ITERATIVE RESILIENCE: SYNCHRONIZING DYNAMIC LANDSCAPES WITH RESPONSIVE ARCHITECTURAL SYSTEMS

MEREDITH SATTLER
Louisiana State University

A GEOGRAPHY THAT DEMANDS MODULARITY AND MOBILITY

On September 1st, 2008 six foot waves hit Grand Isle, Louisiana, destroying numerous buildings in their path. Caused by Hurricane Gustav, the storm surge rolled right over most of this seven foot high barrier island. This storm, the sixteenth to cause major damage to buildings and infrastructure on Grand Isle since the 1893 hurricane (which killed nearly 2,000 people with 130mph winds and 16ft storm surge), not only devastated the island, but shifted its entire landmass northeast. A week later, Hurricane Ike made landfall, delivering another round of destruction.

Between major hurricanes, Grand Isle is hit by smaller storms on average every 2.2 years,[1] rendering it a particularly challenging geography for permanent occupation. Yet close to 1,300 people still insist on calling the island home, and thousands choose to vacation there. Tourism is big business facilitated by 1,380 rental and seasonally occupied properties, referred to as "camps"[2] that house fisherman, boaters, and southerners trying to escape the sweltering deep-south summertime heat and humidity.

Historically, Grand Isle was an island paradise full of orange groves, exotic birds, and resort hotels where wealthy New Orleanians would escape summer malaria-transmitting mosquitos. Today, people are drawn to the island by its relatively cool offshore summer breeze, abundant fishing and crabbing, and its beach, the only "resort beach" in the state. It is as close to an island paradise as one gets in Louisiana.

But this paradise of devastating forces, unstable ground, and cyclical change is one where residents experience geologic time unfolding in seasons, not centuries. Under the assault of these forces, structures

Figure 1.
Grand Isle is 7' Above Sea Level at its Highest Point
On a typical day (above) most of Grand Isle's land mass is within feet of sea level, but maintains defined boundaries between land and water. After Hurricanes Gustav and Ike (below), those boundaries dissolved as water and sand penetrated into the interior of the island. U.S. Highway 1 is seen here completely inundated with former beach sand (from the left side of the image).

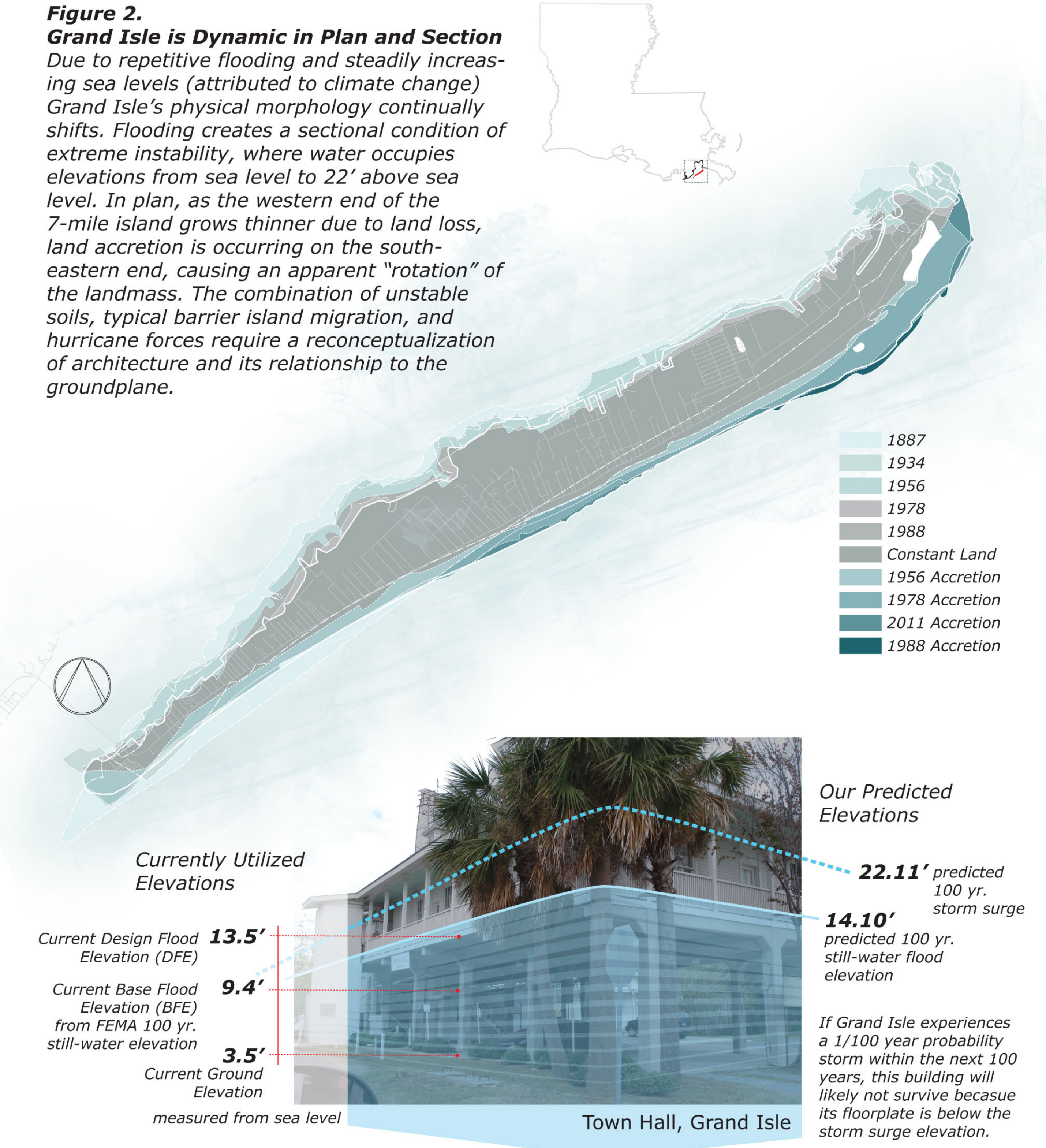


Figure 2.
Grand Isle is Dynamic in Plan and Section
Due to repetitive flooding and steadily increasing sea levels (attributed to climate change) Grand Isle's physical morphology continually shifts. Flooding creates a sectional condition of extreme instability, where water occupies elevations from sea level to 22' above sea level. In plan, as the western end of the 7-mile island grows thinner due to land loss, land accretion is occurring on the south-eastern end, causing an apparent "rotation" of the landmass. The combination of unstable soils, typical barrier island migration, and hurricane forces require a reconceptualization of architecture and its relationship to the groundplane.

and infrastructures that typically last decades are rendered temporary. The environment demands an alternative architecture, one that can mitigate and adapt to the island's fluctuating conditions. Here we show thatBy developing a prefabricated, mobile architectural system, deployed seasonally by gantry cranes, we create an adaptive, provides a resilient solution to shifting sedimentation and settlement patterns on Grand Isle. This solution generates a contextually sensitive form of permanent habitation while simultaneously breaking the "Disaster-Rebuild-Disaster" hurricane cycle that much of the delta, with the assistance of FEMA, currently engages.

THE RISK - TIME RELATIONSHIP

Risk of storm damage is determined by a probability known as "recurrence interval": the chance of being hit by a certain magnitude of storm within a certain amount of time. Based on recurrence interval terminology, it might appear that a "100-year storm" would be a storm that happens only once in every one hundred years, which is somewhat misleading. In actuality, it is the chance that a certain severity of storm, determined by historical data for that geography, would occur once within a one hundred year period; in other words, that a storm of that magnitude would have a one percent chance of occurring in any year. This results in a building having a twenty-six percent chance of flooding during a thirty year period (the life of a mortgage). 100-year storms can occur in consecutive years, and can occur multiple times within a one hundred year period.[3]

Recurrence intervals are utilized to determine the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps (FIRM's) which specify Base Flood Elevations (BFE's) for 100-year storm events in specific geographies. BFEs are minimum recommended lowest floor elevations for buildings, taking into account storm surge wave heights and stillwater flood elevations. However, in order for many coastal communities to qualify for the National Flood Insurance Program (NFIP), their buildings must be elevated higher than the BFE. This elevation is called the Design Flood Elevation (DFE) and consists of the BFE height plus "freeboard" which is either two feet or a somewhat arbitrarily determined additional number of feet added to BFE for good measure.

In order to achieve DFE, traditional coastal construction practices place buildings on piles which elevate them above floodwaters, and, in particular, the devastating high-energy storm surge caused by hurricanes. It is well documented that most structures hit by the intense wave energy of storm surge at or above their lowest floorplate are no longer structurally sound, rendering proper DFE elevations critical for breaking the disaster-rebuild-disaster cycle. In almost all cases, it is too costly to build low enough and strong enough to withstand storm surge loads.

Ironically, recently Louisiana updated its wind building code requirements. On Grand Isle, buildings must now be built to withstand 147 MPH winds.[4] However, flood code has not been revised to the same standards, so many structures are destroyed by flood long before the winds ever reach critical strength, rendering the extra labor, material and expense unnecessary.

Inspired by the above, during a year-long research project sponsored by the Louisiana State University Coastal Sustainability Studio, our team examined FEMA's methodology for determining BFE's, and came to the conclusion that the current BFE's for Grand Isle are misleadingly low, in some cases as much as nine feet too low (see the bottom of Figure 2). This results in buildings which are far more likely to flood than the specified one percent probability per year, leading to dangerous misconceptions regarding risk.

CYCLICAL SCALES OF DESTRUCTION AND OCCUPATION

Grand Isle is particularly subject to dramatic temporal variation on two distinct cyclical scales. Hurricanes only appear in season, from June 1st to November 30th, but their probable trajectories cycle on a much longer duration. The Gulf of Mexico receives a concentration of direct hits approximately ten years out of every thirty. Within the Gulf, Grand Isle has consistently been targeted by dramatic storm events. Because of its location within the Gulf-bowl, and the fact that it is a barrier island, it gets hit first and hardest, resulting in an increase in permanent populations for approximately twenty-five years which then drops dramatically toward the end of each thirty year cycle. Depending on the number of structures that sustain massive damage, and the amount of land lost, this can result in an abundance of derelict properties.

Because Grand Isle is a summertime tourist destination, its temporary population bulges between May and November. This bulge balloons during the International Tarpon Rodeo, the oldest fishing tournament in the United States[5], where typically the population increases twenty-fold near the end of July. Ironically, late summer is also the time when hurricanes are most active, creating a potentially disastrous situation in which the island population is at its greatest during the time of maximum probability of hurricane hits. It is during this time that the community is most vulnerable economically as well: most of the annual income is generated while hurricane risk is highest.

WITH THE LANDSCAPE, THE BUILT ENVIRONMENT MUST MOVE

In addition to the event driven cycles of "pulsing" disturbances described above, Grand Isle experiences long-term and persistent land loss due to the chronic "pressing" disturbances of subsidence, erosion, and deposition.[6] Consistent with all barrier islands, Grand Isle is migrating. Storm events roll the island northward with dramatic speed. Daily tidal shift and Gulf currents gently push the island northeast.

Grand Isle's "land" is composed of loose particulates usually referred to as sand, but in this case, the particulates are composed of deposited Mississippi River sediment which originated in the fertile organic prairie soils of the North American breadbasket. Often referred to as silt or sediment they are the consistency of soft snow, and require saturation in water or plant roots for stability and structure. This sediment cannot be considered terra firma as it does not naturally bind together; it is extremely porous, and regularly swells and shrinks with water saturation. This localized shrinking is exacerbated by regional subsidence, the decomposition and compression of deltaic sediments under their own weight. Between localized shrinking and regional subsidence, it is estimated that subsidence rates can be as high as several millimeters per year.[7]

The sinking land is further exacerbated by sea level rise, which is regionally higher than global averages in Grand Isle. As the land sinks, the water rises, and the sediments dissolve away. The island loses coastline on all sides except the southeastern-most corner, where deposition is extremely active. This pattern of movement makes the island appear to rotate clockwise.

Thus Grand Isle is in constant motion. Waters roll the island northeast and rotate its landmass in the x,y axis. High energy storm winds and water shift the occupiable elevation of the island in the z axis during hurricane season. The island is adrift in both plan and section.

Grand Isle's spatial and temporal land-shifting stresses traditional fixed construction methodologies. Piles, cast into a slab of concrete, are a common foundation strategy on Grand Isle. This method facilitates a degree of structural stability, with the bonus of creating living space/driveway underneath, but is subject to intense scouring during storm events. These uprooted shelves of concrete unintentionally index and measure the continually fluctuating landscape. In this environment, it is necessary to utilize the landscape's natural patterns and processes to determine architectural design parameters.

RESOURCE EXTRACTION

Resource extraction has driven the settlement of the southern Louisiana Delta, in spite of its inhospitable geography. For hundreds of years the estuary has proved one of the richest sources of seafood, oil, natural gas, and other products that have come in and out of use. Specialized equipment and tools have been invented and iterated to mine these resources and to deal with the challenging environmental conditions, creating a rich toolkit from which the project draws.

Today, the delta is populated with these specialized manmade structures and devices that exist predominantly at two scales: landscape and human. The Army Corps of Engineers flood control structures are typically massive ribbons of concrete inserted into profiles of the landscape. Oil and Gas rigs, jack-barges and stacks penetrate the sky; the equivalents of massive skyscrapers in the delta's saturated flats. The shipping industry's trans-oceanic tankers are small floating cities, and the bridges that facilitate auto travel across water bodies on which they float are high, necessary to provide clearance for these large nautical vessels.

These massive landscape elements are juxtaposed against modest family homes in small fishing villages which still bear the name of their founding ancestors. There is a "normal" scalar relationship in the delta, the result of an intensely working landscape, that does not occur many other places in the developed world. It is into this world of super and sub sized elements that the Gantry Crane becomes the logical insertion, facilitating a new architecture of iterative resilience. It is its intermediate scale that links the small, remotely prefabricated residential units to the rhythm of the shifting landscape that becomes their home.

A NEW SYSTEM OF HABITATION REQUIRES A NEW SETTLEMENT PATTERN

Today, when coastline in Louisiana is submerged, the property rights are taken by the State, resulting in property owners simply losing their land. We propose that going forward, Grand Isle's property holdings will be converted to a percentage-performance based system which can maintain property and values in a shifting landscape, and away from a geographically based prescriptive system, which cannot. In order to achieve land ownership equity and equality on this shifting island, we propose that property holding will be frozen on a specific day (to be determined). On that day, the exact landmass of the island will be determined via survey, and property owners will transfer their exact plots into a percentage of ownership of the overall island. From that day forward, each owner will hold a percent of land on the island, not a specific plot of land. Subsequently, as the island shifts, property lines will adjust, parametrically shifting to maintain ownership percentages island-wide, while not necessarily maintaining originally purchased plots.

Simultaneously, we propose a "pile grid" plan be established based on existing conditions. This precise grid would be twelve foot by twelve foot on center, and is designed to support new residential unit modules. No new traditional coastal construction will occur on the island; as older residences are destroyed or abandoned, they will be fazed out and converted to the new prefab modular system that utilizes the pile grid. This way, slowly the island's grid is built up and occupied. Because it is uniform island-wide, the pile grid facilitates shifting property lines and forgives shifting landscape features: residences can easily be moved up and down, and over one grid square at a time, so that all can keep their residence on (above) their current land holding. As the residence units shift, and the landscape moves, an index of pile grid remains, visibly measuring the change.

In traditional residential coastal construction scenarios first piles are driven and then the concrete slab is poured. The lowest floorplate is built as a rigid structure, then attached to the pile-foundation with rigid connections. The attachment point is predetermined at a DFE elevation above the BFE and the rest of the house is framed via conventional construction techniques. In a severe storm event, if the building is subject to a storm surge hit at or above the lowest floorplate it will suffer enough structural damage to be rendered uninhabitable, and must be rebuilt. If demolished and rebuilt, the new structure will likely be placed on or near the footprint of the prior structure, and will often be rebuilt stronger and higher. In the event that this new building survives the next major storm event, and the coastline below it is permanently submerged, the state takes the land and the building must be demolished (see Figure 3).

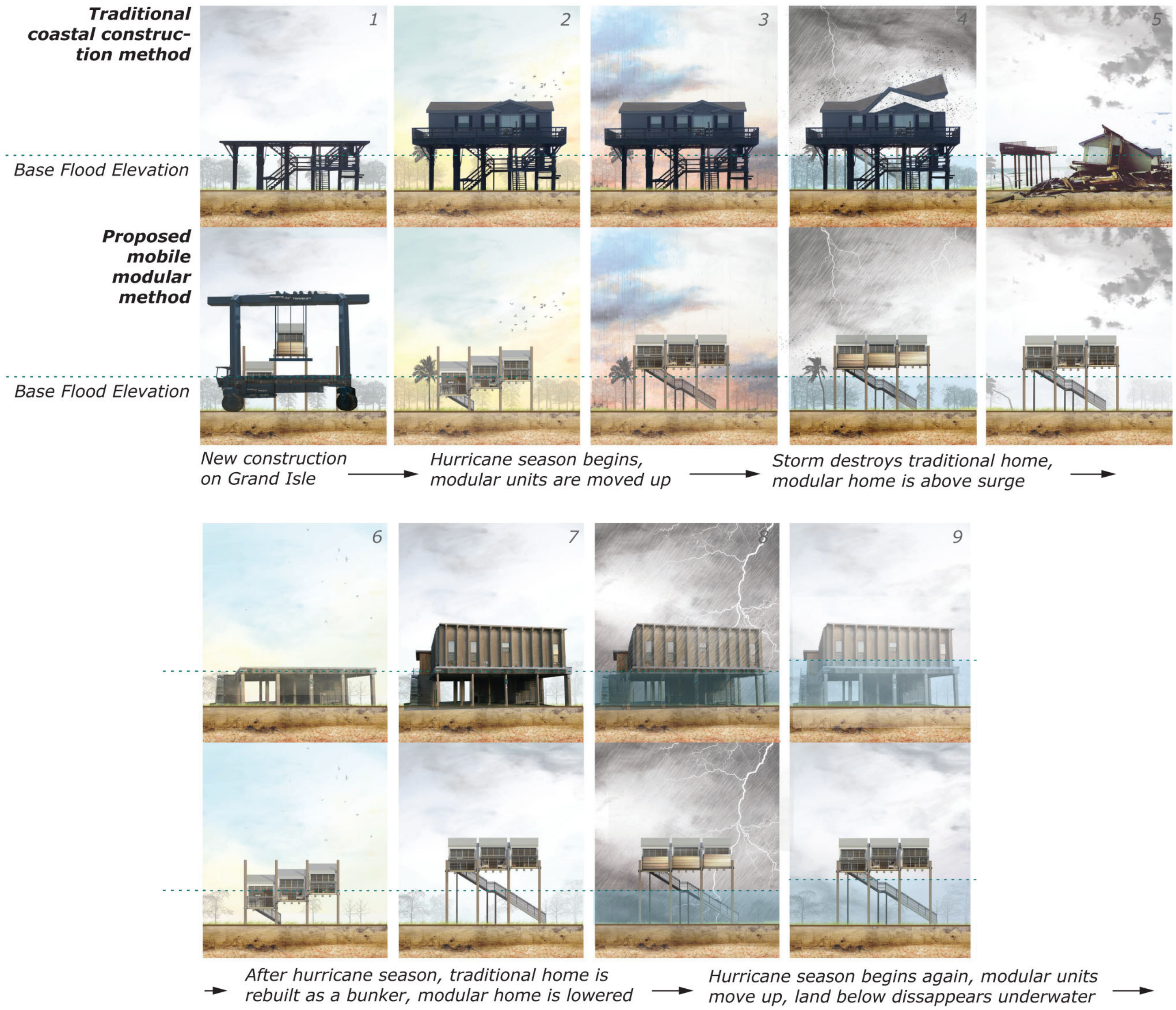


Figure 3.
Breaking the Disaster-Rebuild-Disaster Cycle
The mobile modular method utilizes pile grid logic in conjunction with the Gantry Crane to shift residence locations in both plan and section in relation to the transforming landscape of Grand Isle.

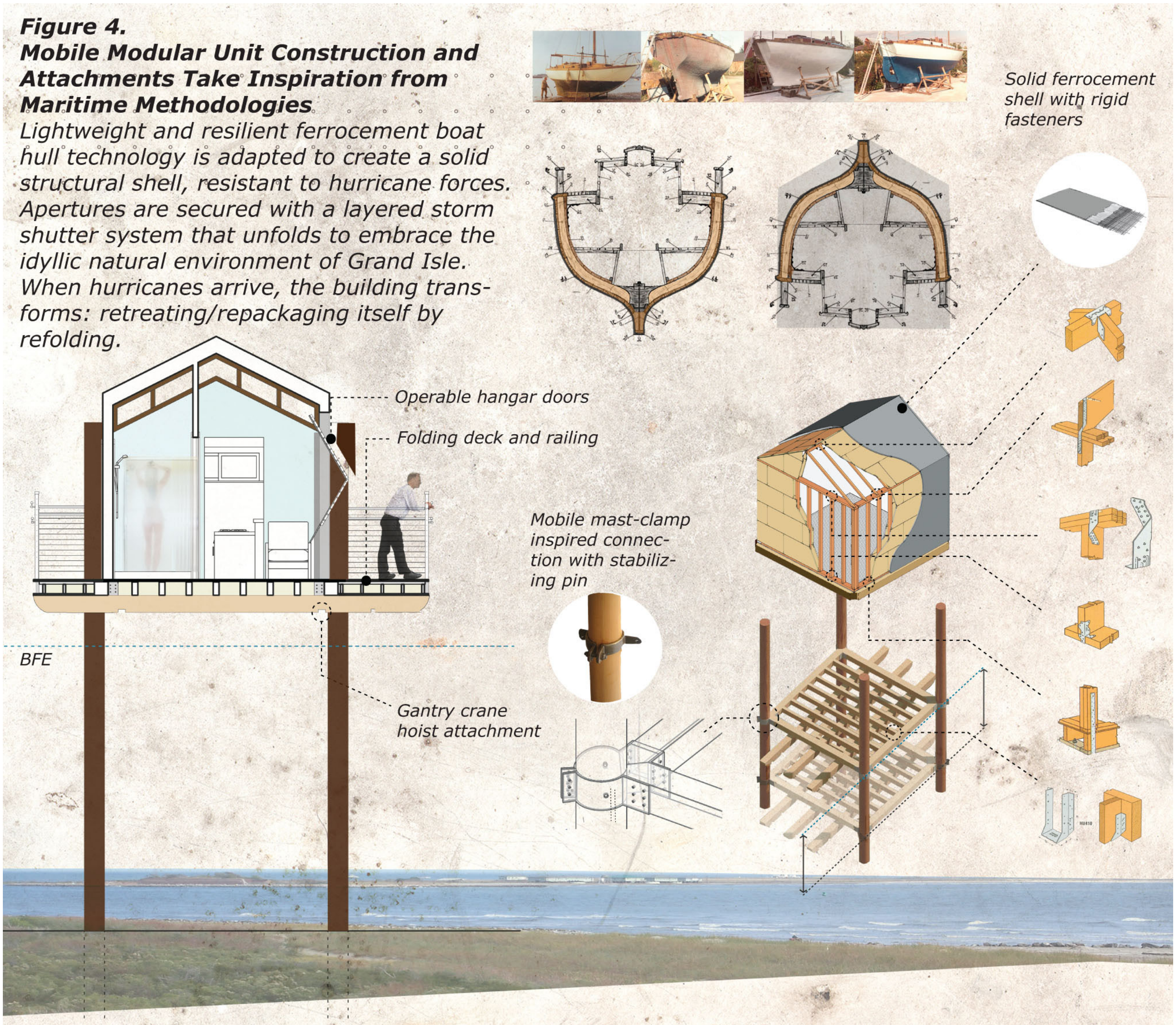


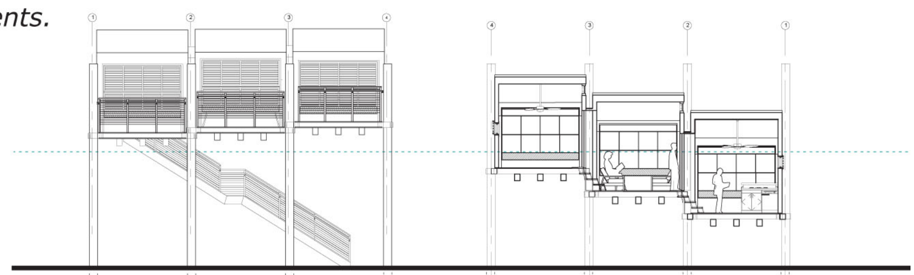
Figure 4.
Mobile Modular Unit Construction and Attachments Take Inspiration from Maritime Methodologies
Lightweight and resilient ferrocement boat hull technology is adapted to create a solid structural shell, resistant to hurricane forces. Apertures are secured with a layered storm shutter system that unfolds to embrace the idyllic natural environment of Grand Isle. When hurricanes arrive, the building transforms: retreating/repackaging itself by refolding.

In contrast, the proposed pile grid system facilitates utilization of x, y and z axis logic. We start with a longer (higher) pile to increase the modules elevation options, and allow for them to be lifted above predicted storm surge heights. In the iterative resilience construction scenario, the grid piles are driven in island predetermined locations. The Gantry Crane delivers the units, one by one, and attaches them to the grid at the appropriate height. When out of hurricane season, the units are configured low to the ground, stair stepping up to take advantage of views and breezes, while still maintaining connection to the groundplane. At the beginning of hurricane season, the Gantry Crane lifts the units into their storm ready position, well above the BFE, and in-line. Additional stair units and intermediary decks are attached to connect the units to the ground. In their elevated position, the units weather the storm above the surge, and are ready to be lowered again once the season ends. Similar to the scenario above, this next storm event may take out the coastline. In this event, all property lines on the island are adjusted, and the units are rolled back in the grid, realigning with the moving landmass. At the beginning of the next hurricane season, all other residences adjust accordingly, so the settlement pattern rolls with the natural movement of the island (see Figure 3).

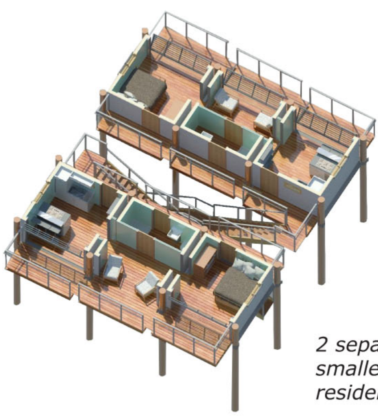
Once new units fabrication is complete, they are delivered via small ships and received at the harbor located on the northeast end of the island. There they are off-loaded by Gantry Crane and directly transported, via new Gantry Crane roads, to site. These Gantry Crane

Figure 5.
A Mobile, Modular Architecture Facilitated by the Gantry Crane
Three module types (kitchen, living/bath, bedroom), linked by interior and exterior circulation, can be configured in multiple arrangements.

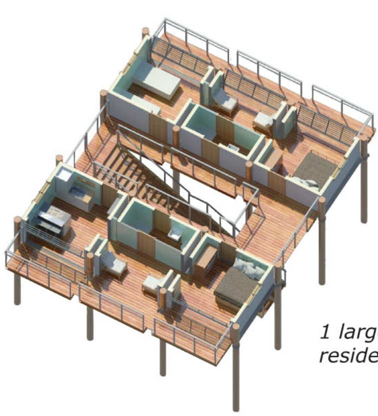
Modules weather storms and are transported in their "closed" configuration. Once in place, they blossom into their "open" or "unfolded" configuration facilitating a seamless camp-like indoor-outdoor lifestyle.



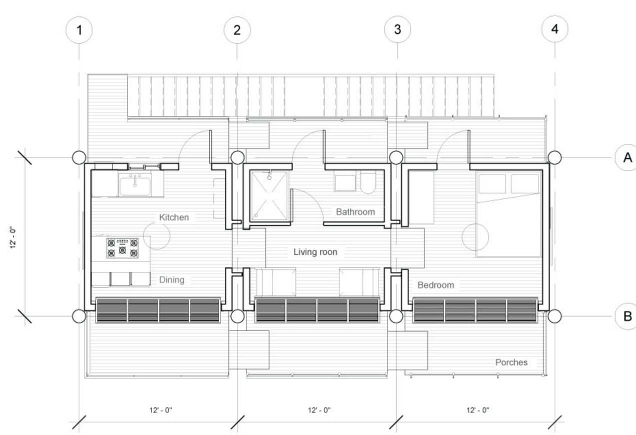
Modules are raised in hurricane season (July-October), then lowered and staggered from November to June to facilitate ease of use and connection with the groundplane.



2 separate smaller residences



1 larger residence



roads are a shared system of crane/bike/pedestrian circulation that is placed within the pile grid to facilitate non-automobile movement around the island. This circulation network introduces novel transverse connectivity across the island from bay to Gulf.

Through time, development on the island is slowly concentrated onto the highest ground, which is also the pivot point of the island's rotation, near its center. Non-development zones, geographies which would result in quick taking by the state, are expanded. Some of this land becomes vegetated buffer zones/water conveyance systems that are developed along the island's longitudinal edges in order to stabilize edges and move water from higher ground, when necessary.

A NEW SYSTEM OF HABITATION

In a landscape whose composition is as much water as "land" it is necessary to reexamine habitation through the lens of nautical architecture in order to utilize the intelligence of its performative characteristics. As discussed above, the aqueous conditions in the southern Louisiana delta has fostered a robust tradition of retooling marine forms, adapting them to shallow waters and high-energy forces. Tapping into specialized local knowledge, labor, resources, and modes of transport is strategic in this remote geography, resulting in an overall increase in the residential system's resiliency.

We propose that the modular housing units are produced within existing shipbuilding facilities because they specialize in large force/water-tight construction. Units would deliver directly from factory to site via boat. Historically, there have been large ferrocement shipbuilders in both the nearby ports of Mobile, Alabama (F.F. Ley and Co.) and Houston, Texas (McCloskey and Co),[8] in addition to smaller shops scattered across the Gulf. With some retooling, shipbuilders in the region have the facilities and knowledge to manufacture these units.

Once complete, delivery utilizing marine transport directly from shipbuilder-manufacturers to Grand Isle, is highly efficient both in terms of fuel usage and logistics. The island has a sizable marina where the units will be off-loaded by one of three dedicated gantry cranes, which then delivers them to nearby storage, or directly to site.

The residential units are timber framed shells, built in compliance with the latest hurricane wind code standards, and sheathed in ferrocement, which is inexpensive and highly durable in maritime conditions. This structural shell is analogous to a ferrocement boat hull, rotated one hundred and eighty degrees along the z-axis, and sealed onto the unit floorplate-deck; essentially creating an upside-down boat. It is highly resistant to transferring wind and water to the interior and tends to buckle, not crack or tear apart, when put under failure inducing stresses. The shell shape is that of a simple gabled roof house (without overhangs that catch wind updrafts that lead to roof uplift) which reference much of the current housing stock on the island (see Figure 4). Ferrocement takes paint beautifully, so units can be colored to match the bright and pastel pallets typical of Grand Isle residences.

Apertures in the rigid shell are sheathed in operable, folding layers, analogous to hurricane shutter systems. The main views and source of breezes on the island are toward the Gulf, and secondarily toward the bay, so the largest apertures and adjoining outdoor deck spaces are oriented accordingly. These spaces literally fold-out into the idyllic natural environment via sets of hangar doors, hinging decks, and railings, creating an expanded hybrid interior-exterior living space. But they are shipped, and weather storms, in their folded/closed position (see Figure 5).

Once on-site, units are positioned into the twelve foot by twelve foot pile grid with the precise controls of the gantry crane, the height of the unit depends on the season and the site's DFE. The units are attached to the pile

grid via an adapted mast-clamp friction style connector with a steel pin that runs through the pile. These customized adjustable connectors, in combination with the folding apertures and decks, constitute the soft-adaptable components of the system which contrast the hard-fixed shell component. Both are necessary to withstand the temporal and energetic fluctuations of hurricanes.

Once installed, adjustable stair units are attached, then the unit decks, and finally the unit apertures unfold, literally blossoming into their living configuration. Twice annually, at the beginning and end of hurricane season, the units are re-folded and their heights repositioned. At the start of the season, units are raised above the BFE, to the DFE, where they will remain high above destructive storm surge forces (somewhere between fourteen and twenty-two feet depending on specific Grand Isle location). The units are floating, almost inline, with one stair tread of elevation difference between them. After the season finishes, units are dropped down and staggered to facilitate ease of use and connection to the groundplane. The lowest unit sits five feet above the ground, and each unit stacks an additional three feet above the one adjacent to it. Sets of accordion stairs slide out to facilitate circulation.

There are three unit types which can be configured in various ways: kitchen, living/bath, and bedroom. Each is sandwiched between decks which increase square footage and provide additional circulation: the larger deck expands living space via sets of hangar style doors which fold up to free the groundplane and provide overhang shade, while the smaller deck is used mainly for circulation. Kitchen units are equipped with island bar-style seating, refrigerator, electric stove, running water/wastewater disposal, small on-demand electric hot water heater, and exhaust fan. Living/bath units have a vestibule space for sofa or chairs which opens directly out onto the large deck, and a bath that contains running water/wastewater disposal, small on-demand electric hot water heater, and exhaust fan. Bedroom units are equipped with an exhaust fan and electrical outlets.

Since Grand Isle is remote, and has one of the most temperate climates in Louisiana, every attempt has been made to reduce active environmental control system loads via bioclimactic strategies. This not only promotes sustainable consumption, but is also a strategy for resilience, as grid power is not often reliable, especially during storm events.

Units are typically grouped into 3-packs or 6-packs. A 3-pack is designed for a couple or single and contains one kitchen, one living/bath, and one bedroom unit. A 6-pack is designed for a larger family and can be configured according to the individual family's needs. The 6-pack unit includes a large common deck space between the two rows of units. Additional platform-deck and stair units can easily be added into the system, increasing living space, circulation, and connection to the outdoors (see Figure 5).

ITERATIVE RESILIENCE

Traditional buildings operate as fixed elements within dynamic landscapes that weather, and ultimately destroy them. As our global climate continues to change at an increasingly rapid rate, it becomes harder to predict what types and severity of weathering will occur at which locations across the globe, and ultimately how this weathering will affect buildings. The dynamic coastline of Grand Isle provides an ideal test geography for future coastal conditions because its local sea-level rise rates are greater than the global average (now estimated at over 3.1 mm annually.[10]) Additionally, its fluctuating barrier island coastline condition, and regular exposure to dramatic storm events, allows us to experience geologic time in less than a generation, providing key data about how buildings perform in these conditions. These generate circumstances with which we can build scenarios and speculate about how necessary new forms of architecture might behave within these conditions.

Through a year of scenario building and design speculation, we have found that mobile prefabricated structures, linked to an infrastructure capable of regular relocation in x, y, and z axes, provides a necessary spatial-temporal linked solution. Utilizing inspiration from nautical architecture, the units can be built at regional shipbuilders, shipped to site, and positioned to withstand storms, while simultaneously responding to local island vernacular character. As the units shift across the expanding grid of friction-pile structural foundations, readjusting their location relative to the transforming landscape, they "nestle" into post-disturbance configurations leaving a pile-forest index of their former positions; an index of the former land. This adaptable modular design creates an integrated built environment, in an unforgiving landscape, expanding architectural scope and agency through the process of reconfiguration.

ACKNOWLEDGEMENTS

The author wishes to thank Carol Friedland, Jeff Carney, the students that assisted with this project: Ben Buehrle, Frank Bohn, Carolina Rodriguez, Elsy Interiano, and Megan Harris, and all participants in the Coastal Sustainabiltiy Studio at Louisiana State University. She also wishes to thank Daniel Sheehy at LSU. The contribution of the ACSA conference organizers and committees is hereby gratefully acknowledged.

ENDNOTES

1 "Grand Isle History," Hurricane City, accessed August 18, 2012, http://www.hurricanecity.com/city/grandisle.htm.
2 "American Fact Finder," US Census Bureau (2010), accessed February 12. 2012, http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=DEC_10_PL_QTPL&prodType=table.
3 Federal Emergency Management Agency, *Coastal Construction Manual* FEMA P-55 (2011): 1, 6-4, accessed February 2, 2012, http://www.fema.gov/library/viewRecord.do?fromSearch=fromsearch&id=1671.
4 "Wind Speed By Parish," Department of Public Safety, Louisiana State Uniform Construction Code Council, accessed August 20, 2012, http://lsuccc.dps.louisiana.gov/pdf/parishes/Jefferson.pdf
5 "Grand Isle Tarpon Rodeo," accessed January 25, 2012, http://tarponrodeo.org/GITR/Home.html.
6 Scott Collins, et al., "An Integrated Conceptual Framework for Long-Term Social-Ecological Research," *Frontiers in Ecology and the Environment*: 2011; 9(6): 351–357, accessed December 9, 2012, doi: 10 1890/100068.
7 T.A. Meckel, U.S. ten Brink, S. Jeffress Williams, "Current Subsidence Rates due to Compaction of Holocene Sediments in Southern Louisiana," *Geophysical Research Letters*: 2006; 33(L11403).
8 "The Ferro-Concrete Builders List," accessed August 22, 2012, http://www.mareud.com/Ferro-Concrete/f-c-list.htm.
10 Intergovernmental Panel on Climate Change, *Fourth Synthesis Assessment Report: Climate Change* (Geneva: IPCC Secretariat, 2007), accessed August 20, 2012, http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html.