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Modular House. Coastal Typological Prototype

TYPOLOGY

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ABSTRACT - *Climate change requires new approaches to coastal settlements at all scales. The architectural community must respond with solutions not only at the urban scale, but also at the scale of the single-family home, long an integral component of the American dream. The single-family typology has been critical to the exploration of architectural ideas and basic societal needs. With shifting coastlines and rising waters, the relationship between built-form and landscape must adapt without losing the important connection between the building and its site. Equally importantly, the transformation of this building type must be broadly available to communities with a wide range of economic resources. Our firm seeks to meet this need through the use of modular construction with thoughtfully restrained site work that limits the short-term impact on the environment, while providing long-term solutions necessary for acclimating to this changing world.*

Keywords: hurricane Sandy, modularity, prefabricated home, resilient housing

Throughout the duration of our practice, SPG Architects has long studied and advanced the relationship between Modernism, regionalism, and sustainable design, and I have focused on the way these influences impact residential single-family houses and their architectural expression. The intersection of these areas of study and practical application have led to a substantial body of work, a large part of which consists of a series of free-standing houses that share both a forward-looking design vocabulary and an emphasis on establishing strong relationships between the buildings and their sites. The common characteristics that define the work are nuanced by the variables associated with building in a range of locales and climate zones: from New England coastal sites to Los Angeles urban neighborhoods, South Florida to the Puget Sound in Washington state, as well as coastal and tropical Costa Rica. These diverse locations serve to modulate how the projects are conceived and constructed, and SPG Architects has responded to the varied factors with a range of building expressions and construction techniques that expand upon local building traditions and materials. The resulting functional and spatial relationships, environmental responses, and sustainable strategies serve to create relevant, lively, and environmentally sensitive architectural solutions.

The buildings designed by my firm address more than clients' immediate housing needs. They also seek to address longer term and larger issues such as adaptability, social relevance, and environmental consciousness. With the imminent threats of climate change, We have sought to apply various sustainable strategies to all projects, when and where applicable. These strategies range from a thoughtful site plan that creates a strong and conscious engagement with a waterfront site in Long Island, to the use of an extensive solar panel array in a fully renewable energy powered off-the-grid residence in Costa Rica. Collectively, the use of sustainable strategies and site sensitive design creates a more environmentally resilient single-family typology. This essay will chart our exploration of the devastating environmental and economic effects of climate change on the built environment generally, and the single-family home more specifically, concluding with a proposal for the "SPG Architects Modular House" as a viable and important architectural response.

THE REALITY OF AN INCREASINGLY WARM WORLD

As many studies have shown, buildings - and the built environment more broadly - are one of the leading contributors to climate change. According to a report by the Center for Climate and Energy Solutions (C2ES), residential and commercial buildings are responsible for approximately 40% of all US greenhouse gas emissions.[1] Coupled with the knowledge that the US is currently the second largest emitter of greenhouse gasses, the importance of reducing the impact of every building type becomes readily apparent.[2] With the clock ticking on scaling back how much global warming is irrevocably locked-in, new construction must confront climate change in two ways: first it must reduce environmentally dangerous emissions, both during the building process and through the life of the building in order to limit future environmental damage to the largest degree possible, and second, it must also be resilient enough to survive the inevitable new and more destructive climate patterns.

Even a small increase in ocean and atmospheric warming can result in devastating effects to vulnerable coastal and marine ecosystems worldwide. As water levels rise, destructive erosion occurs, stripping away vital habitats for birds, fish, and plants. The prospective impact on the built environment is equally profound as this erosion has the potential to destroy vulnerable coastal homes - and lives in the process. This destruction comes not only in the form of sea level rise, but also in more extreme weather patterns that are causing an unprecedented battering of coastal shores. The true enormity of this threat becomes clear when considering that worldwide living patterns indicate a strong preference, or need, for living near the water: eight of the world's ten largest cities are located near coasts.[3] And studies have shown these cities are only getting larger. Each year, 1.2 million more people move to the world's coasts.[4] With a predicted sea level rise (SLR) of 1.24 ft. [37,79 cm] by 2050, extensive reports have shown that the impacts would be wide reaching. Not only would the wealthy enclaves one typically associates with US waterfront living be devastated, the potential exists for hundreds of thousands more homes in middle- and lower-income single-family residential communities to be rendered un-inhabitable or destroyed.[5]

The United States alone has 94,000 mi. [151.278 km] of coastline that comprise some of our most densely populated areas. Some 160 million Americans (or 50% of the entire US population) live on, or near the coast.[6] The Federal Emergency Management Agency (FEMA) has two flood-risk designations for the National Flood Insurance Program (NFIP): the one-hundred-year floodplain and the 500-year floodplain.[7] This is somewhat misleading, as it reads on the surface as though the chance of a flood in the one-hundred-year floodplain were only one in one-hundred years. However, the one-hundred-year designation signals much more dangerous odds: a 1% chance of flooding in any given year. The five-hundred-year designation signals a lower, but still significant, 0.2% chance. This designation only refers to a major flood, and doesn't take into account the many storms that are still deeply damaging without flooding homes.

Of the aforementioned 160 million Americans who live by the coast, approximately 1.6 million people live within FEMA's one-hundred-year coastal flood zone in the Northeastern states, with the majority of those (63%) affected living in New York and New Jersey.[8] New York alone has 269,165 occupied units in the one-hundred-year coastal flood zone, and ranks 4th in the country for most one-hundred-year flood zoned units.[9] New Jersey does not fare much better: it has 230,313 occupied units in the one-hundred-year coastal flood zone and ranks seventh overall.

The 2012 Hurricane Sandy, which was only a Category 1 hurricane, exposed the vulnerability of New York City's 520 mi. [837 km] of waterfront communities, infrastructure, and economy. In addition, this storm and others like it raise larger concerns about how and where we build in both urban and suburban coastal locales. According to the Furman Center Report on Hurricane Sandy's effects on housing in New York City, a total of 16.6% of the land in New York City sustained damage (Fig. 1, left).

Within that substantial portion of land, Hurricane Sandy harmed thousands of buildings, striking single-family homes particularly hard. Of all the damaged buildings, 42% were single-family residences.[10] This damage extended well past the one-hundred-year coastal flood zone into many areas that were both less equipped and less insured.[11] Since the 1980s, this kind of storm activity in the Northeast corridor has only increased due to climate change. As a result, the next hurricane may be even worse: future predictions are showing the potential for more Category 4 and 5 hurricanes.[12] For comparison, a Category 4 hurricane has wind speeds that are twice those of a Category 1 storm, and so we can extrapolate the next hurricane may not damage thousands of buildings, but hundreds of thousands.

FINANCIALLY UNSTABLE WITH UNSUITABLE HOMES

As seen in the example of Hurricane Sandy, most of the damage to single-family residences was in the outer boroughs, where many residents have significantly fewer financial resources when compared with the wealthier Borough of Manhattan. These climate change induced storms will continue

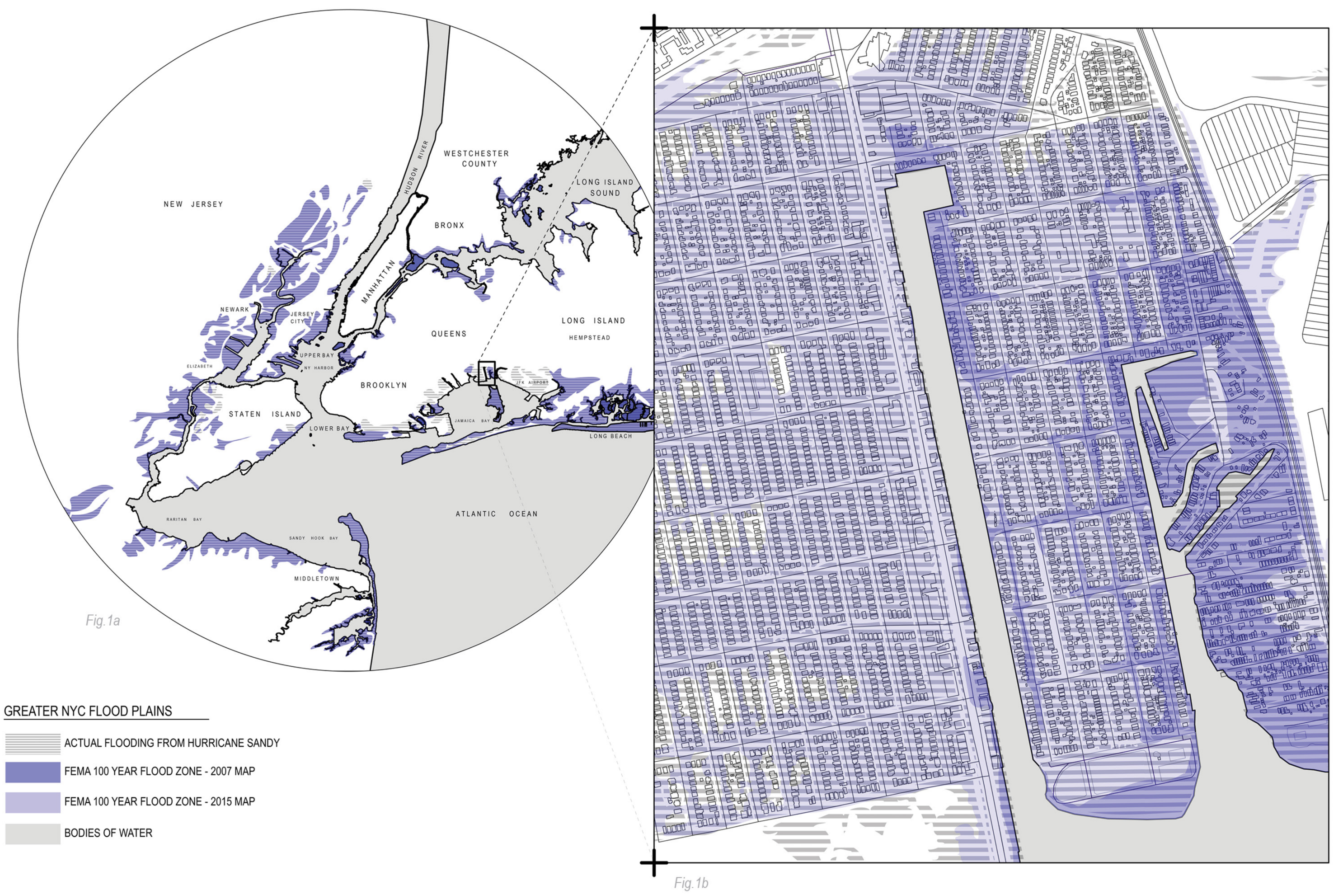

Figure 1. Flood map comparison (left); site context and flood map (right).

to hit especially hard on the most vulnerable in our population. According the US Global Change Research Program:

> Up to 50% of the areas with high social vulnerability face the prospect of unplanned displacement under the 1 to 4 ft. [30 to 122 cm] range of projected sea level rise [by 2100] for several key reasons: they cannot afford expensive protection measures themselves, public expense is not financially justified (often because social, cultural, and ecological factors are not considered), or there is little social and political support for a more orderly retreat process.[13]

Architect-designed buildings have long been financially unattainable for most, and as a result, many populations have been living in ill-conceived or under-designed buildings that are especially unsuitable for the changing climate. The scale of this problem becomes apparent when considering 32,137 single-family homes were damaged in Hurricane Sandy. FEMA has provided a $3 billion grant for Hurricane Sandy repairs, but still more than four years later much of the reconstruction remains unfinished. Basic strategies for all building types must change to reflect the new realities of climate change.

Reports on the rest of the country paint an equally grim picture. According to FEMA, 50% of all housing units in both one-hundred-year and combined floodplains were built prior to 1979.[14] Not only are these buildings older, and therefore likely not as well maintained, but they were also built prior to more strict coastal construction guidelines. This combination of age and lack of standard code features may prove a deadly one in the next super-storm.

To best respond to this changing landscape, architects must become more invested in creating both affordable and resilient architecture. There is a clear need for a new kind of single-family typology that is financially accessible, has a small carbon footprint, and can adapt to changing coastal weather patterns and topography.

DEFINING MODULAR CONSTRUCTION

Architects have explored the design of manufactured homes for much of the last one-hundred years - each home building on the design preceding it. As a result, the prefabricated homes of today can rival their site-built wood structured counterparts in quality and customization. A modular home is a type of prefabricated home, in which the home is constructed in “modules” or units of a defined size. The “module” is often dictated by the size of a flatbed truck, which is used to transport the house to the site (Fig. 2a). This translates roughly to 16 ft. [4,87 m] wide, 11 ft. [3,35 m] high, and up to 60 ft. [18,28 m] long. By the time the home is transported, it is already 60 to 90% complete, as the only major structural task left at that point is to structurally strap the modules together and sit them on structural *piloti* (Fig. 2b). In order to make the assembly of these modules more visually and experientially seamless, the architect specifies site-applied exterior siding to cover exterior joints, and continuous interior flooring and on-site painting to cover the interior breaks between the modules.

OVERCOMING STIGMA

To many, “prefabricated home” brings to mind the lowest common denominator of housing and visions of identical, dilapidated trailers and mobile homes. However, current prefabricated homes have their roots more in Sears Roebuck & Co. than trailer parks. From 1908 to 1940, Sears sold

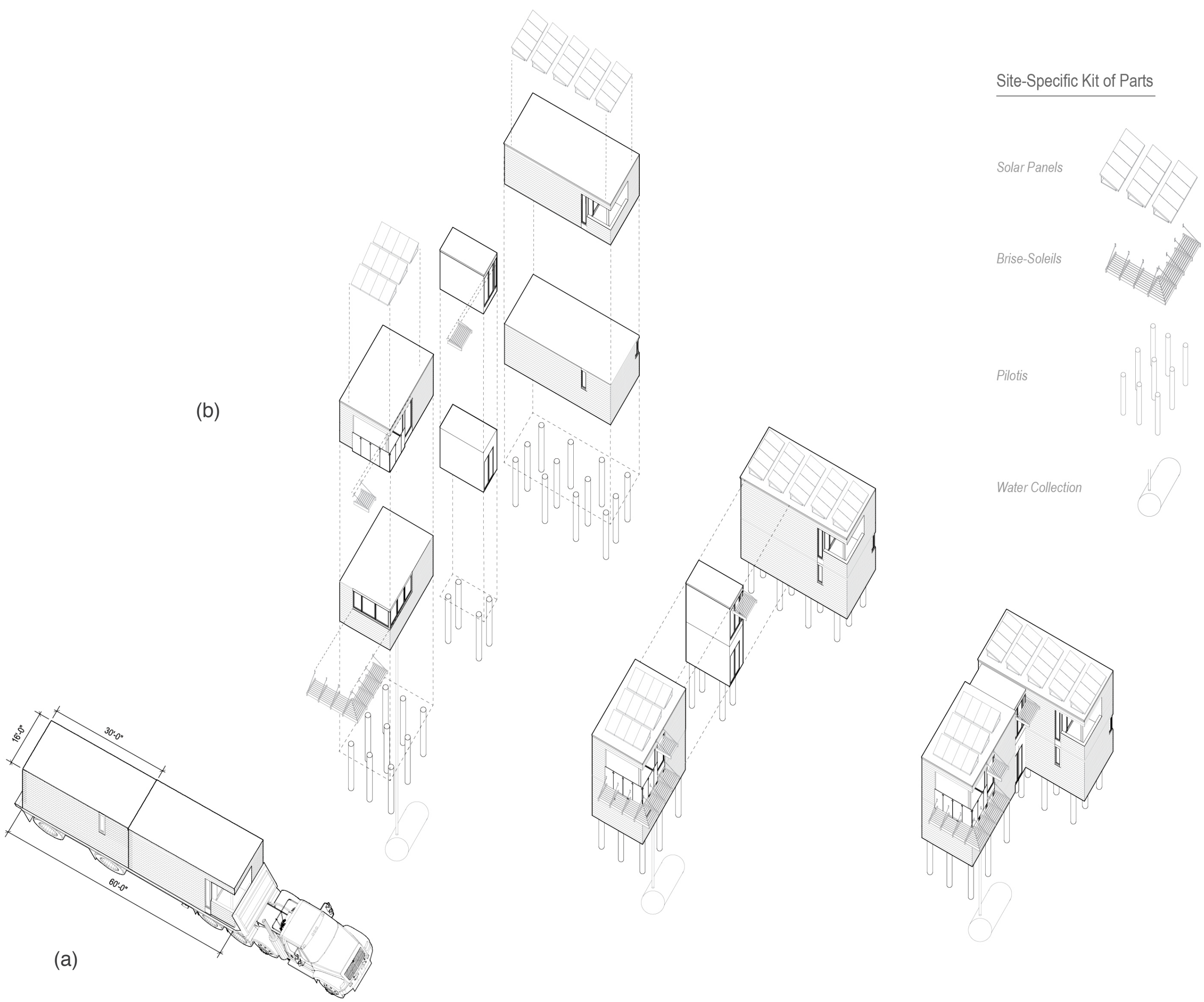

Figure 2. Transport diagram (a); modular construction diagram (b).

more than 100,000 “kit homes” out of their catalogs (Fig. 3, left).[15] The kit homes would be partially assembled in factories, and then delivered to the site to be completed by the homeowner. Boosted by improved roadways and assembly-line production, these homes mainstreamed prefabrication and made home ownership more accessible and viable than ever before.

Yet the most famous prefabricated home building effort of our age is connected to the super-storm before Sandy: Hurricane Katrina (Fig. 3, right). Around 80% of New Orleans, along with miles of Louisiana, Mississippi, and Alabama coastline was decimated and FEMA placed a rush order on 120,000 trailers and mobile homes from sixty different companies.[16] Almost immediately, complaints began coming in about the smell and residents began filing reports of respiratory infections. The CDC (Center for Disease Control) then tested 519 trailers and found five times the formaldehyde levels found in most recently constructed homes.[17] Some were alarmingly even higher - about forty times the recommended levels. The CDC ordered FEMA to evacuate the trailers, but that was not the end of the line for these dangerous homes. Many of them were merely auctioned off with a sticker marking them as not for human habitation.

These dangerous levels were the result of poor construction and toxic materials. Yet, proper modular construction can actually have the opposite effect. Careful attention to the quality of construction and choice use of low- or non-VOC (Volatile Organic Compound) materials provides control mechanisms that eliminate such toxins. A properly supervised factory

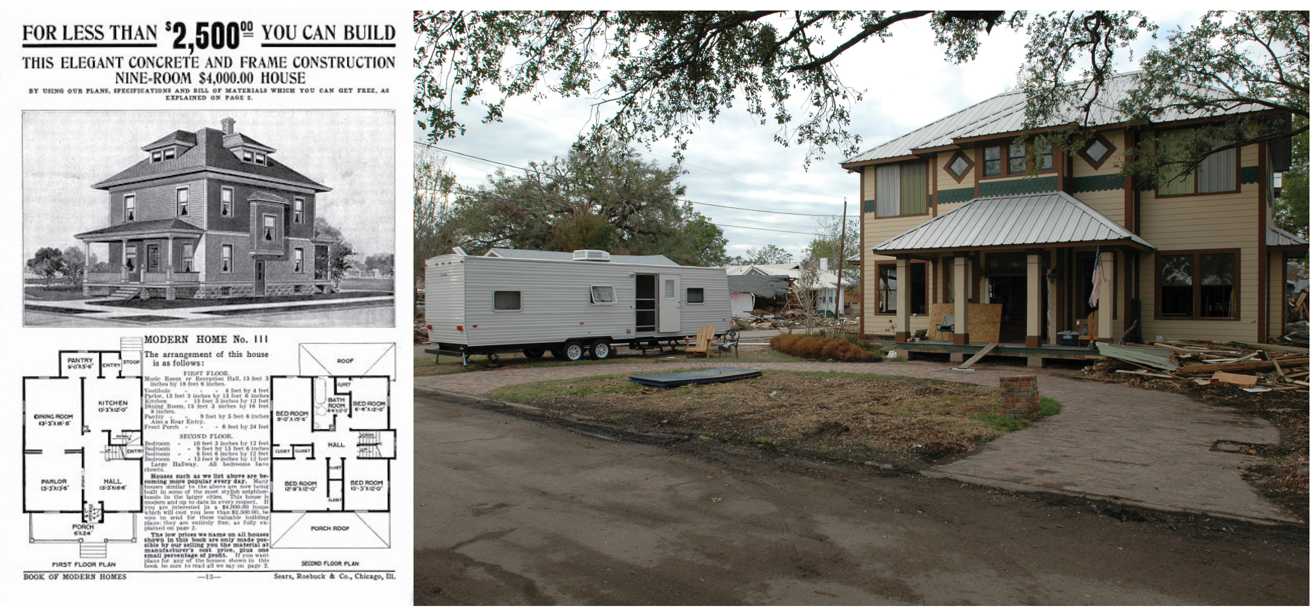

Figure 3. “The Chelsea” (Model No. 111) Sears Home Kit appearing in the 1908 Sears Roebuck catalog (left); post-Sandy FEMA trailer (right).

environment provides the highest levels of quality control during fabrication - potentially allowing for even lower levels of toxins than stick-built construction.

As will be enumerated below, modular homes are capable of bringing numerous assets to the table, as they provide significant economic and sustainability advantages over conventional construction methods.
My practice believes it is vital to design a modular prototype that disproves the negative associations the Katrina FEMA trailers firmly established in the public's mind - showing that modular construction can instead contribute to a reduction in the environmental impact of climate change.

THE ECONOMICS OF MODULAR CONSTRUCTION

In regards to the vast majority of coastal communities, dealing with the effects of climate change requires reckoning with the cost of a single-family home. Modular construction is uniquely positioned to cut down these costs. Since prefabricated modular homes are built in factories, unlike traditional

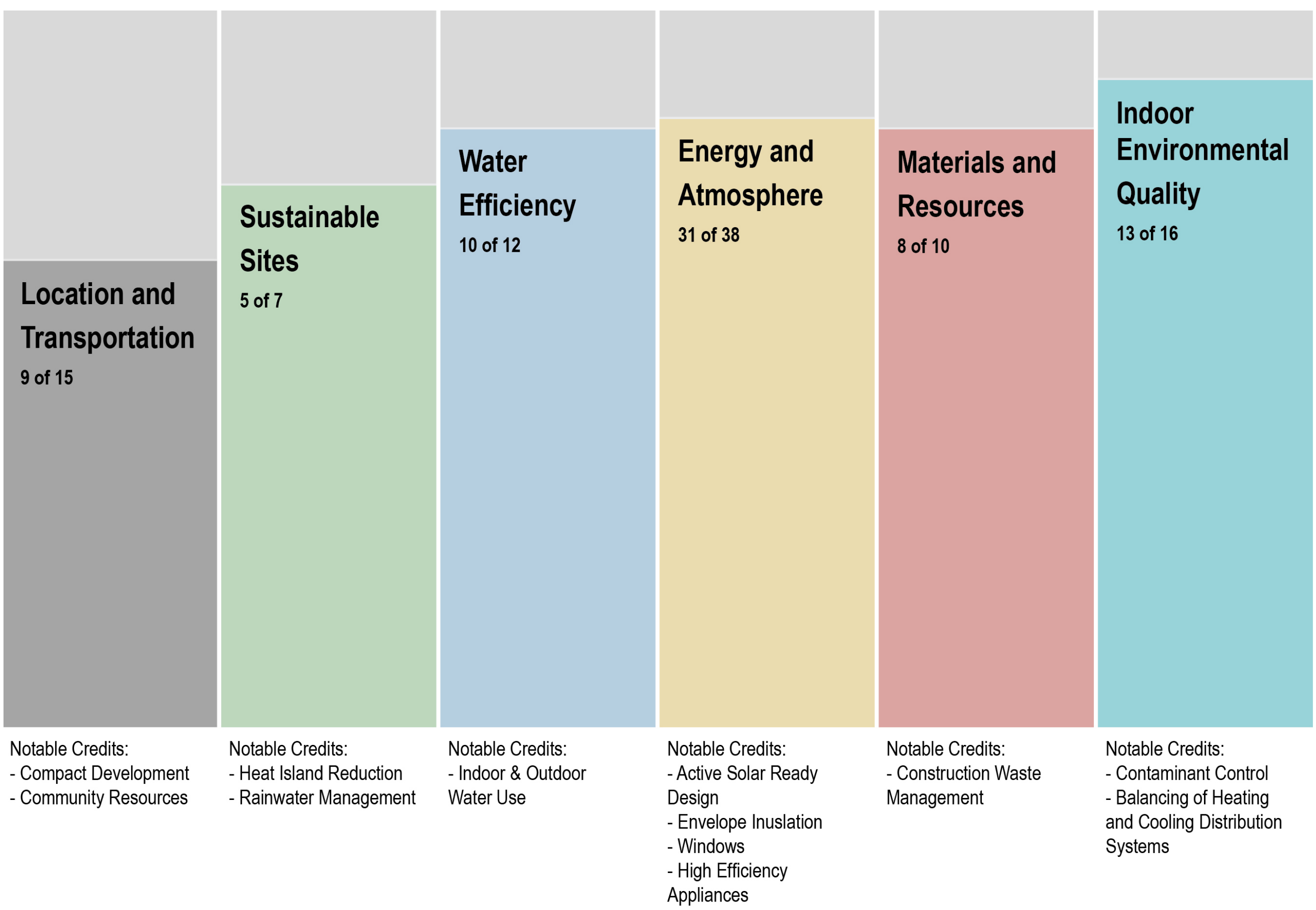

Figure 4. Preliminary LEED credit program.

building methods, the cost saving strategies typically associated with factories are brought to the project.

Given that the majority of the construction does not take place on site, there are savings in both site infrastructure and management of the construction process (also known as site preliminaries).[18] Processes can be streamlined through assembly line production - allowing for more efficient use of energy and labor. Compared to typical stick-built construction, required personnel are cut by half.[19] With these efficiencies in labor come major cost reductions.

In addition, waste control is a significant factor in reducing costs and limiting material waste. The factory management is able to save money by buying materials in bulk. Having several houses on an assembly line also facilitates the sharing of leftover resources between projects, thus cutting down on the amount that has to be purchased generally. Recycling what material cannot be used is also made much easier through the controlled use of waste bins that are easily accessible. This adds a great level of efficiency in the removal of recyclables from the site so that they can be economically processed. Projections of waste management and material savings qualify for USGBC's Construction Waste Management LEED credit (Fig. 4).

Lastly, weather is removed as a factor to construction schedules, further reducing the already shortened timeline associated the efficiencies of factory construction. According to a 2011 survey of 800 architecture, engineering, and contracting professionals, 66% reported a decrease in project schedules due to off-site construction, with 35% reporting a decrease by four or more weeks.[20] A shortened and more streamlined schedule results in lower costs associated with overtime and corrections. Collectively, all of these factory methods add up to a significant increase in savings. Studies have shown these elements lead to a potential 20% decrease in cost in comparison to an equivalent site-built home - thus making good design more accessible to a broader audience.[21]

THE RESILIENCE OF MODULAR CONSTRUCTION

Modular construction has the potential to reduce greenhouse gas emissions of single-family homes and the energy consumption associated with their fabrication and use over time. Building in factories eliminates the variables that come with an uncontrolled environment, resulting in more efficiently insulated building enclosures. For instance, due to the fact that the factory environment allows for the interior finish of the building enclosure to be applied before the exterior sheathing and weatherproofing, insulation can be sprayed and/or applied after the electrical boxes are installed. Installing insulation behind these breaks in the house's thermal barrier eliminates the many leaks that make buildings less efficient to heat and cool.

More efficient use of materials - thanks to optimized factory construction - reduces waste, increases recycling, and saves on the transportation of what waste is unavoidable. This lowers emissions because factory pre-fabrication lessens the amount of new material required for production, and decreases the use of fossil fuels by reducing inefficient transportation patterns. These efficiencies all contribute to a much lower carbon footprint than a stick-built house fully constructed on-site.

Beyond the sustainable element of lowering emissions, modular construction also presents a number of resilient elements in the face of climate change. The benefits of factory-built construction extend to the strength of the building. Climate controlled conditions allow for better welds, stronger assemblies, and tighter joints. Consider that a building module is constructed to withstand the vibrations and vicissitudes of on-road transport. This built-in strength to withstand transport also positively impacts the house's ability to withstand the lateral forces associated with high winds, an invaluable asset when considering the increased threat of higher category hurricanes. In fact, this is exactly what studies have shown: the Insurance Institute for Business & Home Safety (IBHS) conducted a study that found that prefabricated homes fared better then site built homes under strong winds up to 145 mph [233 km/h], due to the structural integrity of building modules.

MODULAR HOUSE DESIGN

Given the statistics of the affordability and inherent sustainability, modular construction provides the base upon which the architect resolved to hone design towards meeting the 2030 goals established by the AIA. The major centerpiece of the 2030 challenge is for all new construction to be carbon neutral. In articulating this design, we saw two clear points on which to push the resilience of modular construction to meet this benchmark: changing its relationship to the site and adding passive design strategies.

Positioning the Modular House

In creating strategies for unifying houses with their sites, we have often used horizontal planes to blur the lines between architectural interiors and exteriors. Often, SPG has used man-made landscape of terraces, decks, and green roofs to extend the building form beyond the limits of the actual building enclosure. This has the overall effect of extending the perceived size of the livable area and linking the building inextricably to its environment, regardless of whether the locale is largely natural in character (agrarian), suburban, or urban.

This strategy had to be reconsidered and adapted to concerns of climate change and coastal living in the design of the Modular House (Fig. 5). To address the vulnerable landscape in flood prone and shoreline locations, this house instead explores the vertical disengagement of the building from the land. Yet it still maintains a distinct and profound relationship between the house and the property on which it sits. In order to link the house with its environs, the vertical planes of the enclosure are perforated, or made more transparent, through the use of windows and large expanses of high-efficiency, UV protected, and hurricane-rated glass. Terraces are also added on the second level to achieve a similar view and experience as patio on the ground level.

The prototypical design exhibited here replaces the traditional horizontal transition from exterior to interior with a vertical element: *piloti*.[22] Long a mainstay of early Modernist architecture and theory, these supports are here made more relevant to the issues of climate change because they allow the natural to remain virtually unbroken landscape when, when coupled with native plantings and pervious materials, serves to absorb the fluctuations of change associated with coastal flooding. When considering the intrinsic resilience of modular housing, the introduction of *piloti* adds yet another layer to the home's and the landscape's ability to withstand a storm.

The actual transition from exterior to interior and from land to house takes the form of a semi-enclosed stair with breakaway walls. As laid out in FEMA's guidelines for floodplain construction, these walls are designed

Figure 5. Modular House in context.

to collapse under the lateral forces of a flood condition and strong winds without impacting the structural integrity of the building. This minimizes damage to both the building and the landscape, and prevents the owner from having to do major reconstruction in the event of a severe storm.

Factory Construction

The deployment of energy-saving and resilient strategies in the Modular House begins in the structure of the modules as assembled in the factory. The breakaway module that contains the semi-enclosed exterior stair also houses a single shaft containing utilities, but otherwise allows light and air to filter through the space without impeding storm or flood surges. The shaft brings power in and waste out, but - given the shaft's small size and its consolidation of utilities - minimizes the building's impact on the land. Limiting the building's overall use of power is made more possible through the intrinsic one-room width of the modules themselves. The constrained width and height of each module ensures no space will be too difficult - or too costly - to heat and cool.

Further cost-savings are enabled through the use of robust insulation. The ceiling is to be insulated to R-60 with 2 lb. [907 g] closed cell spray foam combined with rigid insulation above. The walls and floor will receive R-40 levels of insulation through the use of 2x6 in. [5x15 cm] framing, closed-cell spray foam, and two layers of 1 in. [2,5 cm] rigid insulation. The nature of modular construction means that there is a redundancy between the ceiling of the first level and the floor of the second level - further improving the amount of insulation. The windows will be from Andersen's two-hundred line of windows, which are triple glazed and Energy Star approved, ensuring heat loss and associated costs are kept to a minimum (Fig. 6).

Caulking at all potential points of heat transfer further augments the insulation of the home. Caulking at fenestrations and intersections of horizontal and vertical planes greatly tightens the house's envelope and decreases the need for conditioned air in both winter and summer months. Advances in the fields of building and construction technologies, as well as energy modeling, have shed a light on the importance of small details such as these, as exemplified in the standards promoted by the Passive House and other similar movements.

Beyond the windows, all appliances are also Energy Star approved. These appliances incorporate advanced technologies and use 10-50% less energy than standard appliances. The greater quality of the components used in these appliances have fewer mechanical problems, less maintenance, longer equipment life, and extended warranties. This leads many of these appliances to outperform standard appliances. Energy Star appliances save energy, money and help reduce emissions of greenhouse gases and air pollutants at the source.

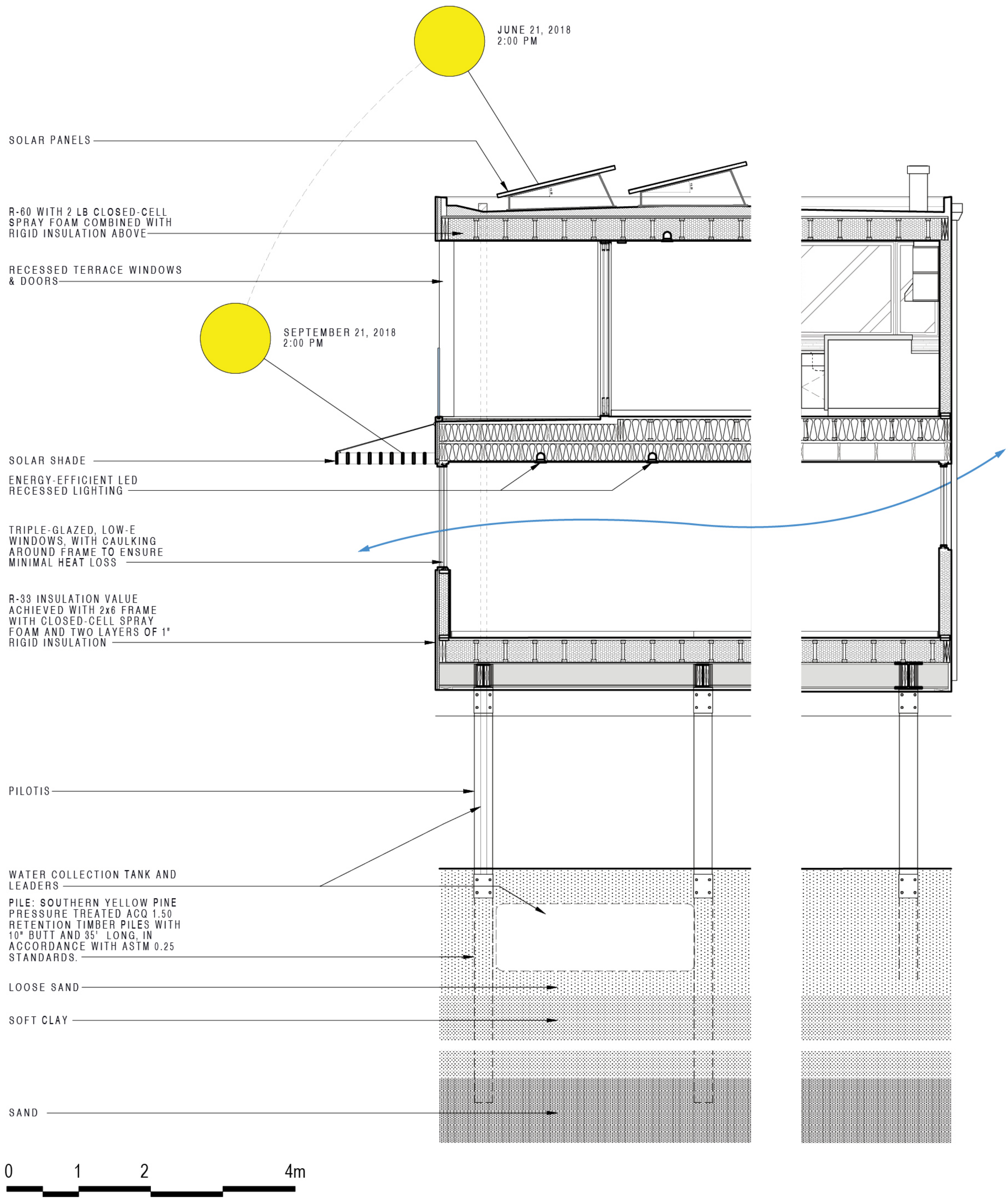

Figure 6. Building section with environmental systems.

Inherent to the House: On-Site Installations

Once the house arrives on site, it is further outfitted with energy-saving technology. After installation, the roof is equipped with an all-over white membrane. This highly reflective material provides significant energy savings to the house as compared to standard black roofs by reflecting the sun's rays, thus diminishing heat gain and the related burdens to the air conditioning system. Also, by being non-absorptive, the material does not deteriorate due to UV exposure and the intense solar heat, which will translate to less required maintenance and more cost savings throughout the life of the building.

The white roof membrane provides a high Solar Reflectance Index (SRI), which is a measure of the material's ability to reject solar heat. Surface temperatures of darker membranes can be up to 90°F [32,2°C] above that of the ambient air; by using a white roof the heat gain is drastically reduced. Since the material is incapable of absorbing and transferring the solar heat through convection and conduction to the building and the local environment, it is a great solution to reduce the "heat island effect" of the built environment. As a result, lower cooling loads will be experienced during the summer months. Smaller air conditioning equipment can be used to service the house and the owner benefits from lower electrical demands.

The one-room-width of the house, combined with the provision of at least two exposures in each room, create a passive strategy of allowing for the natural flow of breezes and fresh air to move through rooms, subsequently reducing the need for supplemental air conditioning. The use of windows for natural ventilation allows for the owner to control the thermal comfort without the use of mechanical equipment (see Fig. 6). This allows for smaller equipment to be used, less demand, causing a savings in energy and cost. It also reduces the emissions from generating the energy to function the mechanical equipment.

In addition, by reducing the "heat island effect," the local microclimate is not impacted by an increase in ambient temperatures or related smog, and the lower cooling loads and energy requirements contribute to a decrease on the associated emissions due to the reduced power required for the air-conditioning equipment – qualifying the house for USGBC's LEED Heat Island Reduction Credit.

Once the house is on site, a rainwater collection system is also put in place. The house will collect approximately nearly 100% of the rainwater that falls on the roof through a series of roof drains and leaders that direct the water to a water tank underground. This tank holds a total of 1,700 gal. [6.435 L] of water that is reused for landscape irrigation and waste water (toilet) purposes. The water is clearly marked as non-potable at the hose-bibs that are located around the house and is not suitable for drinking. However, this system greatly reduces the demand and use of potable water.

Site-Specific: Additional Kit of Parts

While one of the key features of modular design is its adaptability to many different sites, for the purpose of this research we have selected a hypothetical site along the New York City's southern coastline (see Fig. 1, right). This selection allowed for the investigation of solar technology. The project is equipped with Canadian Solar's Dymond CS6K-P-FG module, oriented for maximum solar gain (Fig 7). These sixty cell double-glass modules replace the traditional polymer backsheet with heat-strengthened glass, which provides better protection against the elements, making it ideally suited for use on the coast.

The orientation that benefits the solar panel array also maximizes the benefits of interior day lighting. Well considered window placement and light colored interior surface finishes reduce the need for artificial lighting

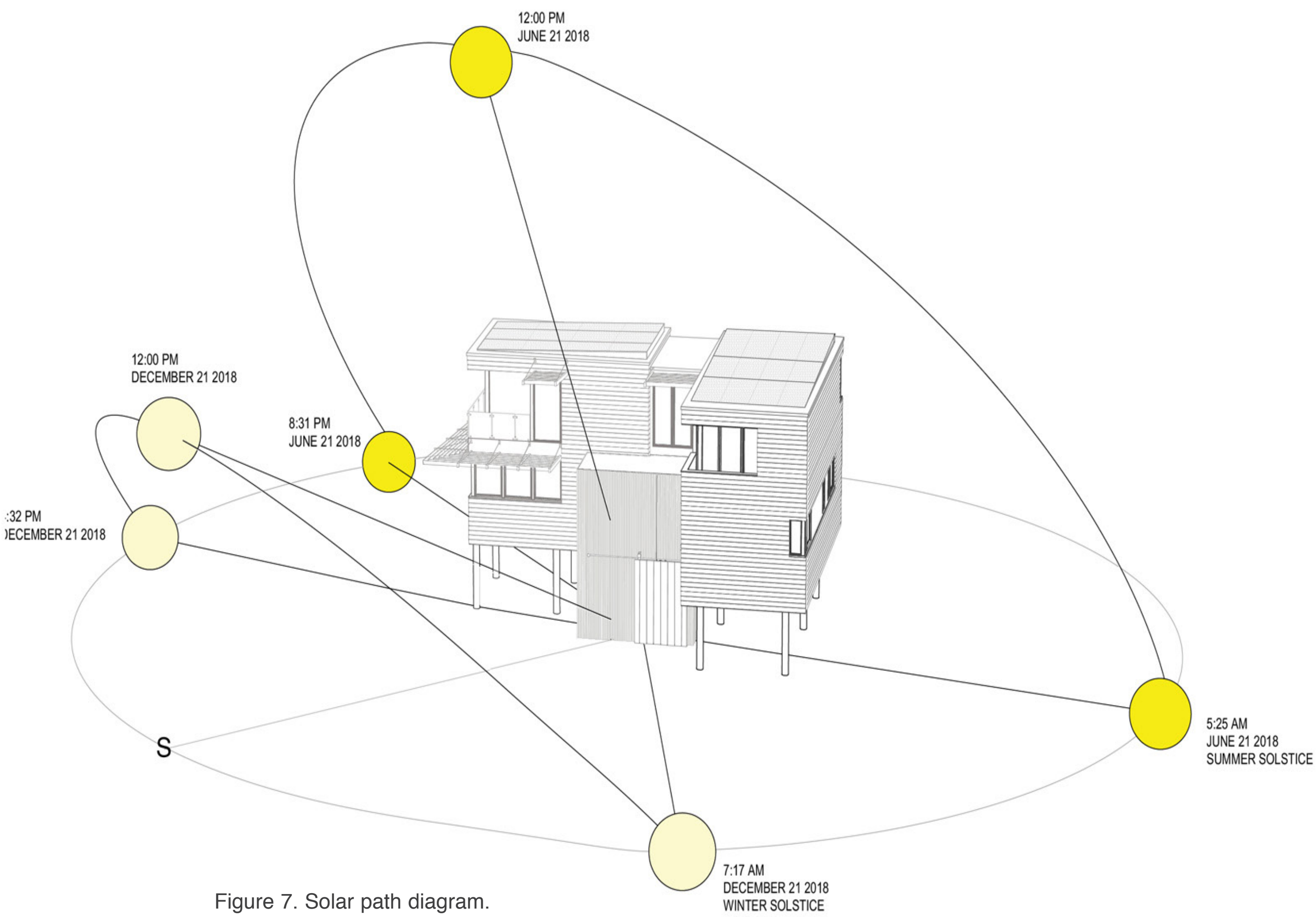

Figure 7. Solar path diagram.

and, by extension, the amount of power the building requires, thus contributing to a reduction in energy use. To further reduce energy costs associated with solar heat gain, *brise-soleil* are added to windows facing south (Fig. 8). These *brise-soleil* serve to block the summer sun from heating the interior spaces - providing significant additional reduction in summer HVAC requirements - while also allowing winter light to penetrate into the interior and reduce the corresponding winter heating costs.

Modular Living

Further lowering the required resources is the design's small footprint (Fig. 9). At 2,000 total sq. ft. [185 m^2] and about 1,750 sq. ft. [162 m^2] of gross interior conditioned living space, this house is significantly smaller than the average US home being built today, which according to census data has almost double that interior area. This qualifies the design for USGBC's Home Size LEED credit, as it is a three bedroom with a smaller than 2,200 sq. ft. [204 m^2] conditioned floor area. This small size would also, by extension, allow the Modular House to be constructed on a much smaller plot of land than a traditional home. This would result in a higher than average unit density per acre of buildable land, and thus making the project eligible for USGBC's Compact Development LEED credit.

To accomplish this, the floor plans had to be designed with maximum efficiency. The lower level contains a stair hall that leads to the upper level living spaces, but is otherwise more compartmentalized with bedrooms that define the private realm. The upper level contains the primary living spaces. Upside-down living, with public spaces atop the private emphasizes the visual link between life and the environment by maximizing view ports. Just as significantly, the well-orchestrated flow of space of the open plan series of modules enclosing the living room, dining room, and kitchen provides commodious interior spaces. Additionally, these interior spaces flow onto covered outdoor decks that serve to blur the line between interiors and the outdoors, while adding additional covered (though unconditioned) living areas. The recessed walls, composed largely of glass windows and doors, are protected from summer solar heat gain, but allow winter's lower sun to light deep into the interior.

Modular Community and Adaptability

The modular home system inherently lends itself to a wide range of solutions accommodating various family types, both traditional and non-traditional. Because the living, kitchen and dining, master bedroom, secondary bedroom, and stair modules are pre-designed for various combinations and configurations, the addition or removal of modular units, reorganized in plan and section according to site and buyer considerations, readily provides well-designed and conceived living solutions. This simplified concept incorporates a series of compatible

Figure 8. Elevations.

Figure 9. Floor plans.

modules and provides a time and cost-saving design and construction processes that eliminate a litany of client- and site-specific problem-solving requirements in favor of efficiently pre-considered and factory-built solutions. One, two, three and four-bedroom solutions have been incorporated into the design system.

This design also incorporates pre-designed components within each module so that master bathroom, secondary bathrooms, and kitchen designs are easily incorporated into the reconfigured modules, again without undue design efforts. This further facilitates the ease of design while providing a broad range of semicustom design solutions. New adjacencies between rooms are facilitated through minor tweaking of door and or window openings, which are also derived from a limited and pre-conceived kit of parts (Fig. 10).

This image (Fig. 11) shows a potential community of coastal modular homes from the waterfront of Howard Beach neighborhood, which serves here as a prototype for similarly vulnerable sites in the NYC outer boroughs and metropolitan region. The same six modules that formed the three bedroom highlighted in this paper are added, subtracted, and recombined to accommodate different families' needs. Three modules form a single story one-bedroom. A module is turned 90 degrees for two-bedroom layout. Lastly, a four-bedroom configuration is formed through the addition of a module. This method of creating layouts using

Figure 10. Seaside View.

Figure 11. Modular Community.

recombination means that there are even more possibilities than shown here, thus ensuring there is a modular design that will work for every family.

The addition of site-specific pre-designed and pre-fabricated components further pushes the adaptability of this design by allowing individualized responses to a range of locales. Given the wide swaths of American coastlines which are threatened by climate change, this kind of specific calibration is vital to respond to the range and magnitude of needs not only in the NYC region but up and down the vulnerable US east coast. The design of the modules in combination with the site-specific additions such as *brise-soleil*, ensures the modular homes could be outfitted on the west coast of Florida as easily as in New York to better respond to the solar orientation in that region. Similarly, the homes could be outfitted with differently angled solar panels to best take advantage of each home's specific location, and of course, the panels can be repositioned on the modular homes' flat roofs to best track the sun's path.

The utilization of *piloti* also provides an opportunity to re-build on land that otherwise may not have been considered, as the raised-house solution allows for the ebb and flow of coastal storm conditions. Previously developed properties that have already sustained soil damage due to flooding or negative human interventions are made usable again by elevating the house above the landscape. This marks an important intention and utility of the design, allowing neighborhoods to be re-built with their social fabric intact while avoiding the harmful impact of new development in fragile or previously undeveloped environments.

Design flexibility, affordability, and timely delivery schedules uniquely position SPG Architects' modular home to be a viable option that provides one component of the many solutions needed to address the issues of renewed feasibility of single-family coastal communities in the age of climate change.

CONCLUSION

The challenges of climate change facing architects and other professionals engaged in designing the built environment are numerous, but not insurmountable. We must not be dejected by the experiences of Hurricane Sandy and Katrina - and the more recent hurricanes, Harvey and Maria, that devastated Texas and the Caribbean - but instead use those lessons as a springboard for better future design. Adapting to climate change cannot be viewed as a choice, but as an urgent necessity. For too long, the typical single-family home has been both too expensive and too static, leading to thousands of families across the United States unequipped and unprepared for the changes global warming will bring. Armed with the economic and environmental efficiencies of prefabricated construction, this Modular House is meant to upend that status quo.

The design allows for an enhanced, fluid relationship between the built and natural environments to develop, wherein the building does not impose itself on the landscape, but instead works harmoniously in concert with the environment. Rather than stand steadfast against the changing climate, this design adapts our style of living to accept and absorb the flows of nature. It has numerous sustainable elements to do its part to slow the tide of climate change, but not at the expense of aesthetic quality. All of this is delivered at a cost much below typical costs for sustainably designed on-site construction, allowing it to be a viable solution for families on the coast.

Our practice has long explored the profound relationship between man and nature. Climate change stands to complicate this relationship - providing both new difficulties and new potentials. Nature now demands a new single-family prototype, expressed in an affordable, nurturing, livable, and environmentally sensitive house form; the Modular House is this response.

Notes

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Credits

Figure 1: images created based on data from WNYC's "100-Year Flood Zones" and "FEMA Flood Map Service Center."
Figures 2, 5, 6, 8-11: images by the Author.
Figure 3, left: image retrieved from Sears, Roebuck & Co. Sears Catalog Home 1908. *Wikimedia*, 30 Mar. 2010: commons.wikimedia.org/wiki/File:SearsHome111.jpg.
Figure 3, right: image retrieved from Mark Wolfe, "FEMA - 18349 - Photograph by Mark Wolfe Taken on 11-01-2005 in Mississippi." *Wikimedia*, FEMA Photo Library, 15 Oct. 2009. commons.wikimedia.org/wiki/File:FEMA_-_18349_-_Photograph_by_Mark_Wolfe_taken_on_11-01-2005_in_Mississippi.jpg (accessed January 10, 2018).
Figure 4: image based on "LEED v4 Homes Design Construction Guide," US Green Building Council, accessed January 10, 2018. https://www.usgbc.org/guide/homes.
Figure 7: image created using solar data from "SunAngle" by Christopher Gronbeck, *Sustainable By Design*. http://www.susdesign.com/sunangle/index.php.

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