Advanced Modular Housing Design: Developing the CORE+

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Abstract

The U.S. housing industry faces three primary challenges that this project addresses—rapid deployment of housing after a disaster, energy efficiency and performance, and affordability of housing. This article will demonstrate the results of a multidisciplinary research project funded by the U.S. Department of Housing and Urban Development (HUD) that developed an advanced modular housing design called CORE+, which provides new housing opportunities for communities facing increased risk from environmental hazards.

CORE+ combines three distinct modular units—CORE, SPACE, and DWELL—into a variety of spatial configurations based on user needs. Deployment of the dwelling begins with the installation of the 160-square-foot CORE unit, followed by the 193-square-foot SPACE addition, and finally, with the 794-square-foot DWELL unit. The CORE+ is deployed in the immediate aftermath of a disaster to provide minimal shelter. As components are added, CORE+ remains on site as an affordable and high-efficiency 1,200-square-foot, three-bedroom, two-bath home.

The research team included individuals with expertise in architectural design, building energy modeling, life-cycle economics, and affordable housing policy. Three design charettes gathered input from local architects and housing manufacturers to inform the CORE+ design. The design was further refined through a fourth community workshop in hurricane-damaged North Port St. Joe, Florida, which revealed design challenges and opportunities for improvement through stakeholder feedback.

This project aimed to develop a roadmap to enable the modular housing industry to design post-disaster housing for rapid deployment, efficiency, and long-term resilience. By working with partners—including professional architects, industrial manufactured and modular home builders, and community stakeholders—the project aimed not only to design a new modular home but also to test its feasibility, cost-effectiveness, and functionality through the design process.

Introduction

Millions of Americans may have to relocate or face sudden displacement as a direct result of climate change and related disasters (Wamsler, 2010). In the Southeastern United States, more intense and frequent hurricanes are predicted for coastal areas, increasing the risk to coastal communities. The provision of safe and affordable housing is already an urgent challenge across the United States. Disasters exacerbate the lack of supply and cost of construction and can cause substantial long-term damage to communities. Advanced modular housing offers potential solutions to alleviate extreme shortages of housing stock, because it can be created with greater quality, accuracy, safety, speed, affordability, sustainability, and more inherent resilience than its site-built competitors (Gunawardena et al., 2014). Through a HUD grant, the Advanced Modular Housing Design CORE+ project addresses this challenge. HUD's support for this research has the potential to spur innovation across the massive manufactured and modular homebuilding industries.

The University of Florida team incorporated six faculty members from the School of Architecture and Rinker School of Construction Management that includes architects, city planners, engineers, and construction managers. The three working groups were based on architectural design, energy efficiency, and affordability. External industry partners included LG Electronics, Clayton Homes, Palm Harbor Homes, and Jacobsen Homes. Six homeowners in the community of North Port St. Joe, Florida, participated in a multiday workshop to test the design with community input.

Substantial speculation exists regarding the potential of modular housing to address significant challenges facing American communities. Architectural researchers have investigated—and in many cases tested—modular constructed housing, including factory-built, three-dimensional printed, rapidly delivered post-disaster, or tiny homes. However, these innovations continue to fail to change the industry, and traditional stick-built housing still dominates homebuilding. Many research projects fail in bridging between innovation and current industry best practices, leading to unbuildable or prohibitively expensive products. The significance of this project is not the novelty of modularity but the integration of post-disaster, hyper-efficiency, and affordability through the careful attention to industry input.

Rapid deployment, energy efficiency, and affordability are three major issues that the U.S. housing industry must address in vulnerable environments to overcome growing risks from disaster, rebuilding, and insurance costs. The results of this research will demonstrate a nexus between speed, efficiency, and affordability only achievable through modular construction. On top of meeting performance criteria, the project also addresses lingering concerns over stakeholder acceptance of modular housing and building codes that can impede its compliance. Through a series of workshops culminating in a stakeholder workshop in Port St. Joe, Florida, the designers worked with stakeholders (homeowners and city officials) to hone a process for customization that will lead to greater acceptance.

Domains of Research

The project's main objective was to develop a post-disaster, modular, single-family housing unit. Developed primarily in response to disasters and climate conditions of the Southeastern United

States, the project focused on the threats of hurricane-force winds, floods, storm surges, high heat, and demand for air-conditioning. High levels of energy efficiency, the capacity for energy self-sufficiency, suitable structural strength, and construction flexibility (for example, disassembly and reassembly) were considered necessary qualities for the design of post-disaster housing. The project focused on resiliency, sustainability, and affordability as the primary drivers of the design.

Resilience

Resilience is a concept that has its roots in ecology, but it has had a considerably broader effect (Holling, 1973). Since the mid-1990s, it has been used to investigate how humans and the environment interact (Mamouni Limnios et al., 2014). The term is applied to a range of topics, including physical security, business continuity, emergency planning, hazard mitigation, and the ability of the built environment (for example, facilities, transportation systems, and utilities) to resist and rapidly recover from disruptive events (McAllister, 2016). The ability of a system to absorb disturbance and reorganize—while going through change and maintaining basically the same function, structure, and identity—is known as resilience (Walker et al., 2004).

Sustainability

In the context of buildings, *sustainability* refers to the capacity to reduce the environmental impact via material choice and energy efficiency, as well as to enhance occupant comfort by using ideal lighting, ambient temperature, and enhanced ventilation (Santillo, 2007). Energy costs can be significantly decreased, carbon emissions can be reduced, and passively constructed, low-energy housing that is outfitted with renewable energy generating and storage technology may help make homes more energy and self-sufficient during longer-term power outages. In addition, waste may be reduced and building components recovered for reuse or recycling during demolition if building materials are selected with their full lifecycle considered (Brown et al., 1987).

Affordability

Regarding housing, the term *affordability* refers to the price of a shelter in relation to the buyer's financial resources (Hancock, 1993). When housing expenditures (including utilities) account for less than 30 percent of the area median income, the home is deemed affordable (HUD, n.d.). In Florida and much of the South along the Gulf Coast, an expanding population has outpaced the number of reasonably priced single-family homes, particularly to those with lower incomes. Cost-burdened families are paying more than 40 percent of their income on housing and account for more than 1.4 million people with earnings less than 60 percent of the annual median income in the state of Florida alone (Shimberg, 2020).

History of Hurricane Disasters and Post-Disaster Responses

Property and other infrastructure in U.S. coastal areas are increasingly in danger due to weather events like large storm occurrences. Hurricane-related floods and storm surges are among the most devastating natural and severe weather-related disasters affecting communities in the United States, particularly in the Southeast. This research focused on zones 1, 2, and 3 on the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' climatic zone map (DOE, 2015).

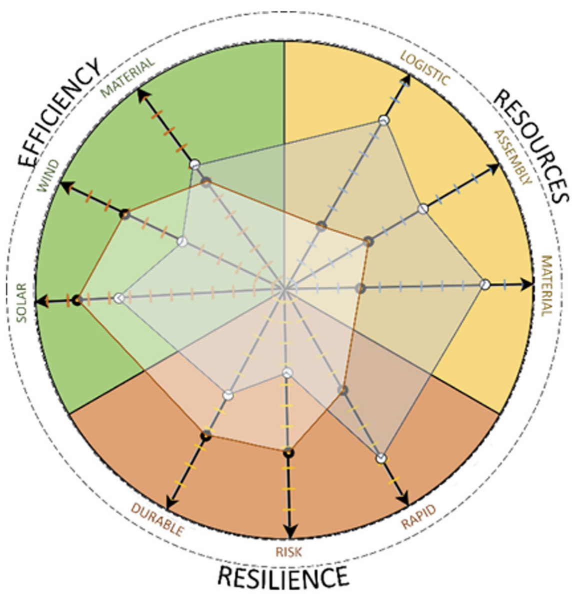
Approximately 500 tropical or subtropical cyclones have made landfall in Florida, the most notable of which were Hurricanes Andrew in 1992, Irma in 2017, and Michael in 2018 (NOAA, 2022). The most active decade was the 1990s for the United States, with 31 storms having an impact.

Project Methodology

The project's main objective was to create a new kind of post-disaster housing that could address the growing scope and frequency of environmental disasters and extreme weather events that have become more frequent as a result of climate change (Phillips et al., 2017). The design process focuses on three distinct, but interrelated, research goals, titled—resource, efficiency, and resilience (exhibit 1). These goals serve as design objectives and as a basis for a set of quantitative indicators that can be used to evaluate the CORE+'s efficacy in relation to its goals and to observe potential tradeoffs.

Exhibit 1

Three Research Aims with Measurable Objectives that Are Balanced Through the Design Process



Source: University of Florida project team

Three interconnected and supplementary research strategies are at play in this investigation. In the first step, the team conducted case studies of evaluating several manufactured modular housing projects, taking a close look at the responsiveness, sustainability, and equality. Case studies provided the basis for a collaboration between academics and industry experts to advance the design of prefabricated modular housing. The initial design was also influenced by the rough specifications of the HUD model home. Although the CORE+ model was not constrained by this design, it did provide a rough scale and expectation of mobility and affordability that drives the HUD house.

Second, design charrettes allowed for the incorporation of industry and professional perspectives into the design process. Three topic charrettes were conducted as part of the project. The initial charrette concentrated on learning about the characteristics of the target consumer for CORE+ and pinpointing potential sites. Because the CORE+'s user is not limited to the individual or family who occupies the building but can also be influenced by the site, the conditions of occupation, and the tenure duration, the second charrette conducted a series of scenario exercises with mortgage and lending experts to investigate the CORE+'s varied user demands. Technology and energy efficiency professionals and fabricators were invited to participate in the third charrette to focus on the technical building systems being developed for the project.

Near the end of the project, the North Port St. Joe Project Area Coalition and Florida Agricultural and Mechanical (A&M) University collaborated with the University of Florida team, as well as the project team's collaborators at the Florida Resilient Cities program to host the last charrette as a public workshop. The goals of the workshop were to test the CORE+ design with real community demands for housing that is affordable, swiftly built, resilient, and energy efficient. The CORE+ was used through this workshop to plan, define, and cost model homes for six community-recommended locations. The workshop took place during a 3-week timespan, which allowed for significant refinement to the designs.

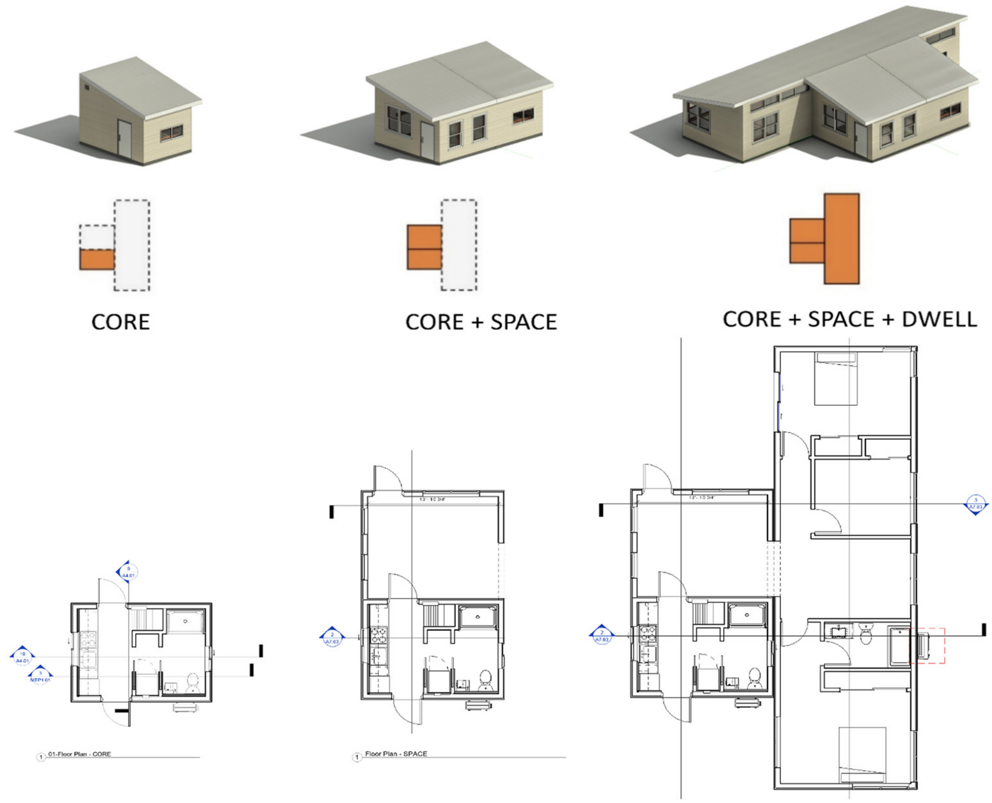
Architecture and Design Methodology

To produce rapidly deployable, resilient, energy efficient, and affordable housing for people who live in disaster-prone regions of the Southeastern United States, the project team based their research and design approach on a balance between the efficiencies of mass production in a factory setting and mass customization informed by clients and site conditions to achieve these goals (Larsen et al., 2019). Modular homes may be built in advance and delivered from less-hazardous areas to the areas most affected by natural disasters (Gunawardena et al., 2014). Although mass production is by definition "generic," the application of modular housing should be informed by regional and microclimatic conditions, specific siting requirements (such as coastal flood risks), individual client stylistic and spatial preferences, budget constraints and financing methods, local building controls, and the inevitable adaptations desired by families. Mass customization makes it possible to demonstrate the advantages of both bulk manufacturing and personalized design.

The research and design project resulted in the CORE+ modular house. It incorporates three different modules—the CORE, the SPACE, and the DWELL—all are built using modular factory building techniques (exhibit 2). Depending on the buyer's location, price, and timeline, these three modules may be put together in a broad range of combinations to create a variety of residence types. CORE+ is a set of interrelated modules, each of which fulfills a specific and vital function in the rapid restoration of safe, low-cost housing for long-term occupation in the aftermath of a disaster.

Exhibit 2

Distinct Modules that Accomplish Three Primary Functions of Housing: CORE+SPACE+DWELL



Source: University of Florida project team

CORE would be delivered to the disaster site within days. If the property is not yet ready, it may be stored temporarily in a parking lot or similar location. The unit, as exhibit 2 shows, is the substantial, storm-resistant "heart" of the whole construction, providing essential living amenities, such as a kitchen, bathroom, laundry room, and sleeping loft. The Core's construction is structurally robust, and it will provide maximum protection against future storms for its inhabitants. This would allow for deployment in high-risk areas such as the Florida Keys. CORE is a rigid (self-supporting) and hardened construction that offers storm protection and foundation flexibility, even to the extent that it may be created and anchored temporarily. The CORE consists of a light gauge metal frame with sheathing and closed-cell foam insulation, constructed as a rigid assembly and shipped in bulk for quick installation.

SPACE is the second supplementary module and provides a space that may be used as a den, sleeping porch, or full bedroom. It is designed to be versatile, and homeowners are encouraged to expand on and alter the structure to suit their own requirements. This unit may be installed with the CORE unit, or it can be added afterward to give extra room. It is semi-rigid and requires additional foundational support.

DWELL is the third and final modular component. It enhances the size of the modular building by adding three bedrooms and an extra bathroom. Due to its conventional sizing for truck transportation, the unit's expenses are kept low even though CORE+ provides 1200 SF of living area.

Material Selection

The modular construction sector has expanded its range of materials, innovated the product sourcing, designed new production techniques, and experimented with logistics and the supply chain from beginning to finish. These advances in building materials and fabrication techniques were instrumental in the conceptual development of the CORE+ design. At the same time, the team's industry partners brought substantial experience in traditional construction and factory assembly techniques. The resulting design attempts to bridge traditional construction with an infusion of contemporary materials that are sustainable, robust, and efficient.

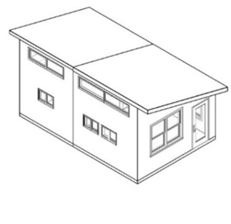
Energy Efficiency

The goal of the CORE+ project is a hyper-energy-efficient building that can be outfitted with cutting-edge systems and renewable energy technologies. However, the efficiency of the structure starts simply with the orientations of a CORE+ unit on site. As a modular unit, there is little control over orientation. Instead, the fenestration ratio of the building was tuned for the lowest possible energy use in any orientation. Additional tuning available through the process of project development would control energy consumption by shielding the south and east-west facades with a mix of horizontal and vertical shading devices is possible. This project employs a variety of passive design solutions to reduce the need for energy-intensive mechanical and utility systems in the building's design and construction (exhibit 3).

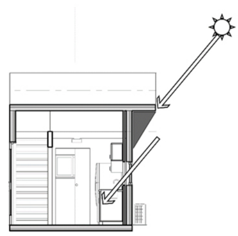
Exhibit 3

Passive Design Strategies

This project has, on average, 30% fenestration ratio for all facades to provide daylight in all seasons and sunlight in cold seasons. The project also has designed pitched roofs to shed rain and greater reflection of solar radiation, and can be extended to protect entries, porches, verandas, and other outdoor work areas.

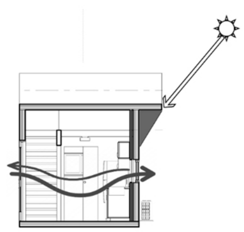


Operable clerestory windows will enhance the effect of "stack ventilation" by allowing the warmer air to leave the space at the higher elevation, which in turn, induces the admission of cooler air through the windows at the lower elevation.

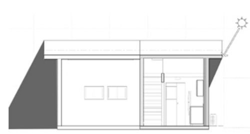


To avoid excessive solar radiation, south facing facades are equipped with overhang. The design also uses light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain.

The design provides double pane high performance gazing (Low-E) on west, north, and east, but clear on south for maximum passive solar gain.



In addition to overhang, having windows facing each other across the space will provide an ample opportunity for cross ventilation, which can significantly lower building cooling demands when outside temperature is relatively low.



The design incorporates screened porches and patios that reduce the building's cooling requirements when the outdoor temperature is relatively high.

Source: University of Florida project team

Resilience

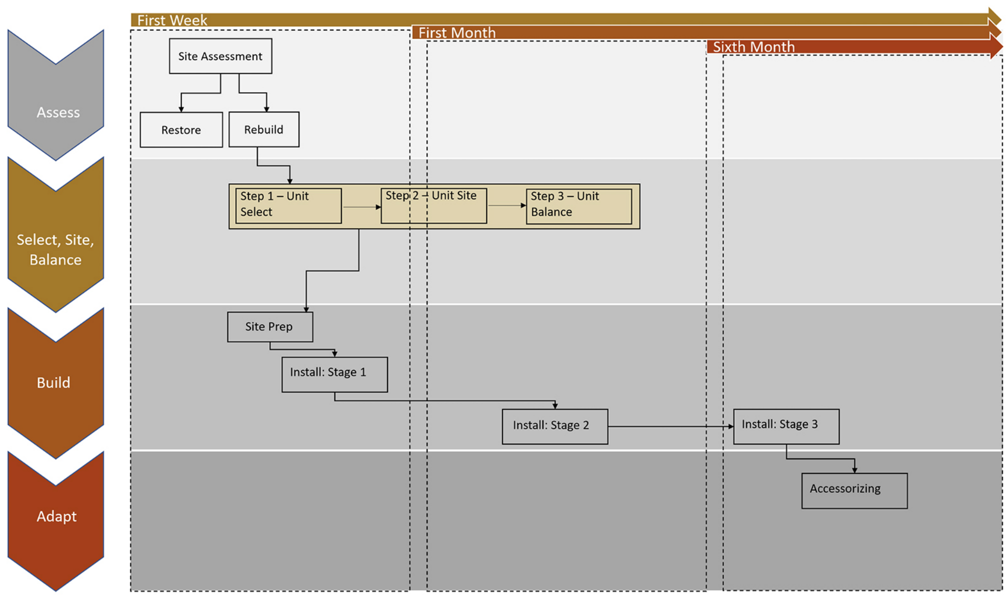
The CORE+ design meets or exceeds all of Florida's building code requirements for wind loading, passive heating and cooling strategies, and systems to mitigate extended power failures. The design includes an affordable piling system that allows for increased home elevation at multiple levels to fit the needs of the site. These technical solutions are built into the project from the start and are required or added according to the project's risk profile. Many of these decisions will be determined during the site selection phase of the project when a chosen home configuration is applied to a specific location. Greater resilience to future risk not only better prepares occupants for future disasters, but also builds a community asset that gains value with time. CORE+ design can contribute to the long-term value of a community, with durability in material, structure, and design that results in longevity that returns equity to the homeowner.

CORE+ Assembly and Manufacturing Process

Three dwelling units—the CORE, SPACE, and DWELL—were created as the primary building blocks of the CORE+ model. These modules may be put together to suit a buyer's disaster needs, site requirements, budget, and family size. Following a disaster, homeowners recover their homes in four broad phases during disaster recovery (exhibit 4).

Exhibit 4

Site, Select, Balance—The Process of Selection and Assembly of CORE+



Source: University of Florida project team

Stage 1. Site Assessment

Following a disaster, the Federal Emergency Management Agency (FEMA), local emergency management, and insurance firms evaluate the site to ascertain the degree of damage, the amount of compensation insurance will provide, and the authorization to rebuild and to what extent. As disaster-prone locations become more fragile, several governments are putting into place predisaster strategies to remove them from circulation. FEMA may also identify a location as a property that often sustains losses and advise a buyout rather than reconstruction. Although this procedure is not directly covered by the CORE+, this overview lays the crucial legal and financial foundation for the next stages.

Stage 2. Rebuild Choice and Finance Options: Select, Site, Balance

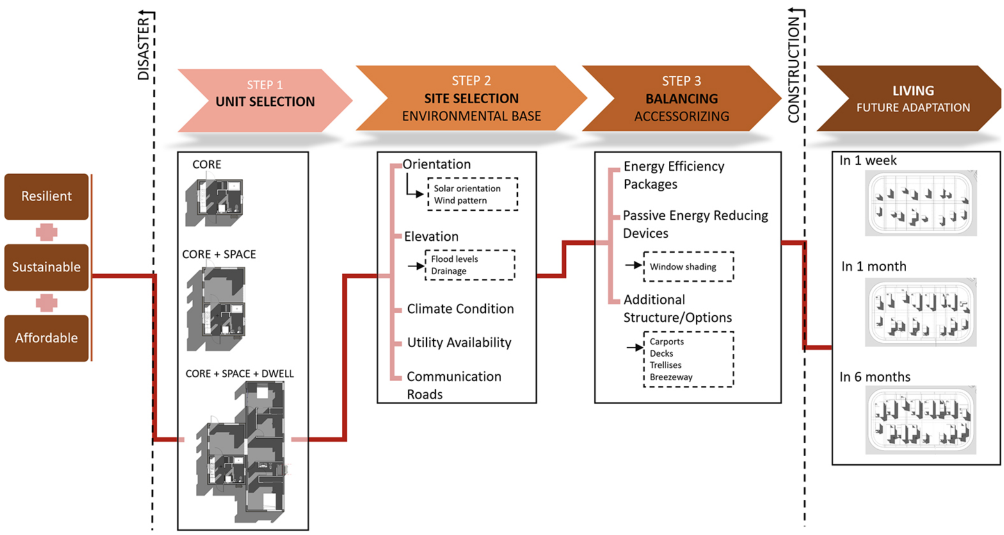
Stage 2 of the AMH design process is the main emphasis. The team increased the number of steps in this stage to three—selection, site, and balance. Each stage acts as a conduit between a prospective homeowner and the building process. Users may choose the CORE+ assembly that best suits the unique needs of their site, family, and financing with the support of upfront, monthly, and life-cycle cost alternatives, for which users provided input at each step.

Step 1. Unit Selection

In this step, the customer may choose the number of units (CORE, CORE+SPACE, or CORE+SPACE+DWELL) and the delivery window. This phase determines the unit's overall size and eventual expense (exhibit 5).

Exhibit 5

Select, Site, Balance



Source: University of Florida project team

Step 2. Site Selection

Given that CORE+ is built for disaster recovery, the precise locations for which the home is intended are exposed to a wide range of dangers. The Southeast of the United States is particularly susceptible to storms, notably those with storm surges and hurricane-force winds. Extreme heat and inland floods are additional dangers. The structure's orientation in respect to the cardinal directions, necessary height above the ground, local solar exposure, and other factors that affect the structure's orientation are all included in its siting. Step 2 would sharpen the unit's cost estimate by adding an anticipated monthly utility bill.

Step 3. Balancing

By giving customers the option to choose between three energy efficiency packages, CORE+ enables owners to further customize the design of the appliance. Window coverings and extra buildings like carports, decks, and trellises are examples of passive energy-saving technologies. The chosen package will further modify CORE+'s base price and anticipated monthly costs and enable the model to operate under various financial frameworks. The Affordability section provides further financial details.

Stage 3. Build

The CORE+ project includes several different construction phases designed to help people return to their homes after a storm as quickly and efficiently as possible. It begins with the post-disaster deployment of a CORE unit, which may be set up only weeks after a disaster on a site that has been initially cleared. After this preparatory stage, the site preparation phase, which involves installing utilities and laying concrete or block foundations, may start. The modular units may be provided over time, which speeds up installation, although thought is given to simple mechanisms for unit mating.

Stage 4. Adaptation over Time

The design has placed a strong focus on resilience so that homeowners may modify their homes as necessary to meet changing needs. The building's mass-produced shell may be modified to include elements that the community, environment, or building owners like, such as decks, carports, window treatments, and trellises. Adaptations can include decisions made during the balance phase. The structure may be changed to accommodate different locations and needs thanks to the assembly's adjustability. The study estimates the ways communities responded to prior disasters to foresee how a community's strengths and weaknesses would evolve to respond to future dangers. In this sense, CORE+ has taken time into account and permits buyer participation depending on potential future needs.

Building Systems, Life-Cycle Costs, Affordability

In support of the overall design of CORE+ the project included substantial research and development around building systems, life-cycle costs, and affordability. These topics were iteratively incorporated in the design process.

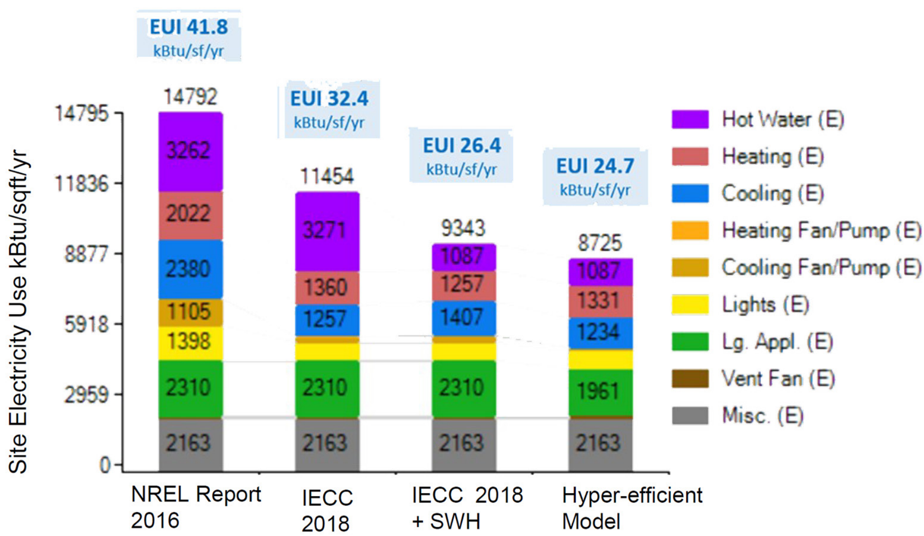
Energy Modeling

In the context of buildings, sustainability is the capacity to reduce the environmental impact via material selection and energy efficiency, while enhancing occupant comfort using ideal daylight, ambient temperature, and enhanced ventilation. Many factors contribute to the decline of total delivered residential energy intensity based on the Annual Energy Outlook reference case, including gains in appliance efficiency, onsite electricity generation (for example, solar photovoltaic), utility energy efficiency rebates, rising residential natural gas prices, lower space heating demand, and a continued population shift to warmer regions (EIA, 2020). As the first measure to reduce the amount of energy a building consumes, proper building design can improve thermal insulation and reduce air leakage by incorporating advanced envelope components (IEA, 2020). Systems have to be selected appropriately for reduced energy use of the whole building, including among others, energy use owing to building envelope, such as walls, roofs, windows, and so on are therefore significant.

The CORE+ project developed a series of whole-building energy models for estimating energy use. Developing energy models of buildings involves extraction, organization, and use of existing building geometry and thermos-physical data as model inputs (Eicker, 2019). Three models were developed for this study—a model that used the National Renewable Energy Laboratory's report (2016; also referred to as the reference model), a model that used International Energy Conservation Code, and finally, a model that used renewable energy and storage systems to achieve Net Zero Energy—also referred to as the Net Zero Energy Capable building (Cole et al., 2016; ICC, 2018). The Energy Use Intensity (EUI), calculated by dividing the total energy consumed by the building in 1 year (measured in kilo-British thermal units, or kBtu) by the total gross floor area of the building, is used as the basis of comparison between the models (exhibit 6).

Exhibit 6

Total Energy Saving



EUI = Energy Use Intensity. IECC = International Energy Conservation Code. kBtu = kilo-British thermal unit. NREL = National Renewable Energy Laboratory. sqft = square foot. SWH = solar water heater. yr = year.
Source: University of Florida project team

Life-Cycle Economics

A thorough understanding of the life-cycle costs of the CORE+ design and its various energy efficiency options (and related cost savings) will provide homeowners with better knowledge of the actual costs over time. The project team's design intent is to develop these options such that the final CORE+ module remains affordable.

Under the cost analysis, this study evaluated the initial construction costs, the simple payback period, and the life-cycle costs during a 60-year period. The initial construction cost refers to the costs associated with the building materials, building equipment, and labor in the model. The simple payback period refers to the time required to recover the project investment without considering the time value of money. It is often defined as the break-even point, that is, the year at which initial investment is offset by the benefits accumulated, which in this case was the energy-associated costs. The project's financial viability was assessed by comparing the payback period of different measures. The life-cycle costs were calculated by summing the net present value of life-cycle expenses associated with the loan, home maintenance, replacement cost, and utility bills.

Affordability

Disasters exacerbate the existing affordable housing problem through a combination of dislocation, physical loss of inventory, and local housing market short- and long-term impacts. The CORE+ module can help to enhance the resilience and sustainability of traditional manufactured and modular housing designs. This project suggests manufactured housing provides an affordable homeownership alternative compared with increasingly expensive single-family homes (Shimberg, 2020). In the first half of 2021, the median sale price for a single-family home was nearly three times as much as the price of a manufactured housing parcel ($324,900 versus $112,500).

Manufactured housing also provides a form of naturally occurring affordable housing for renters. Although small in number, the manufactured housing rental supply provides units that are far more affordable than other market-rate alternatives. The median gross rent for a manufactured housing unit in Florida is $800 per month compared with $1,400 for a single-family home and $1,070–$1,380 for multifamily units (Census Bureau, 2019). In fact, the $800 median manufactured housing rent is lower than the $971 median gross rent in Florida Housing Finance Corporation's multifamily portfolio, the largest source of subsidized rental housing in the state.

Exhibit 7

Section Drawing Through Core Module

Source: University of Florida project team

The development of CORE+ modules will directly address a key problem for Florida's lower-income homeowners—the high cost of energy consumption and its contribution to the housing cost burden. Housing is usually considered affordable if no more than 30 percent of household income is devoted to housing costs, including utility consumption. In Florida, 767,000 homeowners with annual incomes less than $35,000 pay more than this percentage for their housing, including 432,000 owners with incomes less than $20,000 (Census Bureau, 2021). For low-income families, the cost of utilities may amount to as much as one-third of their monthly rent or mortgage payment. Although low-income homeowners typically pay slightly less for utilities than other homeowners, they still pay more than they can afford on average. Florida homes, on average, spend $200 a month on utilities. Owners whose annual income is less than $20,000 pay $150 (Census Bureau, 2019). About one-quarter of the median cost of housing goes toward utilities, which is higher than other essential costs like property taxes and insurance. The CORE+ project and the resulting CORE+ model were developed to provide post-disaster housing to those least able to afford it. Further, the CORE+ module is designed to mitigate future risks from energy costs, as well as from storms. Further development of the CORE+ module to the prototype level will further investigate these issues.

Design Workshop and Refining the CORE+: North Port St. Joe

Hurricane Michael, which made landfall in 2019 in the Florida panhandle as an unprecedented category 5 hurricane, caused catastrophic wind and storm surge damage to the coastal city of Port St. Joe. Some of the effects in Port St. Joe include infrastructure loss, road and building destruction, erosion along the St. Joseph's peninsula, and power outages. The neighborhood of North Port St. Joe was spared substantial flooding from the storm, but wind damage and the legacy of poor construction and poverty meant that damage was significant, and recovery has been very slow.

In 2021, the North Port St. Joe Project Area Coalition presented a community workshop in North Port St. Joe that featured the CORE+ module to address pervasive substandard housing. Led by the University of Florida's Florida Resilient Cities program partnering with the Florida A&M University Architecture program and faculty from across the University of Florida's College of Design, Construction and Planning, the workshop leveraged ongoing university research and outreach efforts. The Jessie Ball Dupont Fund, the U.S. Economic Development Administration, and HUD sponsored the workshop, which partnered with additional expert and community stakeholders to provide innovative housing, landscape, and public policy solutions to residents of North Port St. Joe.

The workshop engaged community stakeholders, elected officials, policymakers, and funders through a series of interactive events and covered all described components of the problems in Port St. Joe and featured four themes, including:

- Housing policy and land tenure.
- Stormwater and landscape.
- Mixed-use development on Martin Luther King Boulevard.
- Modular housing (CORE+).

The modular housing team had the main goal to identify the modular housing design options that can meet select community members' needs for housing that is rapidly constructed, affordable, and energy efficient. The team's objective was to work with community volunteers on specific sites for housing and assessment concerns and opportunities for the deployment of new single-family modular homes. The team worked with the CORE+ model to design, specify, and price the home in six sites that community residents offered (exhibit 8). The team worked with clients to fit homes to space needs, site conditions, and budgets. The design was coordinated with the city of Port St. Joe to ensure that homes meet all local zoning and building codes.

Exhibit 8

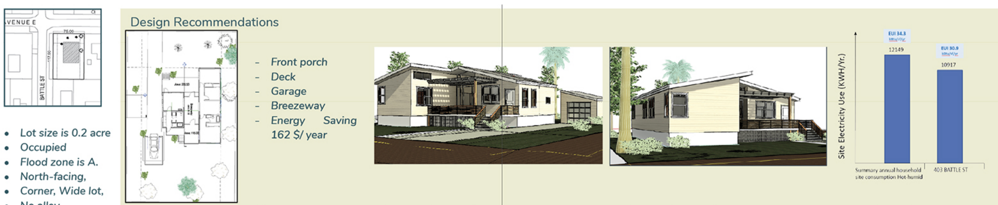
Six Site Locations Proposed by Community Members in North Port St. Joe, Where the Team Tested the CORE+ Model

Source: University of Florida project team

The design development started with conversations with community members as potential clients to understand the needs of the community. Community members suggested six potential sites, and the design team evaluated the flood zone and other site conditions. Then, the design team developed the specific plans shaped by the CORE+ project for each of the six sites, and the team discussed various building options with community members. The design team created a profile that included clients' and existing site requirements, a comparison of the suggested modular home's energy use to that of a typical single-family home, a quantity takeoff for the suggested modular home, and a three-dimensional model of the specific design for each of the six sites (exhibit 8). The team received valuable feedback from active community members. Some of the design recommendations that the team offered to help with the design to best fit a user includes adding a front porch, deck, carport, addition of another SPACE unit, and breezeways between the units that can also be used as extra space and that can be covered. Each site with a different orientation and specification and owner requirement was modeled, and the cost and energy consumption were estimated.

Exhibit 9

Site Number 1 Design Profile that the Team Created



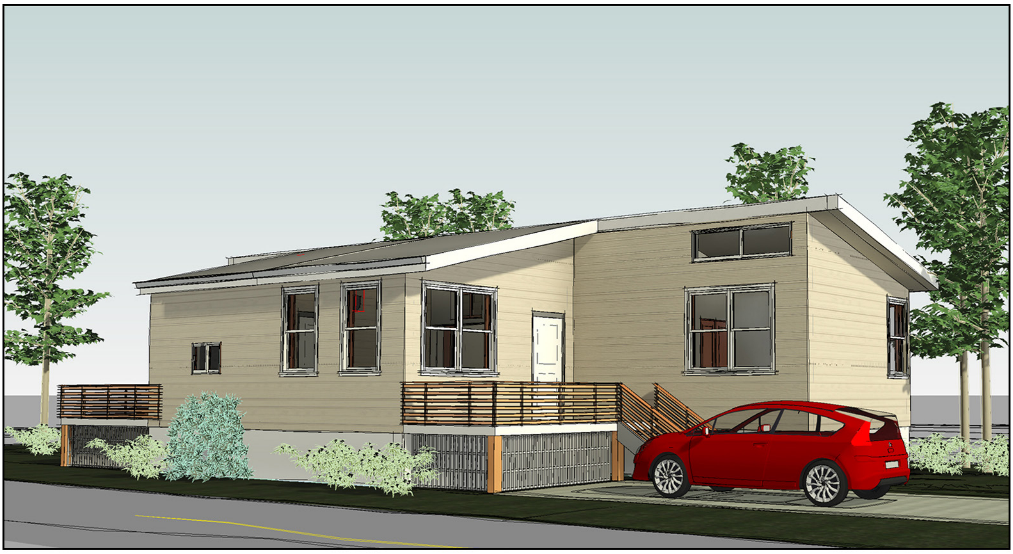
		HUD Units	Cost of Units	Deck Area, SF	Deck Cost ($30 per SF)	Breezway Area, SF	Breezway Cost ($45 per SF)	One-car Garage Dettached $20,000	Covered porch area, SF	Covered porch cost ($45 per SF)	Deck Skirting Area, SF	Deck Skirting cost ($12 per SF)	Area of Driveway/ Walkway, SF	Driveway/ Walkway cost ($6.20 per SF)	Parging and paint CMU, SF	Parging and paint cost ($3.25 Per SF)	Larger Core option	Roof area	Extra cost for Galvanized roof per SF ($5)	Total Cost
Zone A	403 Battle St	CORE+	$129,000	350.53	$10,516	195	$8,775	$20,000	180	$8,100	168	$2,016	700	$4,340	377	$1,225		1340		$183,972

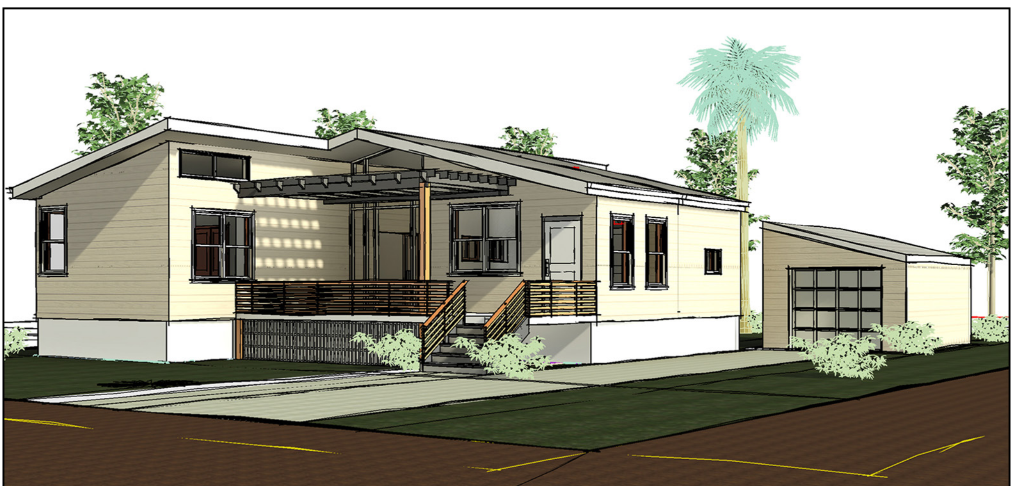
CMU = concrete masonry unit. SF = square feet.
Source: University of Florida project team

The modular housing design team met with the community members and shared their ideas on the development of the CORE+ design in North Port St. Joe. In conclusion, the major outcome of the workshop is about actively collaborating with the community and listening to and receiving feedback regarding the design process. The design team made its contribution to the workshop by presenting the existing options for modular housing and listening to and applying community suggestions and specific needs based on the community preferences and the site requirement. The modular housing team considered the long-term view of the design as a characteristic of a resilient community (exhibit 10).

Exhibit 10

CORE+ Unit with Added Breezeways Between Units and Other Design Modifications After Years of Unit Installation and Adaption of CORE+ Design Capacity, Resulting from Community Workshop





Source: University of Florida project team

Conclusion

The University of Florida's CORE+ project started with partnerships, including the modular home manufacturing industry and other industry and community stakeholders. From the diversity of external expertise and interest, the team developed a project that is innovative, affordable, and buildable. The project tackles the three key challenges facing the U.S. housing industry—rapid deployment following a disaster, energy efficiency and performance, and affordability. The design used industry standard construction where effective, but also brings substantial efficiency to the construction process through mass customization techniques.

The challenge that this project takes on—the rapid delivery of efficient, resilient, and affordable housing in vulnerable locations—is a problem facing many regions of the United States. Following countless hurricanes, including the unfolding humanitarian disaster caused by Hurricane Ian, housing is of utmost importance to communities seeking to stabilize and rebuild. The CORE+ module is a climate-responsive design that makes use of passive energy design principles to create a hyper-energy-efficient building that can be outfitted with cutting-edge heating, ventilation, air-conditioning, and electrical infrastructure, as well as renewable energy sources, like solar power. The CORE+ project prioritized resiliency in two ways. First, the CORE+ unit is structurally the most durable of the three. When it comes to wind loading, passive heating and cooling strategies, and systems to mitigate extended power failures, the CORE+ unit design not only meets but exceeds all Florida building code requirements. The module also includes a cost-effective piling system that makes elevating homes to varying levels simple. Second, the AMH is designed with adaptability and resilience in mind from the start. It provides flexibility for the consumer to adapt the housing units based on their dwelling and lifestyle during a preferred period. Third, the AMH design overcame the cost barrier by factoring in energy usage information to the life-cycle cost. The results of this study show that this method may be used to enhance the sustainability and resilience of conventional and modular house design.

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