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Using a Micro-House as a Starting Point to Create an Affordable House

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INTRODUCTION

The U.S. Department of Energy Solar Decathlon is a competition in which collegiate teams design, build, and operate solar-powered houses that are intended to be affordable, cost-effective, energy-efficient, and attractive. Since its inception in 2002[1], this competition is intended to educate students and the public about the economic and environmental benefits of energy efficient, solar powered homes. The competition also serves as a venue to demonstrate the comfort and affordability of homes that combine energy-efficiency with solar energy systems.

One of the initiating reasons for the development of the Solar Decathlon was to "demonstrate market-ready technologies that can meet the energy requirements of our activities by tapping into the sun's power." [1] Unfortunately, due to the scoring rubrics for the competition, the affordability aspect of the competition was often given only superficial consideration. In 2015 the houses in the Solar Decathlon competition averaged $287,000 (for houses that were less than 1000 square feet) with the winning house costing $290,776 ($291 per square foot). The most affordable house in the 2015 solar decathlon competition was a 680 square foot house that cost $176 per square foot.[2]

The 2013 Norwich University Solar Decathlon entry, the ΔT90 house was the most economical entry in the history of the Solar Decathlon Competition, placing first in the 2013 Affordability Contest, with an estimated cost of $168,385 for a 994 square foot house ($170 per square foot), while scoring 100% for the energy balance portion of the competition.[3] The Norwich University ΔT90 house was named for the 90ºF difference between inside and outside temperatures that residents of Vermont experience each winter.

While this was the most economical solar decathlon house in the history of the competition, based upon findings of the "2015 Housing Needs Assessment" of the Vermont's Housing and Finance Agency, at $170 per square foot, the ΔT90 House at house is beyond the reach of the majority of new households[4]. Based upon average construction costs from national survey and U.S. Bureau of Census figures, the costs for the ΔT90 House must be reduced by over one-third in order for the house to be affordable[5].

In order to reduce the cost of the construction, teams of students from the University's Architecture, Engineering, and Construction Management programs are using lessons from the Department of Energy's Solar Decathlon Competition to develop a regionally derived, solar powered, affordable housing model. Student teams are working to design a series of micro-houses (approximately 300-400 SF each) that can stand alone or be combined with other modules to create a larger, integrated structure. This process is similar to how families in New England would first construct what is known as a half-Cape, and as the family grew, the house would be enlarged into a Full Cape, and then enlarged further with dormers and shed additions. One of the basic principles used in the project was that the entire house does not need to be constructed at once: additional room modules could be added to the house over time.

Norwich University's "Starter" Micro-house Design Philosophy

While the Solar Decathlon Competition is about solar technology, its focus on affordability also speaks to practical marketability of the completed structure. An overwhelming number of Vermonter's cannot afford a house that meets the target construction costs of any but one of the of the 2015 Solar Decathlon's houses, regardless of energy costs.

The Norwich University "Starter" Micro-House was designed to be low cost from the foundation up. The house was not specifically designed for the Solar Decathlon competition, but was designed for use in Vermont and other areas with high housing costs.

The keys to the design approach were:

(1) Perfect is the enemy of the good
(2) Use Less. In construction, space utilization, and operation
(3) Simplify

Figure 1 shows the West Elevation view of the Norwich University "Starter" Micro-House, which contains basic amenities such as kitchen and bathroom, while being large enough to meet the needs of two people. The "Starter" Micro-House is just over 300 sq. ft. The house has an attached porch on the West side of the house, and a relatively large glazed area. This "Starter" Micro-House was designed to serve as the core of a larger house. The outside walls of the "Starter" Micro-House are designed so that additional rooms can be readily attached. These subsequent additions can be designed to be more flexible and less expensive to manufacture than the core, and can vary depending on the needs of the occupants.

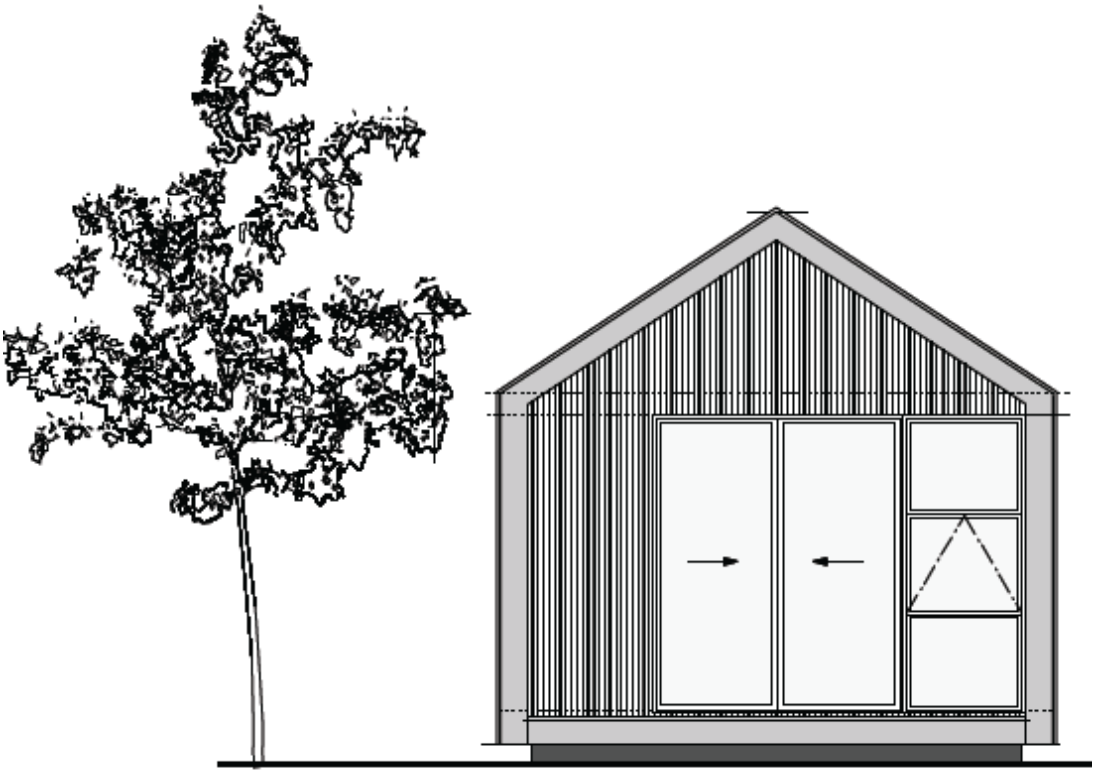

Figure 1: "Starter" Micro-House: West Elevation

This project will serve to demonstrate how houses could be constructed in stages from micro-houses, with the micro-houses being combined, over time, to create a larger house. The design teams will explore non-conventional structural framing for the micro-houses and optimize the mechanical and electrical integration process by designing standardized, modular systems. Student teams are constructing the first core micro-house module during 2015-2016 school year. Lessons from the construction of the first micro-house will be incorporated into the construction of subsequent versions.

The original Norwich University ΔT90 house was designed to not only meet climactic demands of the Northeast, and also was intended to be attuned to the financial demands of the population that lives there. The Norwich University ΔT90 house was designed to be easy to maintain, affordable, did not require a computer to operate and did not have large monthly utility costs. The house maximized comfort, efficiency, and spaciousness through two bedrooms, an office space, and an open living space for lounging, cooking, and gathering.

While some aspects of the overall design fulfilled these economic goals, other aspects proved to be cost prohibitive. Based upon the cost estimates prepared for the Solar Decathlon Competition by Faithful+Gould[6], the HVAC/Mechanical/Plumbing Systems/Electrical systems of the Norwich University ΔT90 house were essentially cost effective, while the structural framing, insulation, and windows were less economical.

Research Question

Given the excellent performance of the ΔT90 house at the 2013 Solar Decathlon, is it feasible to maintain the original concepts and reduce the production cost? This question will be evaluated by examining the various systems in the "Starter" Micro-House by applying different materials to preserve the designed efficiency in comparison to the reduction of the cost.

Based upon the lessons from the Solar Decathlon competition, the following areas were considered for potential cost reductions for the "Starter" Micro-House:

(1) Wall Framing System
(2) Floor Framing System
(3) Roof System
(4) Shipping and Site Construction Considerations

Wall Framing System

The "Starter" Micro-House is the third structure designed and constructed by Norwich University students. The first structure experimented with 2x12 stud construction and spray foam insulation. Spray foam was also applied to the roof and floor systems. This method created a high level of VOC's and the insulation was difficult to install and maintain. The 2x12's also were the source of thermal bridging, reducing the effectiveness of the thick insulation. The ΔT90 house used 2x6 double stud wall framing, in order to take advantage of its three key

benefits: less material waste, simpler and quicker construction processes, and improved insulation performance. However, the relative thickness of the wall, floor, and roof insulation was unbalanced. The building had more wall insulation and floor insulation than was optimum.

As shown in Figure 2, in order to minimize construction waste, the "Starter" Micro-House plan dimensions were optimized so that the main house was 24 feet long, rather than an odd dimension. This simplified construction and eliminated waste material. For example, the floor required exactly 14 sheets of floor sheathing.

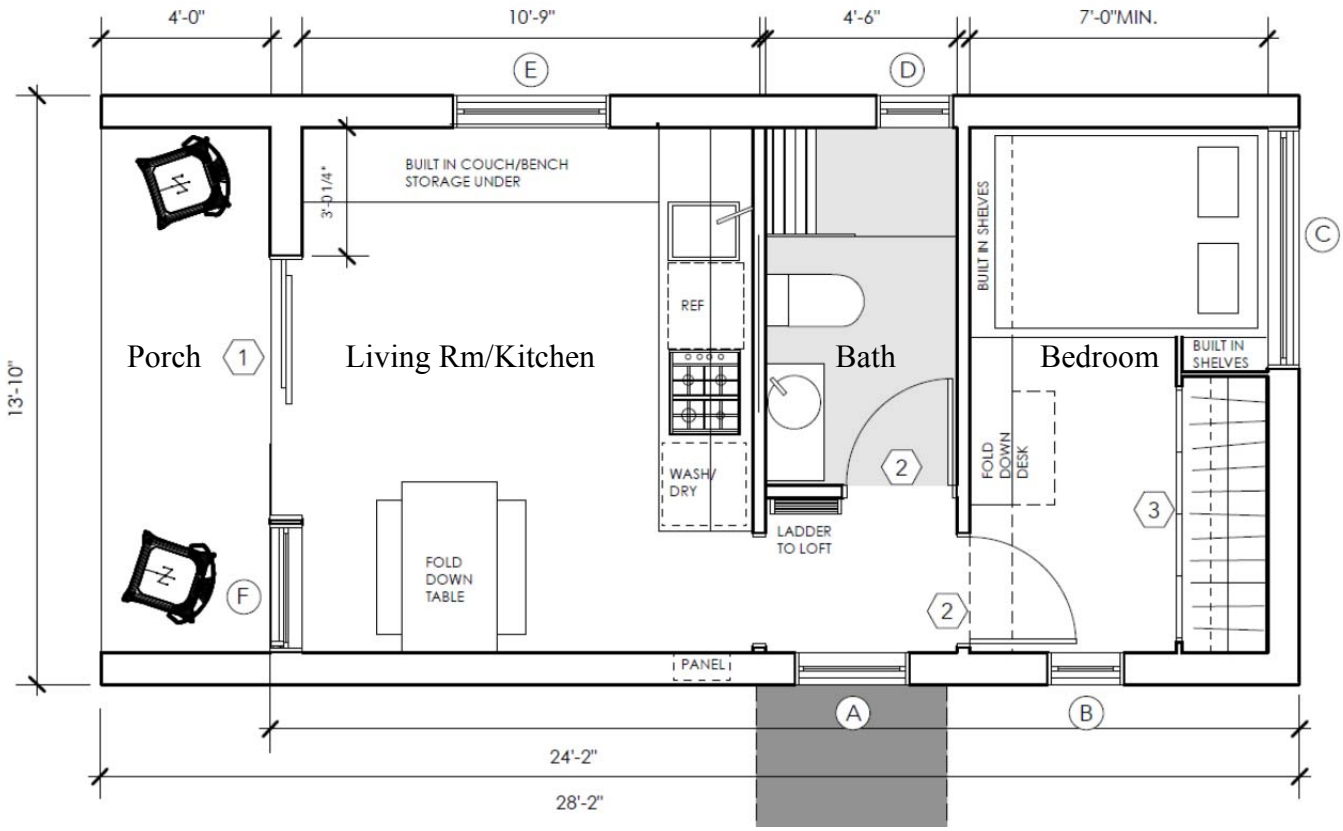

Figure 2: Floor Plan – "Starter" Micro-House

In the "Starter" Micro-House, the wall framing system uses APA's Advanced Framing[7] system, shown in Figure 3, with 2x4 studs at 24 inch spacing, with the roof joists, floor joists, and wall studs are vertically in line at 24 inches on center, which creates a simple, yet direct load path to distribute the roof live loads and dead loads uniformly to the building foundation. The walls were constructed with internal cellulose insulation and external rigid foam insulation, for a total wall thickness of 6.5 inches, plus siding. The exterior rigid insulation eliminates thermal bridging in the wall envelope.

In contrast, the exterior walls of the ΔT90 house were over 14 inches thick. On the 300 square foot "Starter Micro-House, the use of the thinner exterior walls results in an increase in usable interior space of over 45 square feet compared to using the thicker walls. The elimination of thermal bridging offsets most of the effects of using thinner wall insulation. In addition, the APA advanced framing system uses about 10%-15% less framing material than would be used for conventional framing systems.

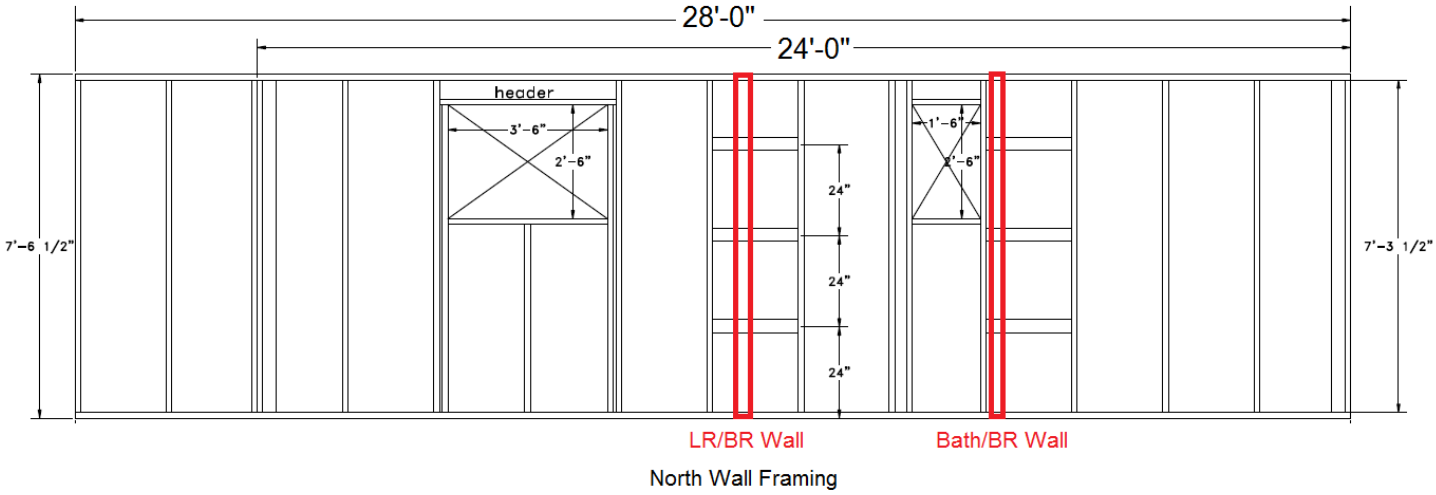

Figure 3: "Starter" Micro-House Wall Framing

Floor Framing System

The ΔT90 floor was constructed with 2x12 framing members, with 1-1/8 inch Tongue & Groove OSB on the upper surface, and ½ inch thick pressure treated plywood on the lower surface. The floor was insulated with dense pack cellulose insulation between the 2x12 floor joists. The 2x12's were not selected based upon strength requirements, but were selected to provide the desired thickness of dense pack insulation. In addition, ½ inch plywood was installed on the lower surface to ease handing at the Solar Decathlon Competition site, where the building would be installed, then later shipped to a final destination.

In the "Starter" Micro-House design, the 2x12's were replaced with 2x10's or 9.5 inch tall "I" joists, based upon floor load vs. span considerations, and the dense pack insulation replaced with fiberglass insulation. The Fiberglass batt insulation provides the floor with insulation that exceeds all State of Vermont and Energy Star recommendations.

Roof Framing System

The ΔT90 roof was constructed with 2x12 framing members, ¾ inch thick OSB on the upper surface, topped with 2 inch thick rigid foam insulation and a waterproof membrane.

The micro-house roof system was constructed with 2x6's on 24 inch spacing, with the cavities filled with foam insulation, and a continuous exterior layer of 2 inch thick rigid foam insulation. The continuous exterior insulation eliminates the thermal bridging that was present in the roof system of the ΔT90 house. Due to the elimination of thermal bridging, and the small size of the house, the heating requirements for the house are very small (less than 1000 watts).

Table 1 shows a comparison between the structural components of the ΔT90 house and the "Starter" Micro-House. Note that in the micro-house the wall system and roof system relative thicknesses are more balanced compared to those of the ΔT90 House.

Table 1: Comparison between ΔT90 House and "Starter" Micro-House

	ΔT90 House	"Starter" Micro-House
Wall System Thickness	14.5" + siding	6.5" + siding
Floor System Thickness	12.875"	10.5"
Roof System Thickness	14"	8"

Shipping and Site Construction Considerations

In keeping with the concept of mass production of the structure, the micro-house design used modular construction, with the dimensions of the structure limited by shipping constraints. In order to minimize shipping costs, the micro-house was designed using only one module, limited to 14 feet width. The living areas have vaulted ceilings and there is a small loft over the bathroom/hallway area of the house. In order to meet interstate shipping height requirements, while still providing appropriate interior ceiling heights, the structure designed needed to account for the equipment that would be used for shipping. Using standard modular home transport trailers, with a deck height of 30 inches, the maximum module height is approximately 11'-0". Using Double Drop Lowboy trailers, with a 18 inch deck height, the maximum module height is approximately 12'-5". This allowed the 6:12 pitched roof to be constructed integrally with the module, rather than requiring that the roof be installed on the house at the building site. Elimination of the requirement for on-site roof construction reduces the construction costs, but may increase transportation costs depending on locally available transport trailers. Originally, we had designed the micro-house using a trailer with a 12" deck, but found that the local businesses only had the trailers with 18" deck height. This required a revision in the building cross-sections as shown in Figure 4.

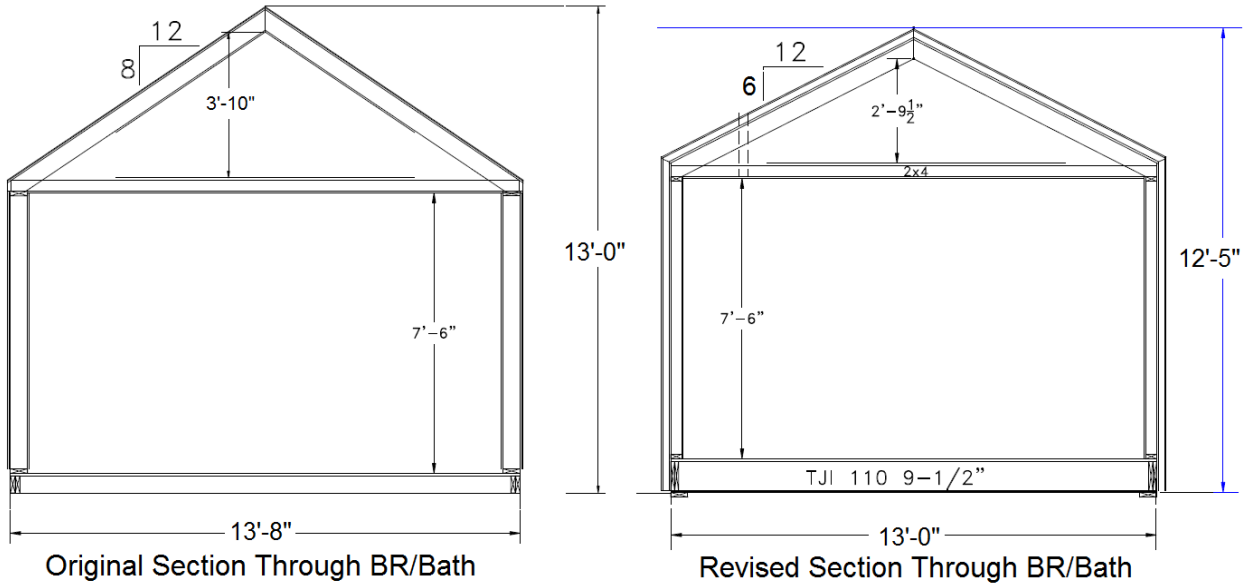

Figure 4: Section Through BR/Bath of "Starter" Micro-House

Foundation Options

The "Starter" Micro-House can be installed on concrete foundation/crawlspace as shown in Figure 5. Alternatively, the micro-house can use slab-on-grade, screw-piles or mobile-home piers.

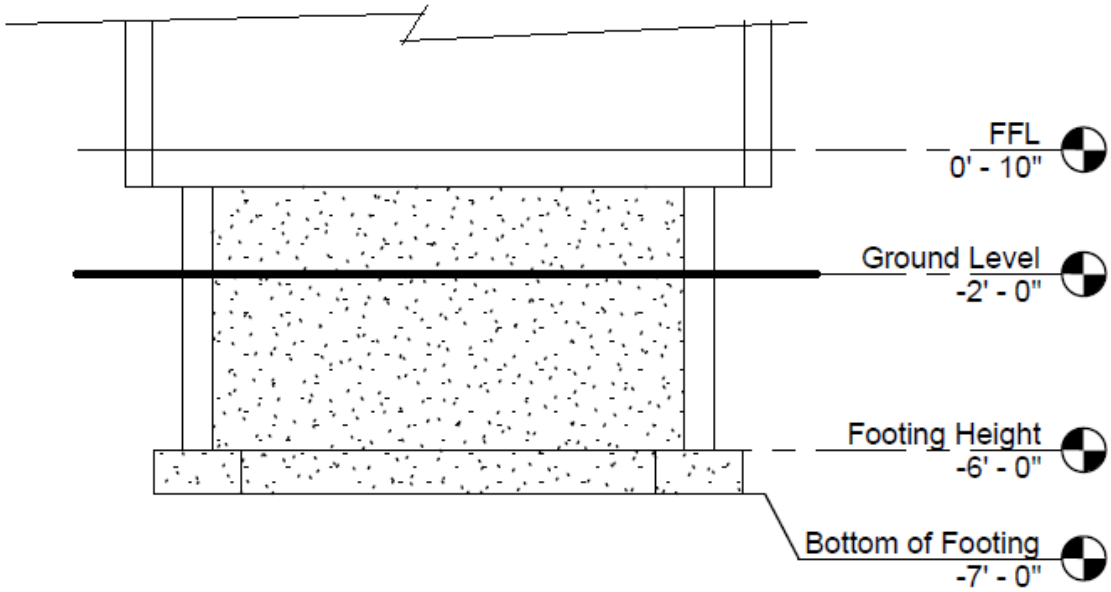

Figure 5: Crawlspace Foundation Option

The crawlspace foundation shown in Figure 5 is typical for areas like Vermont that have significant frost penetration into the ground.

Expected Results

In examining the different systems incorporated in the construction of the "Starter" Micro-House compared to the ΔT90 house, it is expected that the cost will have been reduced and the energy efficiency maintained. This will provide the students in the various areas the effects of applying value engineering. They will gain further knowledge as they move forward in constructing the micro-houses. The results of the research present to the students the necessity of examining alternative construction practices.

Conclusion

This paper shows how teams of students from Norwich University's Architecture, Engineering, and Construction Management programs are using lessons from the Solar Decathlon Competition to develop a regionally derived, solar powered, affordable housing model. Toward these ends, the student teams are working to design a series of modular micro-houses (approximately 300-400 square feet each) that can stand alone or be combined to create a larger, cohesive structure (similar to how a New England 1/2 Cape was first constructed, then as the family grew, the house was enlarged into a 3/4 Cape or a Full Cape, etc.) Additional room modules could be added to the house over time. The students have discovered an alternative method of assembling the structure at a lower cost and keeping the required efficiency required for homes in Vermont. The reduction in cost and application of different materials will continue to evolve as the students further examine the micro houses and explore alternative materials and construction techniques.

The core micro-house module is designed to contain basic amenities, such as kitchen and bathrooms. Two walls of the core module are designed so that additional room modules can be readily attached. These "add-in" modules can be designed to be more flexible and less expensive to manufacture than the core module, and can vary depending on the needs of the occupant. This project will serve to demonstrate how houses could be constructed in stages from micro-houses, with the micro-houses being combined, over time, to create a larger house. The design teams will explore non-conventional structural framing for the micro-houses and optimize the mechanical and electrical integration process by designing standardized, modular systems.

The student teams are constructing the first core micro-house module during the 2015-2016 school year. Lessons from the construction of the first module will be incorporated into the construction of subsequent modules. The student built structure involves several disciplines and is related to courses for direct application. The research has involved value engineering, reassessment of energy efficiency, new designs are being produced, systems and structural analysis and estimating and scheduling of the project.

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