



1. 沙丘整合策略：渗漏阻滞
1. Dune integration strategy: Leakage detention

美国加尔维斯顿岛西部地区 风暴潮防护基础设施景观整合

LANDSCAPE INTEGRATION FOR STORM SURGE BARRIER INFRASTRUCTURE: WESTERN GALVESTON ISLAND, USA

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项目背景

沿海风暴灾害及其导致的洪水定期威胁着美国德克萨斯州的海岸线。自1900年以来，德克萨斯州共遭受了40次重大的飓风侵袭——每5年一次飓风，每15年一次重大暴风雨。艾克大坝即是为保护休斯顿-加尔维斯顿大都市统计区（H-G MSA）免受万年一遇的暴风雨侵袭而设计的风暴潮防护系统，其命名源于2008年侵袭H-G MSA的四级飓风艾克——这场飓风在当时造成了84名人员伤亡和超过190亿美元的财产损失。在设计方案中，防护基础设施与德克萨斯州加尔维斯顿岛的走向平行，以保护休斯顿港——该港口是美国第二大港口，每年的经济产值达1785亿美元。此防护系统的组成部分包括分踞两侧的一系列防御区和泄洪闸，以及一条沿加尔维斯顿岛长边形成防护脊线的强化线形沙丘（图2）。

在世界范围内，洪水都是造成损失最大和最具破坏力的自然灾害，这一点在低洼沿海地区的开发建设中体现得尤为明显。同时，全球沿海地区的日益发展却侵占着天然湿地并使其越发脆弱，将人们置于危险之境。对百年一遇洪泛区的开放空间进行保护的举措平均每年可以为美国减少591 436美

元由洪水造成的损失^[1]。由于湿地能够滞留、积蓄和缓释地表径流，故可以降低风暴潮带来的洪水影响^[2]，并有助于减少社区的洪水量和相关损失^[3]。塞缪尔·D·布罗迪等人^[4]发现，因德克萨斯州沿海湿地面积的减少而造成的洪水财产损失已大大增加，每个行政区每次洪涝的平均损失增加超过38 000美元。另外，墨西哥湾沿岸的天然湿地每减少1英亩（约0.4hm²），每年由洪水造成的财产损失平均增加约150万美元^[4]。传统的开发模式是造成洪灾风险的重要因素，流域内不透水面层的增加会加剧由土壤入渗减弱和地表径流增加而产生的洪水^{[5][6]}。在德克萨斯州沿岸，每平方米的不透水面层每年增加的财产损失约3 602美元^[4]。

目前美国在设计风暴潮基础设施时，主要采用机械方案，以增加那些发展机遇受洪水风险阻碍的地区的开发潜力。然而，鲜有案例表明可以利用湿地和绿色空间衰减洪水^{[7][8]}。这些生态服务包括积蓄和疏导洪水、降低河流洪峰和缓冲风暴潮^[9]。当地的公园、操场和未开发土地在洪水与周边资产之间形成一块暴雨缓冲区，空间导向型设计或开发策略也能在洪水威胁区域起到阻隔或缓冲作用^{[10][11]}。

该项目为面积40.5km²的加尔维斯顿岛

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摘要

该项目以美国德克萨斯州加尔维斯顿岛西部地区为研究场地，探索整合风暴潮防护系统和海岸景观的设计途径。其利用岛上的4处目标场地，进行了综合性总体规划，并提出了堤岸整合的设计策略和参考准则。

关键词

风暴潮；飓风；弹性；景观生态学；洪水衰减

ABSTRACT

This project uses western Galveston Island, Texas, USA to explore design options for integrating a projective storm surge barrier system into the coastal landscape. The design creates a comprehensive master plan by using four target sites on the island, develops design strategies for barrier integration, and suggests principles for successful integration.

KEY WORDS

Storm Surge; Hurricanes; Resilience; Landscape Ecology; Flood Attenuation

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项目地址:
美国德克萨斯州加尔维斯顿岛

项目面积:
40.5km²

项目委托:
可持续海岸社区研究所

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项目团队:
夏露、任远、李珠霖

设计时间:
2013年6月~2015年6月

LOCATION:
Galveston Island, Texas, USA

AREA (SIZE):
10,000 acres

CLIENT:
Institute for Sustainable Coastal Communities

CHIEF DESIGNER:
Galen Newman

PROJECT LEADER:
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PROJECT TEAM:
Lu Xia, Yuan Ren, Joomee Lee

DESIGN PERIOD:
June 2013 ~ June 2015



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西部地区提出了4项总体规划，并为艾克大坝系统中强化沙丘所在区域提出了概念化的替代性整合方案。这些方案整合并改善了现有生态条件，以帮助减小防波堤的负面效应：修筑堤坝可能造成淡水、咸水和半咸水之间的交换加剧、沉积增多、地形极端变化和绿地规模骤减等诸多后果^[12]。

方案运用以洪水最小化为目的的构筑性和非构筑性的管理方法来使洪灾影响降到最低。构筑性的方法通常包含以抵御洪水威胁为目的的物理结构，包括海堤、河堤、大坝、沟渠、高架建筑、防御区和泄洪闸，以及护岸。这些构筑物常常会令现有景观的视觉品质大打折扣，造价昂贵且结构易损^[13]。在已被开发的洪水多发区中，构筑性的方法已被证明行之有效，然而其一旦建成，即会扰动现有的生态系统^[14]。再者，日益增加的物质风险，加之土地利用类型的快速变化，

亦会扩大不良的生态学影响。非构筑性方法则寻求通过土地保护政策和/或其他非开发性途径，引导开发方向使其避开洪灾多发地区^[15]。从已有的几个行之有效的洪水管理项目经验中可以得出，针对各地与众不同的条件，因地制宜地将构筑性和非构筑性方法综合运用。

问题和挑战

该地区风暴潮的平均高度约2.4m。若水面升高1.8m，大部分绿地（97%）、居住用地（82%）和商业地产（84%）都将被洪水淹没^[16]（图3）。事实上，美国国家海洋和大气管理局海平面上升预测部门^[16]预测海平面每上升30cm，加尔维斯顿岛西部地区的洪泛区面积即会增加11%。目前，加尔维斯顿岛西部地区超过一半的土地（56.3%）由湿

地组成，其中大部分湿地（43.7%）是咸水沼泽。总体来说，场地的主要用地类型是绿地，约占61%，而居住用地（32%）、商业用地（1%）和沙滩（6%）也占据了大片空间（图4）。由于岛上对经济增长的需求不断增大，在未来开发计划中，应更多地考虑以防护为目的的自然区域保护。

岛上沙滩的现有平均宽度不足61m，这使得沙丘难以在现有已开发区域内进行整合。此宽度比其他海滩的平均宽度要窄得多——比如加利福尼亚州圣地亚哥海滩宽约98m、佛罗里达州迈阿密海滩宽约113m，或者荷兰的普通海滩宽度约为180m（图5）。在规划方案中，该系统中沙丘的一般尺度约35m宽、6m高。这意味着在近海岸的已开发区域，现有海滩线的一半都将被防波堤所占用。同时，现有的住宅建筑约9~12m高，如果沙丘不能很好地融入现状，那么可

- 艾克大坝风暴潮防护基础设施组成部分方案
- 若水面升高1.8m，加尔维斯顿岛西部地区将呈现的状况。
- 加尔维斯顿岛西部地区的湿地及开发分布
- Projected components of the Ike Dike surge barrier infrastructure system
- Six foot sea level rise projections for Western Galveston Island
- Wetlands and developed areas on Western Galveston Island



未被淹没土地总面积
2.8km²
TOTAL LAND AREA
699 Acre

Green Space
绿地

Residential
居住用地

Beach
沙滩

Commercial
商业用地



Legend 图例

绿地 Green Space
居住用地 Residential Area
沙滩 Beach Area
商业用地 Commercial Area

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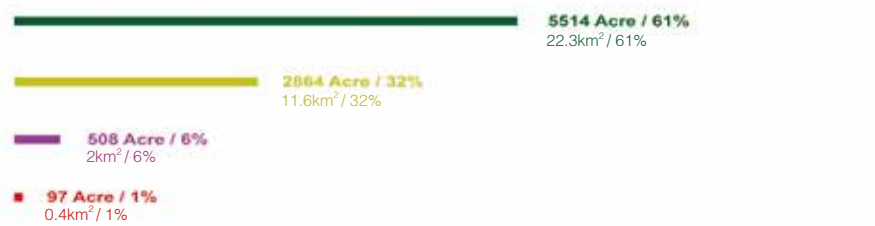
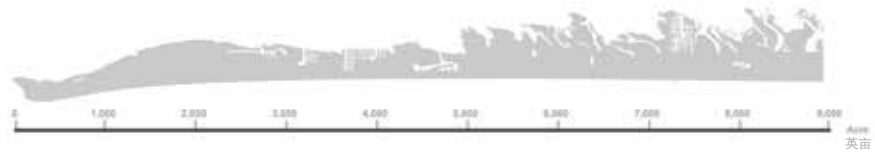
土地总面积
36.4km²
TOTAL LAND AREA
8984 Acre

Green Space
绿地

Residential
居住用地

Beach
沙滩

Commercial
商业用地



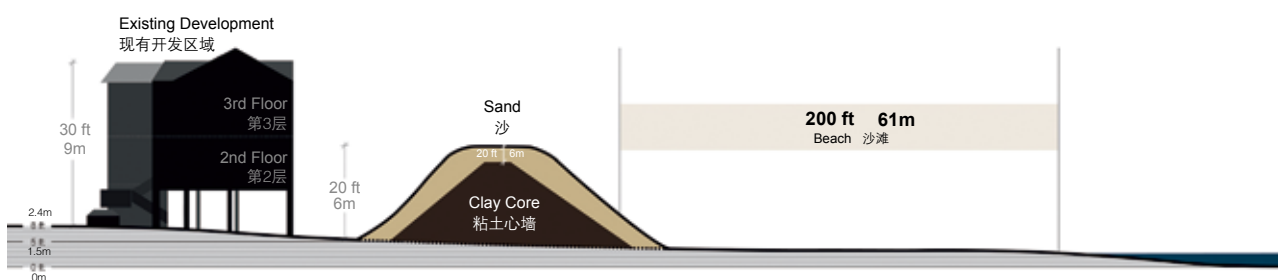
Legend 图例

绿地 Green Space
居住用地 Residential Area
沙滩 Beach Area
商业用地 Commercial Area

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5. 加尔维斯顿岛海滩与其他主要海滩的平均宽度对比图
6. 方案中的强化沙丘尺度与典型现有开发区域对比图
7. 各目标场地位置示意图

能出现的风景或社会联系的断裂或许将损害这些住宅建筑的品质(图6)。

理念和策略

该项目的设计理念是将沙丘作为保护性的多功能线形生态骨架整合到景观中。沙丘作为结构骨架,由不停增长的介质所包裹,与之平行的滞洪区则被用来阻隔涌过加强沙丘的暴风潮产生的漫溢现象(渗漏)。自然和社会系统都被视为一个个社区,需保护它们长期免受巨浪的侵袭,同时支持旅游、休闲和经济的发展。该项目将重心放在岛上4个

独特的目标场地上(图7),并为它们提出了具有原型意义的未来开发综合规划,而后为针对不同的生态环境和发展背景制定适宜的沙丘整合方案。

1) 宽阔海岸区——该区域的海滩宽度几乎是其他所有场地的5倍(约305m),目前用于沙滩及水上娱乐休闲活动。总体规划(图8)力图在大幅度提高旅游业发展契机的同时保留现有的开放空间。在沙丘面向海岸一侧设有用于阻滞渗漏的储水绿地,而在面向沙滩一侧则有三个作为休闲节点的多功能平台。这里风景十分优美,可以租赁水上交通设施,体验空中滑翔、垂钓、泛舟和其他

沙滩活动,由此来巩固旅游业的发展。

2) 过渡区——目前对该区域仅进行轻度开发,但其仍具有很大的开发潜力;它处于未开发和将来开发之间的过渡状态。H-G MSA是高度工业化的地区,在空间上被规划为未来的工业园区。总体规划(图9)计划建设4层的办公空间、中等密度的居住区和综合性开发项目,并拟建休闲游径、与现有步道的连接、研究设施和新型工业用地。

3) 都市区——该区域相对来说已经被高度开发,目前它包含了一个温泉度假综合体,以及小规模商业开发项目组群。该区域被规划为岛屿西部的小型城市中心。总体规划(图10)包含了多功能的社会机构用地、连接公共空间的混合用地、中等密度的居住用地,以及包含豪华酒店、度假村和新滨海公寓的多样化商业开发项目。

4) 最小影响区——该场地与加尔维斯顿岛州立公园毗邻却缺乏连接,需要通过非构筑性方法、土地保护和与现有步道及活动相联系等措施来进行整合。总体规划(图11)力图在沙丘完工后保留当地现状。设计师将一系列现有步道编织到沙丘之中,以增加户外休闲项目、提高低密度住宅数量,并加强绿地保护。

随着每个目标场地总体规划的制定,沙丘的整合策略也被提出。其提供了一系列整合机遇(图12),可以综合为8个关键性策略:

1) 渗漏阻滞——一系列相互连通的现有小尺度湿地或开挖区域在规划中被设计安置在强化沙丘的后方。这些区域被设计为滞洪池,常年保留一定的水量,并且可以吸收涌过沙丘的暴风潮水。

2) 栖息地保护——鼓励把现有的州立及地方性公园、小型栖息地和公共空间作为保护区来帮助衰减洪水(图13)。这些区域被沙丘保护起来,为周边已开发或尚在开发中的社区提供缓冲保护。

3) 提升旅游业——基于社区的旅游业提升可以为经济发展提供更多的机遇。沙丘可以推动旅游业发展和社区开放,并在保留该岛文化的同时增加被动性和主动性休闲活动。

4) 休闲产业发展——增长的人口与项目

开发和旅游业的不断发展使得公园和沙滩等公共空间成为了休闲活动的重要场所。方案将创新的休闲方式和更多的户外活动机会植入沙丘，以助力经济发展并提供工作机遇。

5) 侵蚀防治——强化沙丘上覆盖有乡土沙丘植物以增加沙丘的稳固性。通过策略性地栽植须根系植物来减少沙丘海岸一侧的沉积损耗非常重要。长远来看，侵蚀的减少还将降低沙丘的维护成本。

6) 沙滩最大化——鉴于沙滩面积较小，沙丘的布设力图使现有沙滩宽度最大化。未来可能开发的场地需策略性地布设沙丘，以为未来的居民提供足够的沙滩空间；而目前已开发的区域需尽量保留现有沙滩面积。在这里，填沙和沙滩延长策略尤其受到鼓励。

7) 连通沙丘两侧的可达性——现有沙丘与构筑物之间的连接取决于业主的喜好。在每个住宅建筑的第2层或者3层建立与沙丘的连接，并配合私密性结构来限制进入。针对

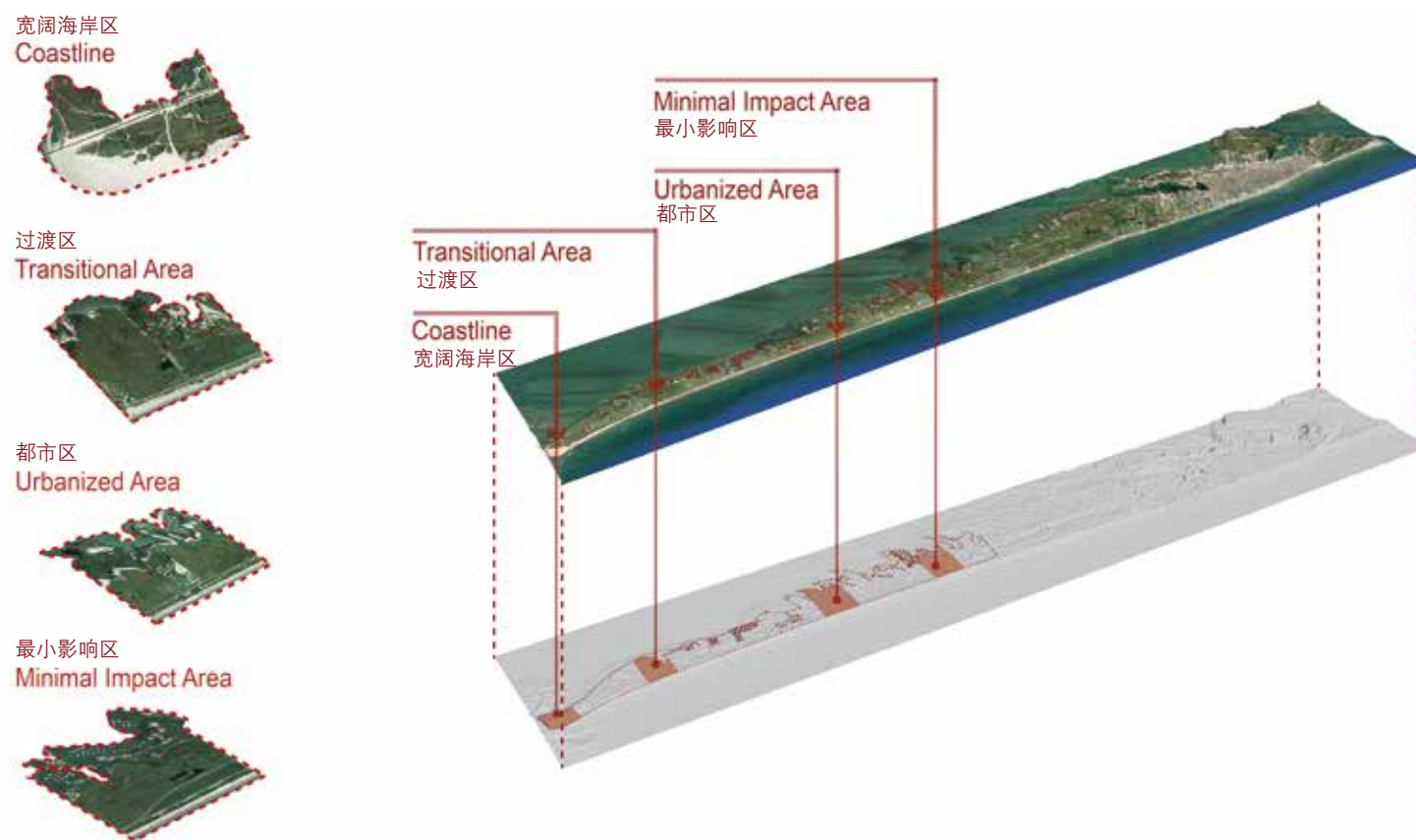
那些沙丘完工后仍可能进行开发的区域也提出了沙丘两侧的连接方案（从海岸一侧到沙滩一侧）。阶梯、坡道和栈道将创造一系列的连接类型以增加沙滩的可达性。

8) 平行连接——建立沙丘两侧的连接非常重要，而沿着或者平行于沙丘的连接也不容忽视。方案也对自行车道、步行道、现有游径连接处和商业活动空间进行了设计。为了使绿地保护范围最大化，设计主张只在空间紧凑且地势较高的区域进行新的开发。

沙丘整合原则

在艾克大坝的设计过程中，为了显著改变加尔维斯顿岛的自然海岸景观，必须采用非构筑性的方法将堤岸融入景观之中，从而创造弹性的社区并提升生态系统服务。方案中的沙丘系统是一种创新的线性生态系统节点，且能够提供构筑性防护。它利用开放

空间来帮助衰减风暴潮带来的洪水；通过须根系植被的种植模式防治侵蚀，以减少风暴潮造成的沉积损耗；并为现有公园、开放空间和绿地提供相互联系的脊线。作为融合构筑性和非构筑性两种途径防护洪水的综合性方法，其成功整合需遵循三个关键性的原则：1) 一旦开始施工，沙丘的布设必须确保沙滩面积最大化。同时也应考虑通过何种方式来逐步延长沙滩。2) 应该使风暴潮防护措施的非构筑性达到最大化。这将创造一个绿色生态网络，在提供生态系统服务的同时对该岛进行保护。改善该岛的生态环境也将有助于阻滞涌过沙丘的潮水。3) 穿过或沿着防护结构开展人类活动，从而使堤岸成为一条社会活动带，将已开发区域和海岸线连接起来，推动休闲产业和旅游业发展，为整个海岸线提供步行连接系统。该项目为基于实证的设计准则提供了框架，这一准则适用于遭受洪水威胁的各类社区。LAF

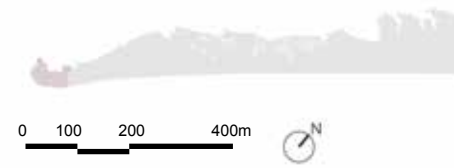


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Coastline

宽阔海岸区



- ① Galveston Island Welcoming Entrance
加尔维斯顿岛迎宾入口
- ② Ground Level Viewing Deck 地面观景台
- ③ Upper Level Viewing Deck 上层观景台
- ④ Erosion Control Area 侵蚀防治区
- ⑤ Beach Vehicle Access Road 沙滩车通道
- ⑥ Dune 沙丘
- ⑦ Private Seating Area 私人座椅区
- ⑧ Family Picnic Area 家庭野餐区
- ⑨ Leakage Detention Area 渗漏阻滞区
- ⑩ Unpaved Parking 未铺装停车场
- ⑪ Trails (connect to existing trail system)
小径 (与现有道路系统相连接)
- ⑫ Galveston Island West End Broad Beach
加尔维斯顿岛西端宽阔海滩
- ⑬ Living Breakwaters 现有防波堤
- ⑭ Single-family Residential 独栋住宅
- ⑮ Wetland 湿地

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Background

Coastal storm damage and related flooding threatens the Texas, USA coastline on a regular basis. With nearly 40 significant hurricane impacts since 1900, Texas experiences a hurricane every five years, and a major storm every 15 years. The Ike Dike is a projected storm surge protection system which is intended to protect the Houston-Galveston Metropolitan Statistical Area (H-G MSA) from a 10,000 year storm event. The Ike Dike is named after category four Hurricane Ike that hit the H-G MSA in 2008, resulting in 84 casualties and over \$19

billion in damages. The proposed barrier infrastructure extends parallel to Galveston Island, Texas to protect the port of Houston, the second-busiest port in the U.S. with an economic base of 178.5 billion dollars a year. The barrier system consists of a set of sector and sluice gates on each side and a fortified linear dune which creates a protective spine along the length of Galveston Island (Fig. 2).

Floods are the costliest and most disruptive natural hazard worldwide and are especially problematic where development resides in low-lying coastal areas. Simultaneously, increasing development in coastal areas globally puts populations

at risk and can cause losses in naturally-occurring wetlands which further exacerbate vulnerability. Protecting open space in the 100-year floodplain can reduce flood losses in the U.S. by an average of \$591,436 annually^[1]. Wetlands can reduce the impacts of inundation from storm surge^[2] and help reduce the flooding of communities and associated losses due to their ability to hold, store, and slowly release runoff^[3]. Samuel D. Brody et al.^[4] found that losses in wetland areas along the Texas coast significantly increased property damage from floods, adding over \$38,000 to each jurisdiction per flood. Further, for each acre loss of



Transitional Area 过渡区



0 100 200 400m



- 8. 宽阔海岸区总体规划
- 9. 过渡区总体规划

- 8. Master plan for the Coastline Area
- 9. Master plan for the Transitional Area

- 1 Single-family Residential 独栋住宅
- 2 Recreation Center 娱乐中心
- 3 Dock for Private Yacht 私人游艇码头
- 4 Community Administration Building 社区行政大楼
- 5 Alternative Energy Research Lab 替代能源实验室
- 6 Testing and Interactive Area 测试与互动区
- 7 Fire Station 消防站
- 8 Disaster Reduction Museum 防灾博物馆
- 9 Multi-family Residential 多户住宅
- 10 Retail Store 零售店
- 11 Pedestrian Overpass 人行天桥

- 12 Boardwalk on the Dune 沙丘上的木栈道
- 13 Beachside Restaurant and Bar 滨海餐厅与酒吧
- 14 Rock Pier 石砌突堤
- 15 Lighthouse 灯塔
- 16 Dune 沙丘
- 17 Private Access Bridge 只允许私人通行的桥
- 18 Existing Single-family Residential 现有独栋住宅
- 19 Home Office 家庭办公区
- 20 Employment Center 就业中心
- 21 Coast Manufacturing and Testing Lab 海岸制造与测试实验室

- 22 Hydrometeorological Monitoring and Data Analysis Center 水文气象监测与数据分析中心
- 23 RV Park 露营车公园
- 24 Wetland Park Administration Building 湿地公园行政大楼
- 25 Hike Trail 健行步道
- 26 1-mile Trail 一英里步道
- 27 2-mile Trail 两英里步道
- 28 Canoeing Route 划艇路线
- 29 Kayak Route 皮艇路线
- 30 Waterway to Galveston Bay 通往加尔维斯顿湾的航道

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Urbanized Area

都市区



0 100 200 400m



- | | |
|--------------------------------|---|
| ① Multi-Family Housing 多户住宅 | ②① Floodable Water Plaza 可浸水广场 |
| ② Leasing Office 物业管理处 | ②② Plaza 广场 |
| ③ Gym 体育馆 | ②③ Shopping Mall (Mixed Use) 综合购物中心 |
| ④ Playground 操场 | ②④ Commercial Corridor 商业街 |
| ⑤ Private Condominiums 私人公寓 | ②⑤ Luxury Condo Hotel 豪华公寓式酒店 |
| ⑥ Luxury Hotel 豪华酒店 | ②⑥ Office (Mixed Use) 综合办公区 |
| ⑦ Single Family 独栋住宅 | ②⑦ Commercial (Mixed Use) 综合商业区 |
| ⑧ Pedestrian Bridge 人行桥 | ②⑧ Music Hall Theater 音乐厅 |
| ⑨ Resort 度假村 | ②⑨ Parking Garden 停车场花园 |
| ⑩ Restaurant 餐厅 | ③⑩ Rainwater Tunnel 雨水运输渠 |
| ⑪ Pond / Detention Pond 池塘/滞洪池 | ③① Green Roof 绿色屋顶 |
| ⑫ Pergola 花架 | ③② Regional Planning Commission / City Council
区域规划委员会/市政府 |
| ⑬ Park 公园 | ③③ Town Hall 市政厅 |
| ⑭ Public Boardwalk 木栈道 | ③④ Healthcare Center 医疗保健中心 |
| ⑮ Dock 码头 | ③⑤ Fishing Pier 垂钓码头 |
| ⑯ Entertainment Pier 休闲码头 | ③⑥ Retail 零售店 |
| ⑰ Library 图书馆 | ③⑦ Dune 沙丘 |
| ⑱ Art Gallery 美术馆 | ③⑧ Gateway 入口 |
| ⑲ Private Boardwalk 私人木栈道 | |
| ⑳ Church 教堂 | |

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naturally-occurring wetlands along the Gulf of Mexico coast there was an increase on property damage caused by flooding by an average of approximately \$1.5 million per year^[4]. Conventional development patterns are a significant factor contributing to flood risks. Increases in impervious surfaces across watersheds can exacerbate flooding^[5] from reduced soil infiltration and increased surface runoff^[6]. In Coastal Texas, every square meter of impervious surface translates into approximately \$3,602 of additional property damage caused by floods per year^[4].

Current design approaches for storm surge infrastructure in the U.S. primarily

favor mechanical solutions to increase development potentials in areas where flood-risks hinder development opportunities. Few examples, however, illustrate harnessing the power of wetlands and green spaces as a means of attenuating flooding^{[7][8]}. These ecosystem services include storing and disseminating floodwaters, reducing peak riverine flows, and buffering storm surge^[9]. Local parks, playing fields, and undeveloped lands acting as a storm buffer to surrounding properties and spatially-targeted design / development strategies that create setbacks from or buffers around flooding threatened areas can also be effective^{[10][11]}.

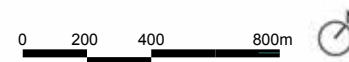
The design presented in this project

- 10. 都市区总体规划
 - 11. 最小影响区总体规划
-
- 10. Master plan for the Urbanized Area
 - 11. Master plan for the Minimal Impact Area



Minimal Impact Area

最小影响区



- ① RV Park 露营车公园
 - ② State Park Store 州立公园商店
 - ③ Parking 停车场
 - ④ Leakage Detention 渗漏阻滞
 - ⑤ Dune 沙丘
 - ⑥ Pedestrian Bridge (across the dune) 人行桥 (横跨沙丘)
 - ⑦ Skateboard Plaza 滑板广场
 - ⑧ Pedestrian Bridge (across the highway) 人行桥 (横跨公路)
 - ⑨ Vehicle Access 机动车入口
 - ⑩ Groins 防沙堤
 - ⑪ Existing Pond 现有池塘
 - ⑫ Entrance Plaza 入口广场
 - ⑬ Existing Residential Building 现有住宅建筑
 - ⑭ Observation Tower 观景台
 - ⑮ Hiking / Jogging Trails 健行步道
 - ⑯ Pergola 花架
 - ⑰ Filter Strip 隔离带
- Design Boundary 设计边界

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develops four master plans for the western portion of Galveston Island (10,000 acres) and conceptualizes alternatives for integration of the fortified dune component of the Ike Dike system. This project approach integrates and enhances existing ecological conditions to help mitigate negative effects of surge barriers. The amplification of water exchange between fresh, salt, and brackish waters, increased sedimentation deposits, extreme topographic alteration and large-scale green space depletion can all be possible consequences to barrier implementation^[12].

Both structural and non-structural flood management approaches for flood

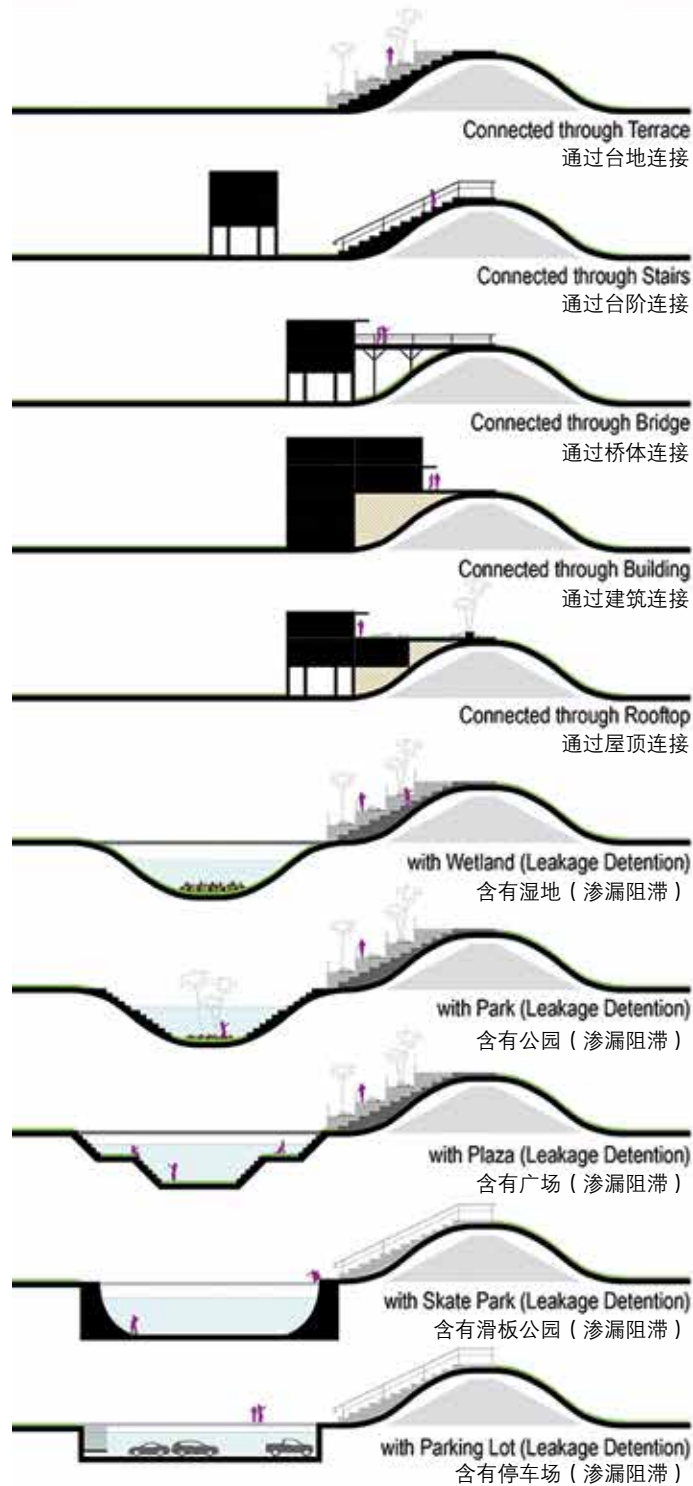
minimization are employed to help minimize these impacts. Structural approaches typically involve physical construction seeks to resist the threats of floodwaters. These include seawalls, levees, dams, channels, elevated buildings, sector and sluice gates, and revetments. Often, these can significantly diminish the visual quality of the existing landscape and are costly, and can be prone to structural failure^[13]. Structural approaches have proven effective in protecting populations in developed flood prone areas but can disturb the existing ecological system once introduced^[14]. Further, increasing physical risks combined with rapid land use changes can amplify

adverse ecological impacts. Non-structural techniques seek to guide development away from flood vulnerable areas through land conservation policies and / or other non-developmental measures^[15]. Several effective flood management programs recommend a mixture of structural and non-structural techniques tailored to the different and unique conditions of each local area.

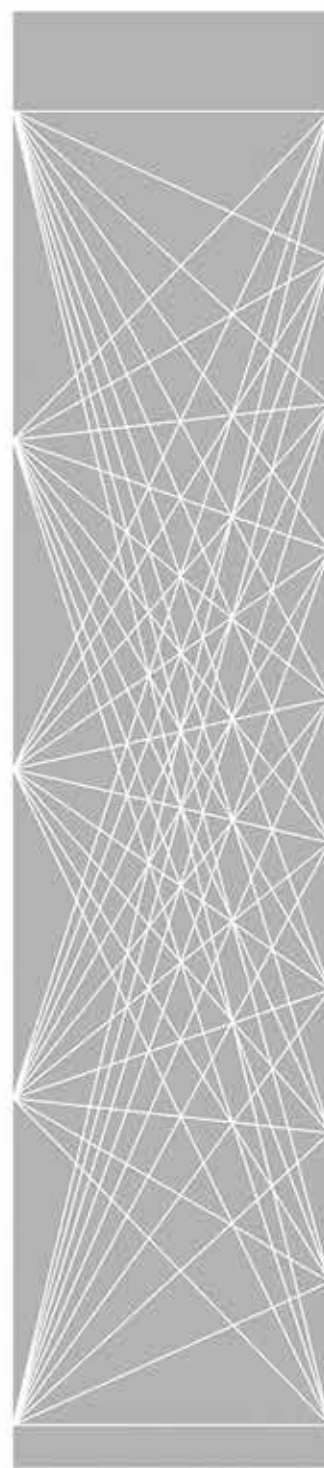
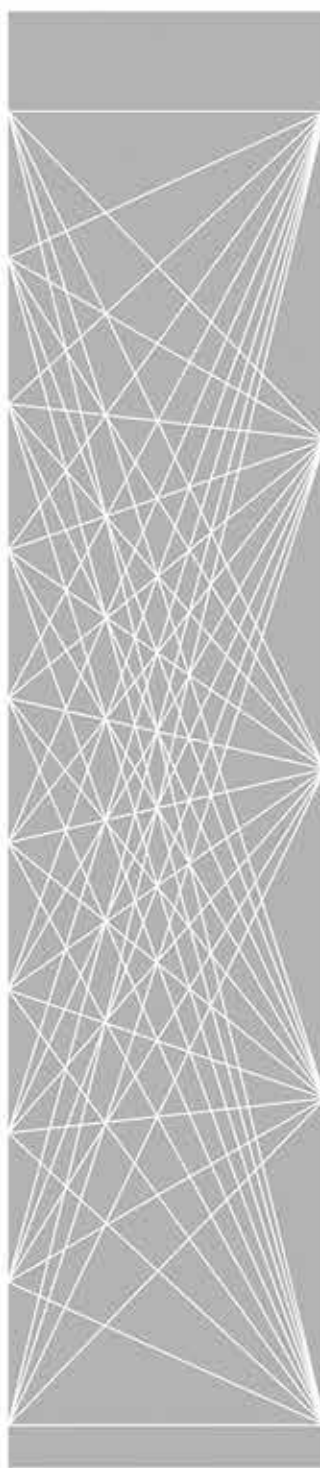
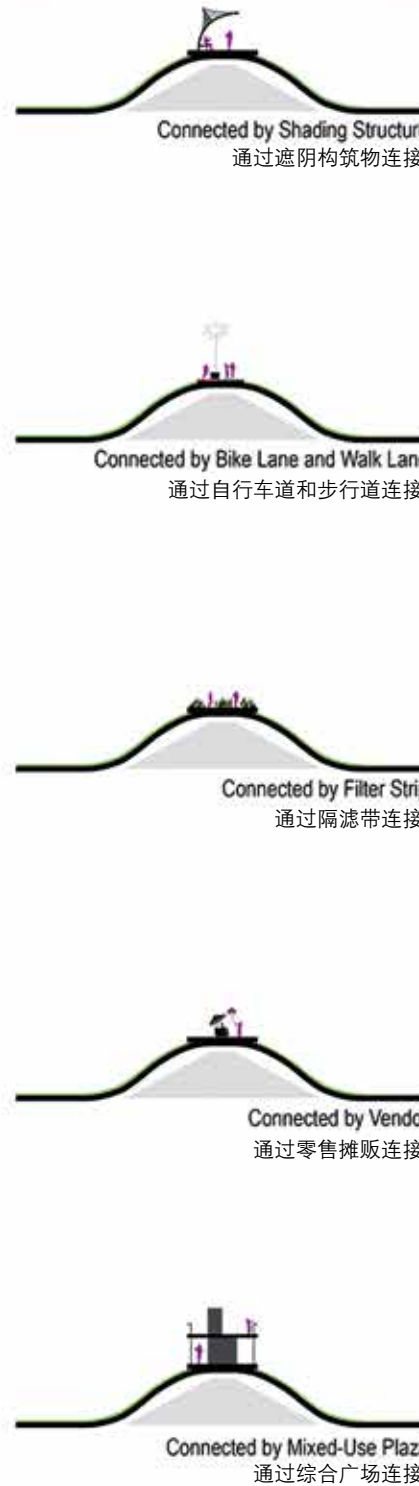
Issues and Challenges

Storm surge in the region has an average height of around eight feet. In the context of a potential six feet rise in water heights, the majority of green spaces (97%),

与陆地一侧的连接
CONNECTS TO THE LAND SIDE



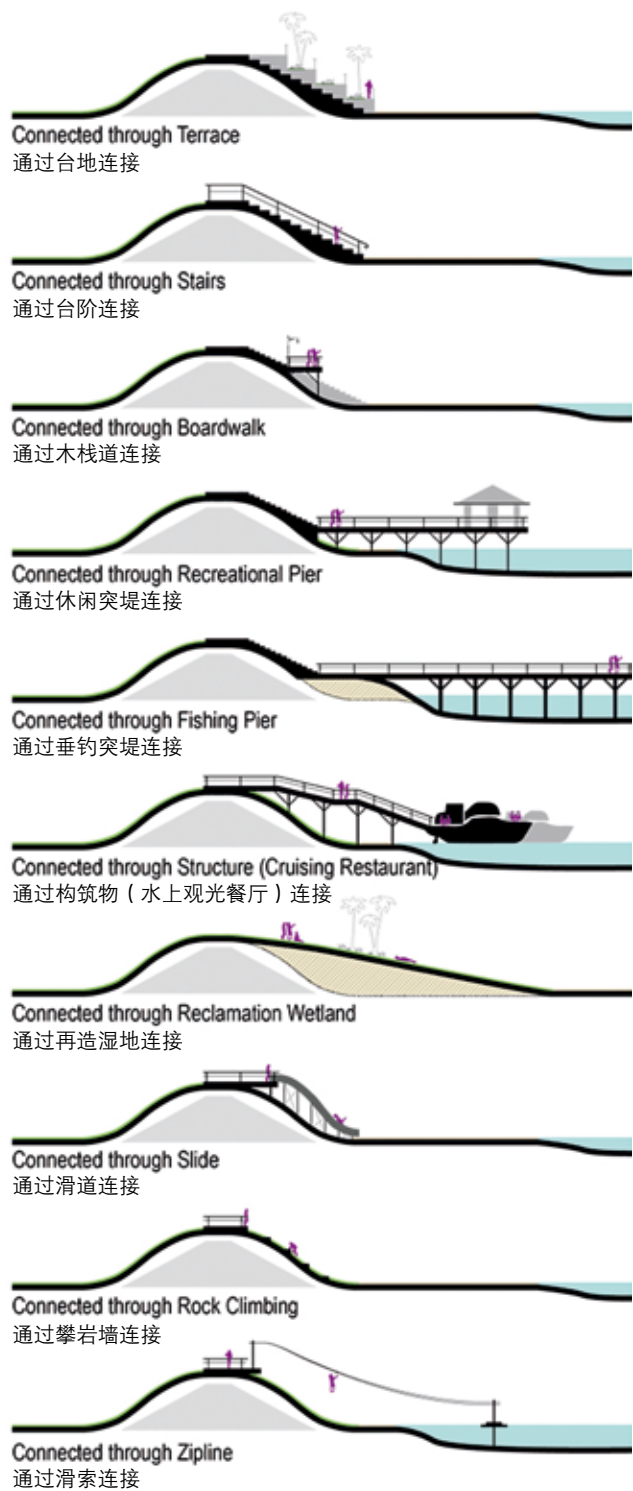
沿沙丘方向
ALONG THE DUNE



12. 设计与强化沙丘的连接方式选项。

12. Design connection options for the fortified dune.

与沙滩一侧的连接
CONNECTS TO THE BEACH SIDE



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residences (82%) and commercial properties (84%) would be places flooded^[16] (Fig. 3). The National Oceanic and Atmospheric Administration Sea Level Rise Calculations^[16] actually project that every one foot of sea level rise will lead to around 11% of flooded land in western Galveston. Currently, over half of western Galveston Island (56.3%) is composed of wetland area and a majority of these wetlands (43.7%) are saltwater marsh. Overall, green space is the dominant land use on the site, comprising around 61%, with residential (32%), commercial (1%) and beach area (6%) also occupying large tracts of space (Fig. 4). Demands for economic growth on the island are increasing and natural area conservation for protective purposes should be considered in future development plans.

Current beach widths on the island average close to 200 feet. This could make dune integration difficult within currently developed areas. This width is much smaller than average widths of other beaches such as San Diego, California (320 feet), Miami, Florida (370 feet) or a typical beach in the Netherlands (600 feet) (Fig. 5). Proposed typical dimensions for dunes in the system are approximately 115 feet wide by 20 feet high. In developed areas near the coast, this will lead to nearly half of the existing beach line being consumed by the barrier. Simultaneously, existing residential structures are around 30 ~ 40 feet in height and could be impaired by potential scenic and social disruptions if the dune is not well integrated into existing conditions (Fig. 6).

Design Concept and Strategies

This design concept is to integrate the dune into the landscape as a protective multi-functional linear ecological armature. The dune serves as a structural skeleton enveloped by a growing medium and paralleled by detention basins to detain overtopping (leakage) from storm surge

which may crest higher than the fortified dune's height. Both natural and social systems are assimilated as communities are protected from surge over the long-term while simultaneously supporting tourism, recreation, and economic opportunities. The project focuses on four unique target sites on the island (Fig. 7) for which prototypical comprehensive master plans for future growth are proposed. Dune integration options are then offered for each different ecological and developmental context.

1) Coastline — This site's beach area is nearly five times as wide as all other sites (1000 feet) and is currently an area for beach and water recreation. The master plan (Fig. 8) seeks to significantly enhance tourism opportunities while retaining existing open space. While conserved green space is used for leakage detention on the bay side of the dune, three multifunctional decks are built into the beach side of the dune as recreational nodes. These areas are highly scenic and allow for aquatic vehicle rentals, para-sailing, fishing, boating, and other beach activities to enhance tourism opportunities.

2) Transitional Area — This site is currently only lightly developed but has a high development potential; it is in transition from non-developed to future development. The H-G MSA is a highly industrialized area and this area is spatially planned as a future industrial park. The master plan (Fig. 9) projects four-story office spaces, medium density residences, mixed-use developments, proposed recreational trails, connections to existing trails, research facilities and new industrial land uses.

3) Urbanized Area — This site is already relatively highly developed and consists of an existing resort and spa complex and small clusters of existing commercial development. This area is projected to become a small town center for the western side of the island. The master plan (Fig. 10) is comprised of multiple institutional

land uses, mixed use areas abutting public spaces, medium density residences, and multiple commercial opportunities including luxury hotels, resorts and new beachside condominiums.

4) Minimal Impact Area — This site is tangent to Galveston Island State Park and requires integration through non-structural means, land preservation, and connections to existing trails and activities. The master plan (Fig. 11) seeks to retain existing local conditions, after dune implementation. A series of existing hiking trails are rewoven into the dune, providing increased outdoor recreation options, low density residences, and green space conservation.

As master plans for each target site have been developed, integration strategies for the dune are also proposed. A toolbox of integration opportunities are provided (Fig. 12) which can be synthesized into eight key strategies:

1) Leakage Detention — A series of existing small scale, linked wetlands or excavated areas are projected to be installed behind to the fortified dune. Projected as wet ponds that are designed to permanently retain some volume of water at all times, these can also be used to absorb storm surge that may overtop the dune.

2) Habitat Preservation — Existing state and local parks, ecological niches, and open space are encouraged for conservation purposes to aid flood attenuation purposes (Fig. 13). These areas are protected by the dune and help buffer the surrounding developed and developing communities.

3) Tourism Enhancement — Community-based tourism enhancement can offer more opportunities for economic development. The dune is designed to promote tourism opportunities, open up communities and increase passive and active recreation while retaining the culture of the island.

4) Recreational Opportunities — Increased population, development and tourism make public space such as parks and beaches essential venues for recreational activities. Innovative recreational offerings and increased

outdoor opportunities are built into the dune to contribute to the economy and generate job opportunities.

5) Erosion Control — The fortified dune is covered with native dune plantings to protect the stability of the dune. It is important to reduce sedimentation loss to the coastal side of the dune through the strategic planting of species with fibrous root systems. Decreased erosion will also reduce dune maintenance costs over time.

6) Beach Maximization — Considering the relatively low amount of beachside land, dune placement seeks to maximize existing beach widths. Places where future development may occur should strategically locate the dune to provide ample beach space for future residents. Areas with existing development must seek to maintain existing beach dimensions. Beach nourishment and elongation strategies are especially encouraged in these areas.

7) Cross Dune Accessibility — Existing dune-to-structure connections are dependent on owner preference. Connections will be made from the second or thirds stories of each residence and will incorporate privacy structures to limit access. Connections over the dune (from the bay side to the beach side) are also proposed in areas which may be developed after the dune is implemented. Stairways, ramps, and boardwalks will create a series of connective typologies to increase beach access.

8) Parallel Connections — While connections across the dune are important, linkages along, or parallel to, the dune are also necessary. Bike lanes, walkways, existing trail connections, and spaces for commercial activities are also proposed. Placement of new development is recommended to occur only in spatially clustered and high elevation areas to maximize green space protection.

Principles for Successful Dune Integration

The Ike Dike projects to significantly alter the physical coastal landscape of Galveston and must emphasize non-structural mechanisms

13. 沙丘整合策略：栖息地保护

13. Dune integration strategy: Habitat Preservation

to integrate the barrier into the landscape, thereby creating both resilient communities and enhancing ecosystem services. The proposed dune system acts as an innovative linear ecosystem linkage which also provides structural protection. It utilizes open space to help attenuate flooding from storm surge, provides erosion control measures to decrease sedimentation losses from surge through fibrous-root planting specimens, and provides a connective spine for existing parks, open spaces, and green spaces. As a hybrid approach using structural and non-structural mechanisms for flood protection, three key principles are necessary for successful integration. First, once implementation begins, placement of the dune must strive to maximize beach space. Approaches for elongating the beach over time should also be considered. Second, maximization of non-structural solutions for surge protection should occur. This will create a green space network to help protect the island while

providing ecosystem services. Enhancement the ecology of the island will also help in detaining overtopped surge. Third, incorporating human functions across and along the defense structure will make the barrier a line of social activity which links developed areas and the coastline, increases recreation and tourism, and provides the entire coastline with a pedestrian linkage. This project serves as a framework for an evidence-based design guideline which can be implemented in multiple communities threatened by flooding issues. **LAF**

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