Also they perform very important roles in keeping these ecosystems in balance and functioning in a healthy manner. Therefore designing such areas should not affect their functions in maintaining the equilibrium of the immediate ecosystems and their components and must support their long-term sustainability.

To insure ecosystem balance and support long-term sustainability of developed water

fronts requires not impeding or diminishing coastal natural processes on one hand, and on the other hand enhancing biodiversity and sustainable use of the site resources and facilities. Several studies have been conducted in this matter. Brandon and Lombardi (2005) developed a technique to measure sustainability of residential areas' landscape. Also Gerbens-Leenes et al (2003) discuss number of studies to set a measuring method for sustainable food production. They evaluate three environmental indicators that address global environmental issues of energy, land and water which expressed in three performance indicators.

Based on that, this proposed framework emphasises five major elements which seem to be important for any modification intended to be applied on natural ecosystems:

a. Maintenance and enhancement of natural processes.
b. Enhancement of biodiversity.
c. Continuity of site productivity.
d. Continuous use of the modified site at different times and seasons, and
e. Environment and physical quality.

A quantitative scale is used to measure the efficiency and/or deficiency of the indicators related to each of the aforementioned elements. This is based on watching the performance of the indicators of the designed ecosystem in terms of their increase, decrease, disappearance or not being affected, etc. For the 'increase' and 'disappear' measures on the scale, numbers will be assigned as 3 for high, 2 for medium and 1 for low; and similarly for measures of decrease -3 for high, -2 for medium and -1 for low decrease, while 'not affected' will be assigned a zero (0). Table 1 below shows the indicators of the five elements of environmental sustainability to be measured, where impacts can be identified as positive or negative. This is will be used accumulatively as a signal of environmental sustainability.

Table 1: Elements and components of the framework used to measure environmental sustainability in the designed natural ecosystems

Elements of environmental sustainability	Indicators	Measurement scale				Impacts
		Increase	Decrease	Disappear	Not affect	
a. Maintenance of natural processes	Wave action					
	Tidal activity					
	Coast development					
	Coast protection					
b. Enhancement of biodiversity	Flora					
	Fauna					
	Succussional process					
c. Site productivity	Marine products					
	Quality of marine products					
	Terrestrial products					
	Quality of terrestrial products					
d. Continuous use of the site	Day/night					
	Carrying capacity					
	Summer/winter					
	Carrying capacity					
e. Design and used materials	Perceptions of users toward environment					
	Durability of design and used materials					
	waste					
	General appearance					
	Maintenance cost					
	Health and ecological protection					
	Microclimate modification					

This framework is designed to be adapted certain level of flexibly in terms of adding or

removing some elements and indicators to suite the sustainability measurement of different ecosystems.

3.2 Site inventory and analysis:

In the design and construction of the KAP, large areas were filled and the coastline was modified. Modification of the coastline led to creation of small isolated bays and subjected about two-thirds of the total length of the park water front to the effects of strong waves. Also land filling operations had brought the coastline a water depth of more than two metres which led to the loss of inter tidal and beach zones.

Usually inter tidal and beach zones are the natural coastal defences they respond to the wave energy being received (Haslett, 2000). Their responses to wave energy depend on coastal conditions which can be either normal (fair-weather) or rough-storm. Under normal (fair-weather wave) conditions (low to moderate wave energy) beaches have steep 1:8 slope, tend to reflect the wave energy back out to sea. When a wave breaks on to a beach, water travels up the beach as swash and after it has travelled as far up the beach as the energy will allow, the water returns to the sea under gravity as backwash (Haslett, 2000).

In the case of rough-storm conditions (moderate to high energy) beaches have gentle 1:40 slope, tend to dissipate wave energy because waves have a greater beach surface area over which to break. Spilling breakers roll across low-angled beaches for a considerable distance due to swash/backwash interactions. Waves arrive in relatively rapid succession at the beach with the backwash of the previous wave returning down the beach whilst the swash of a subsequent wave is travelling up the beach (Haslett, 2000).

Analysis of the KAP has emphasized the five elements of the environmental sustainability and their indicators, based on the personal observations of the researcher, where the area can be divided into four segments (figure 4):

Figure 4: Site analysis of the KAP highlights characteristics of the four segments

- First segment: located at the far northern end of the park; subjected to strong and heavy wave actions due to its being part of the open sea with no inter tidal zone on which waves can break. In addition, the wind direction (north-west) helps the acceleration of wave actions and tidal currents; and in this case waves energy hits the constructed wave barrier (coastline defence rocky barrier) resulting in eroding its materials underneath and causing collapse of the constructed barrier (figure 5).

Figure 5: This segment is subjected to strong waves due to disappearance of inter tidal zone.

Also sequential waves can easily hit each other and the coastline barrier causing huge swash that may cover as far as 10m ahead. This action has number of impacts on both hard and soft landscape materials as well as the elements of street furniture (figure6).

Figure 6: Effects of huge swash on the street furniture and paved surfaces along this segment.

- Second segment: festival platforms zone which consists of two peninsulas embraced two bays in a circular form as whole. The two bays surrounding the main festival plaza which was filled to about 3.5m above its surrounding walkways; and more than 5m above the sea level (figure 7).

Figure 7: Reshaping the coastline created semi-circular wave-protected areas in this segment.

This segment is partially protected from the effects of strong waves by the created northern peninsula but, with the help of the north-western prevailing wind, litters and rubbish are easily driven to the far end of and accumulated in the two created bays As a result, bad odours might be emitted and affect the surrounding areas of this segment (figure 8).

Figure 8: Accumulation of litters and rubbish at the ends of the created bays in the second segment.

- Third segment: this segment is located at the central part of the KAP which is partially protected from the strong wave and tidal currents by the artificial Al-Murjan Island (figure 9). Water may become stagnant for long time especially during low tide, and unpleasant odours might result from litter decay and the acceleration of algae growth and death in summer seasons. During the hot months of summer, the area experiences clear sky and high temperatures that, with other factors, stimulate algal growth. According to Mandorah (2005) and Al-Mansi (1999) excessive nutrient and organic enrichment together with high temperature will encourage the growth of aquatic plants and algae which result in blooms of some toxic types of phytoplankton causing what is known as *green or red tide* phenomena.

Figure 9: The third segment of the KAP gains protection from constructed artificial island and road to it. It constitutes of two strips of grass-planed area and walkway.

Excessive growth of algae as a result of over-enrichment of coastal waters lead to oxygen depletion as processes of decomposition and respiration in bottom waters are likely to foster decay of accumulated algae and waste. This depletion of dissolved oxygen in the water results in death of fish and invertebrates (Al-Mansi, 1999) which becomes a noticeable phenomenon, especially during summer months, along most of the Arabian Gulf reclaimed coastal areas.

Furthermore, accumulation of the dead creatures along the coastline produces unpleasant odours that may alienate the areas' visitors.

- Fourth segment: this segment is continuation of the previous one and constitutes the far south end of the KAP which is relatively calm area gained protection against the effects of waves and tidal currents from the constructed artificial Al-Murjan Island and the road connecting it to the mainland. Due to calmness of currents and their gentle effects, large amounts of rubbish and litter are driven to the far end of the water body and coasts of this segment (figure 8).

4. RESULTS AND DISCUSSION:

4.1 Application of the proposed environmental sustainability framework:

Collected data by means of direct and indirect observations and analysis of the various indicators consist the five elements of the environmental sustainability were applied to the designed framework to measure environmental sustainability of the KAP.

The application has revealed the results summarised in the following table 2, and further discussed in the following subsection 4.2.

Table 2: Results of applying the proposed environmental sustainability framework to the KAP

Elements of environmental sustainability	Indicators	Measurement scale				Impacts
		Increase	Decrease	Disappear	Not affect	
a. Maintenance of natural processes	Wave action	3				Negative
	Tidal activity	3				Negative
	Coast development		-2			Negative
	Coast protection		-1			Negative
b. Enhancement of biodiversity	Flora			-3		Negative
	Fauna		-1			Negative
	Succussional process			-2		Negative
c. Site productivity	Marine products		-1			Negative
	Quality of marine products				0	Neutral
	Terrestrial products			-3		Negative
	Quality of terrestrial products		-3			Negative
d. Continuous use of the site	Day/night	2				Negative
	Carrying capacity		-3			Negative
	Summer/winter		-1			Neutral
	Carrying capacity				0	Neutral
e. Design and used materials	Perceptions of users toward environment		-2			Negative
	Durability of design and used materials		-2			Negative
	waste	3				Negative
	General appearance				0	Neutral
	Maintenance cost	3				Negative
	Health and ecological protection		-2			Negative
	Microclimate modification	3				Negative

4.2 Discussion:

As it appears from the above table, most of the indicators are negatively affecting environmental sustainability. By discussing each indicator of the environmental sustainability, the negative impact can be related to the way to which coastline is modified and the overall design of the park. In the measurement framework, most of the indicators

have negative impacts on the environmental sustainability of the water front. Wave actions and tidal activities are highly increased as a result of pushing coastline toward deep water especially in the two northern segments. This modification revealed obvious impacts on all coastal processes. Generated swash as a result of strong wave and currents hit the coast and cause massive damage to both hard and soft landscape elements as far as 10m off coastline landward. So all north and northwest-facing paved areas together with elements of street furniture are badly eroded and ugly looking due to continuous spill of salty swash. Such effects have extended to the nearby green areas causing the grass to die and distortion of other upright plants such as tress and shrubs (figure 10). Spread of salty swash to the nearby hard and soft areas has noticeable contribution to salt accumulation and soil erosion especially on hilly areas.

Figure 10: Effects of swash on pavements, street furniture and plants.

Also, strong waves and currents have discouraged coastal development and weakened the coast protection. It is known that coastal waves and currents can reshape coastal zone landforms in two different mechanisms, either by cut-off or deposition based on the width and topography of the inter tidal zone. By cut-off mechanism headlands, capes, bays and cliffs might be developed as progression of coastal development, while deposition can help formation of beaches, sand-deposits and marine dunes. Such coastal development is essential for biodiversity enhancement as large numbers of flora and fauna are flourishing and developing in inter tidal zones. By filling these areas or reducing their width, such development is impeded and numbers of flora and fauna sharply decline. Also coastal protection will be affected, even with the constructed walls or coastal defences (see subsection 3.2 and figure 5 above).

Similarly the productivity of the area is affected by the destruction of inter tidal habitat and deterioration of the near shore ones. The terrestrial areas that were providing nesting and feeding ground to many of the terrestrial species were filled where marine resources sharply decline. Consequently the area lost its importance as one of the Arabian Gulf destinations for migrant birds where only few numbers of *Ardea cinerea* (grey heron) and *Socotra cormorant* (white-breasted cormorant) were noted in some places along the coast of the developed area in late winter. Prior to the massive development of the area, thousands of *Socotra cormorant* were observed touring the Tarut Bay most of the winter seasons (figure 11). Land filling of shallow water areas led to the loss of the nursery grounds that incubate many marine species (especially fish and shrimps) on which marine birds are feeding.

Figure 11: Socotra Cormorant is one of the affected bird species trying to find safe area with the shallow waters of the KAP, where only few numbers are seen on the coast.

The major positive of this developed area is the attraction of considerable number of users and visitors which has moderately increased especially during the evening times in the seasons of mild climate. However, users' numbers have sharply declined during day time and summer seasons. This is possibly related to the way of designing the park and used materials in hard and soft areas. The area is almost equally divided into soft and hard surfaces without any shading devices and protection against harsh wind, sun and salty swash. Also feeling of privacy and personal space are completely lost when numbers of users exceeded the carrying capacity of place. Therefore, a number of negative impacts is expected due to inhumanity of the space that reduces the perceptions of users toward environment clearly noticed from the amount of rubbish they left behind each day and vandalism practiced against site elements (figure 12).

Figure 12: Perception of the users reflected as leaving rubbish behind and vandalism.

In addition, the large areas covered in pavement absorb heat all the daytime and reradiate it overnight which makes the microclimate of the area at least $5^{o}C$ higher than the surrounding especially if the humidity is relatively high which makes the site less used during hot seasons daytimes. Furthermore, the large areas of grass and pavement require continuous care which increase the maintenance cost.

5. CONCLUSION:

Development of coastal areas as water front parks and the design of such parks require more attention to be applied to the sensitivity of such areas, ecological interactions within their ecosystems and coastal processes. Development authorities may face great pressures to

provide coastal recreational areas and, at the same time, face a challenge to maintain environmental sustainability of such sensitive areas.

In the design and implementation of the above discussed case (King Abdullah Park) all indicators of environmental sustainability were ignored which clearly emphasises the resultant negative environmental impact. Such huge projects require careful planning and environmental impact assessment studies for the purposes of identifying its contribution to social, economical and environmental sustainability. Thus future of the area in terms of environmental sustainability is not secure enough. The park is only three years on from its opening and several problems and effects have started to show up; some of them might be due to improper maintenance but the great majority are linked to planning and design of the park.

Since the Kingdom of Saudi Arabia has coasts of more than 2,500 km long on the Red sea and the Arabian Gulf where number of highly populated cities and towns exist, it is recommended to deal sensitively with the coastal environment along and within the vicinity of these urban areas. This includes: preservation of the existing coastline and its related processes and avoidance of all development intended to modify coastline and/or alter its related natural interactions.

In-depth and multi-disciplinary studies may help setting guidelines for the development of coastal areas. In this case, the future research will emphasise the improvement of the proposed framework and environmental sustainability measurement scale which may be tested on other case studies for more reliable results to extract general guidelines for the future coastal areas development that emphasise environmental, social and economical sustainability.

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