SOLAR LIVING HOUSE

U.S. Department of Energy Solar Decathlon 2015

FINAL TECHNICAL REPORT

DOE Award No: DE-EE0006557.0000

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Prepared by

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Participating Team Member Institutions

University of Florida + Santa Fe College + National University of Singapore

Prepared for

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Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

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  - Department of Interior Design
  - Program in Sustainability and the Built Environment
- University of Florida College of Journalism and Communications
- University of Florida Herbert Wertheim College of Engineering
  - Department of Mechanical & Aerospace Engineering
  - Department of Electrical and Computer Engineering
- National University of Singapore
- Santa Fe College
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- AIAS UF Chapter
- Bosch Community Fund
- Bosch (BSH Home Appliances Corporation)
- Bradley Walters Architect
- Breeze Navari
- Gouvis Engineering
- Graybar
- It's Your Green Energy
- Lee Smith
- Linda Sartain
- Magnum Wood
- Panda Express
- Power Design Incorporated
- Resource Furniture
- SoMa Art Media Hub
- Terrill Parham
- Yogurtology of Florida

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EXECUTIVE SUMMARY

The Solar Living House is a high-performance solar-powered dwelling designed by a team of faculty and students from the University of Florida, in collaboration with Santa Fe College, the National University of Singapore, and Alachua Habitat for Humanity. The project was designed in accordance with the Solar Decathlon 2015, a research, design, education, and outreach program developed by the U.S. Department of Energy (DOE). The Solar Living House is fundamentally a house for *living*, centered on people and the activities of daily life while quietly introducing advanced design, construction, and engineering technologies. The 993 square-foot two-bedroom one-bath home was designed to embrace and frame an exterior courtyard space. This courtyard acts as an extension of the interior living spaces, maximizing the spatial potentials of a modest building footprint and introducing natural light into the primary living spaces of the house.

Research Outcomes

The Solar Living House advances work on high-performance buildings through three principal technological innovations: wet/dry modular construction, a building automation system, and solar dehumidification systems.

Wet / Dry Modular Construction

The house is designed as a series of five modules, including one that is designated as the "wet core." The wet core consolidates the mechanical systems and bathroom into a single module to reduce plumbing runs, efficiency losses, and on-site construction time. The other four modules are designed to eliminate interior load bearing walls to allow for maximum flexibility in the reconfiguring of the space over time. The modules are designed to meet the structural challenges of both Florida's hurricanes and California's earthquakes.

Building Automation System

The house is equipped with an integrated building automation system, allowing the houses environmental systems, lights, security systems, and smoke detectors to be programmed, monitored, and controlled through any mobile or computing device. These systems allow for more precise calibrations of temperature/humidity/lighting to correspond with user needs and preferences, minimizing energy losses with economical night- or day-time setbacks.

Solar Dehumidification System

The most significant technological innovation in the Solar Living House is the solar thermal dehumidification system. This system generates hot water through two rooftop-mounted evacuated tube solar thermal collectors. The hot water is used to continually dry a regenerative solid desiccant material, typically white silica gel. The solid desiccant is used to adsorb moisture and humidity from the air without additional mechanical cooling. This strategy allows humidity to be modulated independently of air temperature, providing greater thermal comfort and reducing the opportunity for the growth of mold spores within the house while also reducing the overall energy consumption of the HVAC system.

Economic Feasibility

The team set aggressive goals for affordability, targeting a construction cost of $138,710. An independent professional cost estimator determined the overall project costs, as designed, would be $333,799, or $336.15 per square foot of finished floor area. This is more than 2.4 times the target construction cost. By comparison, the average construction cost for a home in the United States in 2015 was $289,415, or $103.29 per square foot of finished floor area.

Following work on the Solar Living House, team leaders incorporated many of its objectives into a net-zero energy home on a site in Gainesville, Florida. This site-built home avoided many of the constraints and complications of modular construction necessitated by the Solar Decathlon, allowing it to be built for a much more modest budget. This two-bedroom two bath 1,800 square foot home was constructed for $135.39 per square foot, including active photovoltaic solar systems, careful attention to continuous air barriers, increased insulation levels, and permanent site constructions. This project suggest that high-performance buildings can be realized for more modest budgets.

Public Benefits

Work on the Solar Living House and Solar Decathlon 2015 offered our student team unparalleled learning opportunities. Because of the duration of the project, a number of students participated at different points in their education, from first year undergraduates all the way through to advanced graduate students. The opportunity for collaboration with students and faculty from the National University of Singapore was also extraordinary, allowing for a sharing of technical knowledge and cultural exchange.

The wider public has benefited from this work as its findings have been shared through public presentations and publications. It serves as a useful stepping stone along the path towards affordable, high-performance buildings.

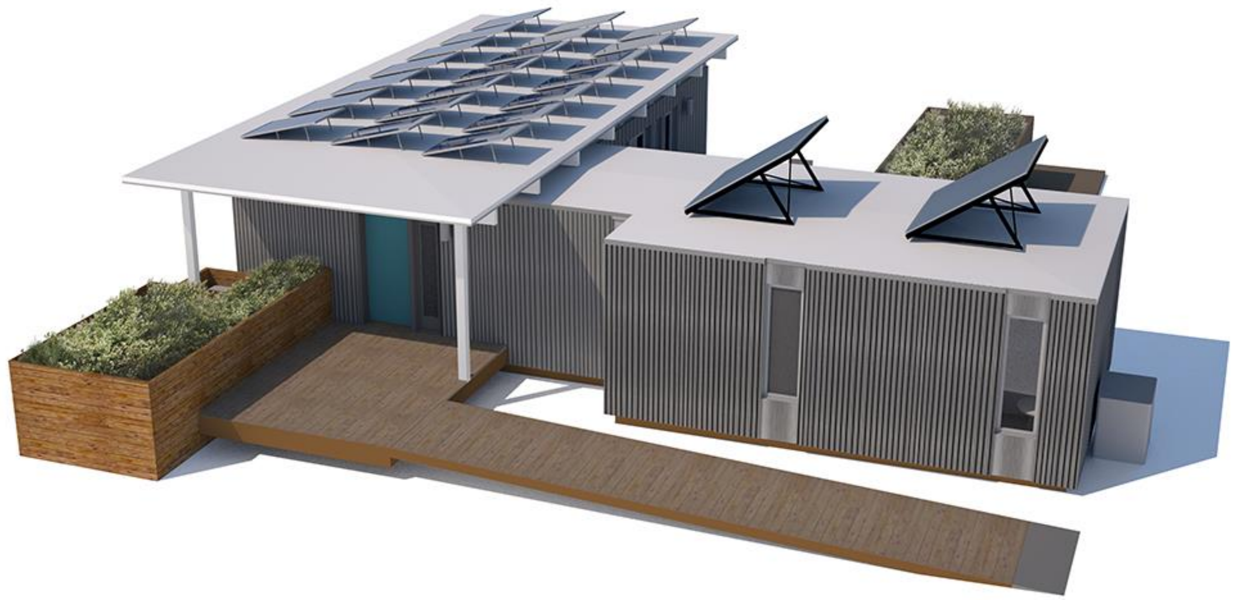

Figure 1. Solar Living House. Aerial View (front).

INTRODUCTION

The Solar Living House is a modular single-family home designed by a team of faculty and students from the University of Florida, in collaboration with Santa Fe College, the National University of Singapore, and Alachua Habitat for Humanity.

The Solar Living House is a house for *living*. It centers on people and the activities of daily life while quietly introducing advanced design, construction, and engineering technologies. The 993 square-foot two-bedroom one-bath home was designed to embrace and frame an exterior courtyard space. This courtyard acts as an extension of the interior living spaces, maximizing the spatial potentials of a modest building footprint and introducing natural light into the primary living spaces of the house. Innovative solar thermal systems control humidity, increase comfort, improve air quality and reduce energy use.

The project was designed in accordance with the Solar Decathlon 2015, a research, design, education, and outreach program developed by the U.S. Department of Energy (DOE). Organized and administered by the Office of Energy Efficiency and Renewable Energy (EERE), the program promotes the development and implementation of solar energy systems in residential construction.

The explicit and stated purposes of the Solar Decathlon are described by the U.S. Department of Energy as follows:

> *One of the U.S. Department of Energy's most successful outreach efforts, the Solar Decathlon helps accelerate the adoption of energy-efficient products and design by:*
>
> - *Educating students and the public about the money-saving opportunities and environmental benefits presented by clean energy products and design solutions*
> - *Demonstrating to the public the comfort and affordability of homes that combine energy-efficient construction and appliances with off-the-shelf renewable-energy systems*
> - *Providing participating students with unique training that prepares them for the clean energy workforce.*[1]

As of July 2016, the DOE has identified the following impacts and benefits resulting from the Solar Decathlon program:

> *Since 2002, the U.S. Department of Energy Solar Decathlon has:*
>
> - *Involved 130 collegiate teams, which pursued a multidisciplinary approach to study the requirements for designing and building energy-efficient, solar-powered houses*

[1] U.S. Department of Energy, "About Solar Decathlon," http://www.solardecathlon.gov/about.html.

- *Established a worldwide reputation as a successful educational program and workforce development opportunity for thousands of students*
- *Positively impacted nearly 20,000 collegiate participants*
- *Expanded to Europe, China, Latin America, and the Middle East to involve an additional 94 teams and nearly 12,500 participants through Solar Decathlon Europe 2010 (Madrid, Spain), Solar Decathlon Europe 2012 (Madrid, Spain), Solar Decathlon China 2013 (Datong), Solar Decathlon Europe 2014 (Versailles, France), and Solar Decathlon Latin America and Caribbean 2015 (Santiago de Cali, Colombia)*
- *Educated the public about the benefits, affordability, and availability of clean energy solutions by generating widespread media coverage and harnessing digital tools to reach millions of people.* [2]

Origins of the Solar Decathlon

Because the organizers of the Solar Decathlon were interested in addressing the complexities of complete buildings, addressing many different issues, they looked for evaluative models that allowed for many different metrics to be considered simultaneously, rather than allowing a single issue to carry undue weight. They found just such a strategy in ancient and contemporary athletic contests.

The concept of a competition consisting of multiple contests is rooted in athletic competitions that aim to identify and celebrate the "best all-around" athlete. The Greek pentathlon, introduced in Olympia in 708 BCE, was one of the earliest examples, where athletes competed in events intended to evaluate both speed and strength. The ancient pentathlon consisted of five contests: a long jump, discus throw, javelin throw, a sprint, and ended with a wrestling match.[3]

When the modern Olympics began to take form in the late nineteenth and early twentieth century, the multi-competition event was revived. In preparation for the 1912 Olympic Games in Stockholm, Sweden, organizers planned the first ten-event contest, which they named the "decathlon." As recounted by Dr. Frank "Zeke" Zarnowski, decathlon historian:

> *The word decathlon (deka = ten, athlos = contest) was first used in Scandinavia (Danish tikamp) and (Swedish tiokamp) as both nations offered "decathlons" in the early years of the 20th century with different events, order and tables. In 1911, using today's ten events and sequence, the Swedes conducted the first modern decathlon as a rehearsal for the Stockholm Olympic Games a year later. The decathlon has not changed since.*[4]

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[2] U.S. Department of Energy, "About Solar Decathlon," http://www.solardecathlon.gov/about.html.
[3] Zarnowski, Frank, "The Decathlon in Olympic History," DECA The Decathlon Association, http://decathlonusa.typepad.com/deca/history.html.
[4] Ibid.

Just as the Olympic Decathlon seeks to identify the "best all-around" athlete, the Solar Decathlon organizers sought to identify the best performing solar home. But just as is the case with athletic competitions, organizers realized that each competition event measures certain strengths/weaknesses and that it is only when seen in relation to one another that an overall assessment could be made.

Most discussions of "sustainability" acknowledge the complexity of assessment. Many reference what is known as the "triple bottom line," a term coined by John Elkington in his 1997 book "Cannibals with Forks: The Triple Bottom Line of 21st Century Business" (Oxford: Capstone Publishing Ltd, 1997). The term grew out of an earlier work on collective business concepts authored by Freer Spreckley in 1981. Spreckley was amongst the first to expand traditional accounting and valuation methods to include social and environmental considerations in addition to financial performance. [5]

In recent discussions of sustainability, the "triple bottom line" has been used to refer more explicitly to "people, planets, and profit" as a way of incorporating a more diverse set of issues in any design or decision-making process. These issues have been envisioned by William McDonough as a fractal structure, organized in terms of "ecology, equity, and economy."

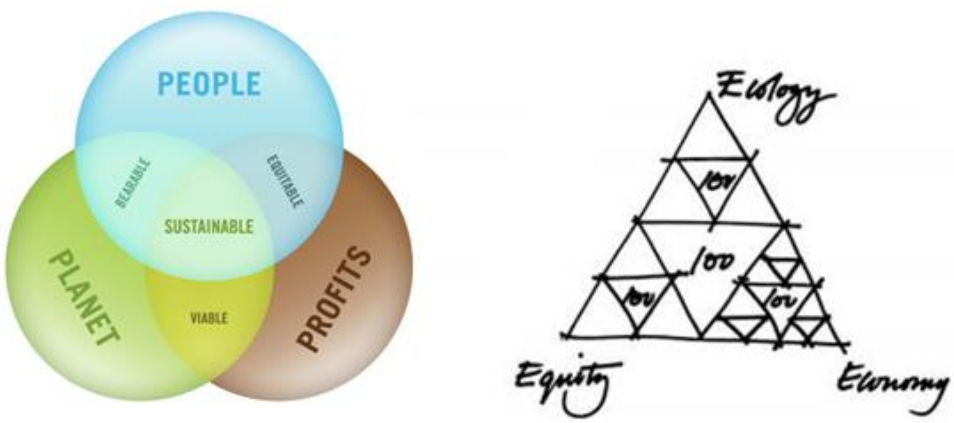

Figure 2. Visualizing the Triple Bottom Line [6]

While the specific terminology and graphic structures vary, the basic premise remains the same: to work sustainably requires us to consider diverse issues, and to find ways to balance between them.

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[5] Spreckley, Freer, "WORKAID Social Audit: A Management Tool for Co-operative Working," Figure 1, Leeds UK: Beechwood College, 1981, 12.

[6] Garcia, Aitana Leret, "DP4.- Cradle to Cradle: Sustainable development through fractal geometry," Escuela de Organización Industrial (EOI), 1 January 2012, http://www.eoi.es/blogs/aitanaleret/2012/01/01/dp4-cradle-to-cradle-sustainable-development-through-fractal-geometry/.

Solar Decathlon Contests

One way of balancing many competing demands is to identify as many of these demands as possible and provide positive rewards for addressing each of them successfully. To do this, the Solar Decathlon competition was created around ten different contests, each focused on particular aspects of sustainability, design, engineering, and public outreach. Winners are determined in each of the contests, and the scores from all contests are combined to determine an overall winner.

Since the Solar Decathlon's inception in 2002, the particular contests have varied, as follows:

2002	2005	2007	2009	2011	2013	2015
Design & Livability	Architecture	Architecture	Architecture	Architecture	Architecture	Architecture
	Dwelling			Market Appeal	Market Appeal	Market Appeal
Presentation & Simulation	Documentation	Engineering	Engineering	Engineering	Engineering	Engineering
Graphics & Communication	Communications	Communications	Communications	Communications	Communications	Communications
-	-	Market Viability	Market Viability	Affordability	Affordability	Affordability
Comfort Zone	Comfort Zone	Comfort Zone	Comfort Zone	Comfort Zone	Comfort Zone	Comfort Zone
Refrigeration	Appliances	Appliances	Appliances	Appliances	Appliances	Appliances
Hot Water	Hot Water	Hot Water	Hot Water	Hot Water	Hot Water	Home Life
Lighting	Lighting	Lighting	Lighting	-	-	
Home Business	-	-	Home Entertainment	Home Entertainment	Home Entertainment	
Getting Around	Getting Around	Getting Around	-	-	-	Commuting
Energy Balance	Energy Balance	Energy Balance	Net Metering	Energy Balance	Energy Balance	Energy Balance

Figure 3. Solar Decathlon Contests, 2002-2015. Source: By Author.

Certain contests have persisted from year-to-year while others have been introduced, removed, consolidated, or expanded. Architecture ("Design and Livability" in 2002), Communications, Comfort Zone, Appliances, and Energy Balance ("Net Metering" in 2009) have been consistent in all competitions from 2002 through 2015. Market Appeal as a separate contest was introduced in 2011. Issues of affordability were addressed when the Market Viability contest was introduced in 2007 (renamed "Affordability" in 2011). In 2015, Hot Water, Lighting, and Home Entertainment were all consolidated to create the "Home Life" contest. Commuting, present in the first three competition years, was temporarily abandoned from 2009 through 2013, only to be re-introduced in 2015. The changing contests reflect changes in DOE priorities, political tendencies, design/engineering possibilities, sensor technologies, market trends, and demographics.

In the 2015 competition, there were five juried contests and five measured contests, and each contest was worth one hundred points. The contests were as follows:

Juried Contests:	Measured Contests:
Architecture	Comfort Zone
Market Appeal	Appliances
Engineering	Home Life
Communications	Commuting
Affordability	Energy Balance

Several of the contests had separate sub-contests or tasks that were individually measured and scored. In total, teams were eligible to earn as many as 1000 total points, including 500 total juried points and 500 total measured points, from 21 individually-scored contest elements.

Solar Decathlon 2015

The Solar Decathlon 2015 was the seventh iteration of this program conducted in the United States and organized by the Department of Energy. Prior competitions were held in 2002, 2005, 2007, 2009, 2011, and 2013. The first four events were held on the National Mall in Washington DC. In 2011, the event was held at the National Mall's West Potomac Park, on the banks of the Potomac River along the path between the Lincoln and Jefferson Memorials near the Martin Luther King Jr. National Monument. In 2013 and 2015, the event was held at the Orange County Great Park in Irvine, California.

In addition, the DOE collaborated with other groups to create the Solar Decathlon Europe (held in Madrid, Spain in 2010 and 2012 and in Versailles, France in 2014) and the Solar Decathlon China (held in Datong, China in 2013). The University of Florida led a team that competed in the inaugural Solar Decathlon Europe in 2010 and participated as a part of a team in the Solar Decathlon 2011. In addition, the National University of Singapore competed in the inaugural Solar Decathlon China held in 2013.

The first Solar Decathlon Latin America and Caribbean will be held in December 2015 on the campus of Universidad del Valle in Santiago de Cali, Colombia. Other upcoming events include the US Solar Decathlon, planned for Denver, Colorado in 2017, and the next Solar Decathlon China, also scheduled for 2017. Planning for the first Solar Decathlon Middle East is currently underway, with the competition planned for Dubai, United Arab Emirates in 2018.

Selection of Participating Teams

On 1 November 2013, the US Department of Energy issued Funding Opportunity Announcement (FOA) Number DE-FOA-0000959, FOA Type: Initial, CFDA Number: 81.086. This FOA outlined the application process that would be used for the selection of participants in the Solar Decathlon 2015. The submission deadline was set for 20 December 2013, 5:00pm Eastern Time.

In response to this FOA, a team from the University of Florida (with assistance from Santa Fe College and the National University of Singapore) prepared and submitted a proposal for consideration by the DOE.

On 13 February 2014, the DOE announced that twenty (20) university teams had been selected for participation in the Solar Decathlon 2015. Of those selected, the following fourteen (14) teams were able to complete their homes and participate fully in the competition:

- California Polytechnic State University, San Luis Obispo
- California State University, Sacramento
- Clemson University
- Crowder College and Drury University
- Missouri University of Science and Technology
- New York City College of Technology
- State University of New York at Alfred College of Technology and Alfred University
- Stevens Institute of Technology
- The University of Texas at Austin and Technische Universitaet Muenchen
- University at Buffalo, The State University of New York
- University of California, Davis
- University of California, Irvine; Saddleback College; Chapman University; and Irvine Valley College
- West Virginia University and University of Roma Tor Vergata
- Western New England University, Universidad Tecnológica de Panamá, and Universidad Tecnológica Centroamericana

In addition to those teams that fully participated in the competition, the following six (6) teams were selected to participate but withdrew from the competition prior to completion:

- Team Michigan: Lansing Community College, Kendall College of Art and Design, and Ferris State University *(withdrew 12 March 2014)*
- Oregon Institute of Technology and Portland State University *(withdrew 12 March 2014)*
- Stanford University *(withdrew 30 September 2014)*
- Vanderbilt University and Middle Tennessee State University *(withdrew 3 February 2015)*
- University of Florida, National University of Singapore, and Santa Fe College *(withdrew 31 July 2015)*
- Yale University *(withdrew 21 August 2015)*

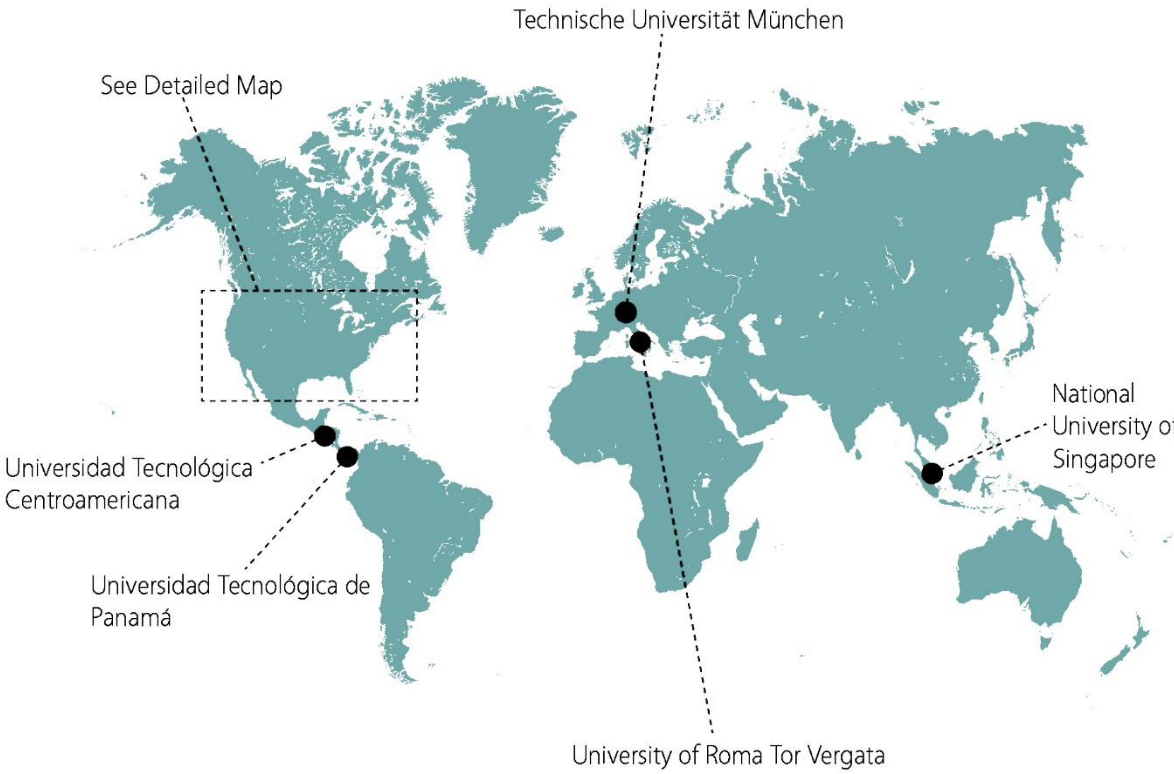

Figure 4. World Map, Showing Locations of Universities Participating in Solar Decathlon 2015

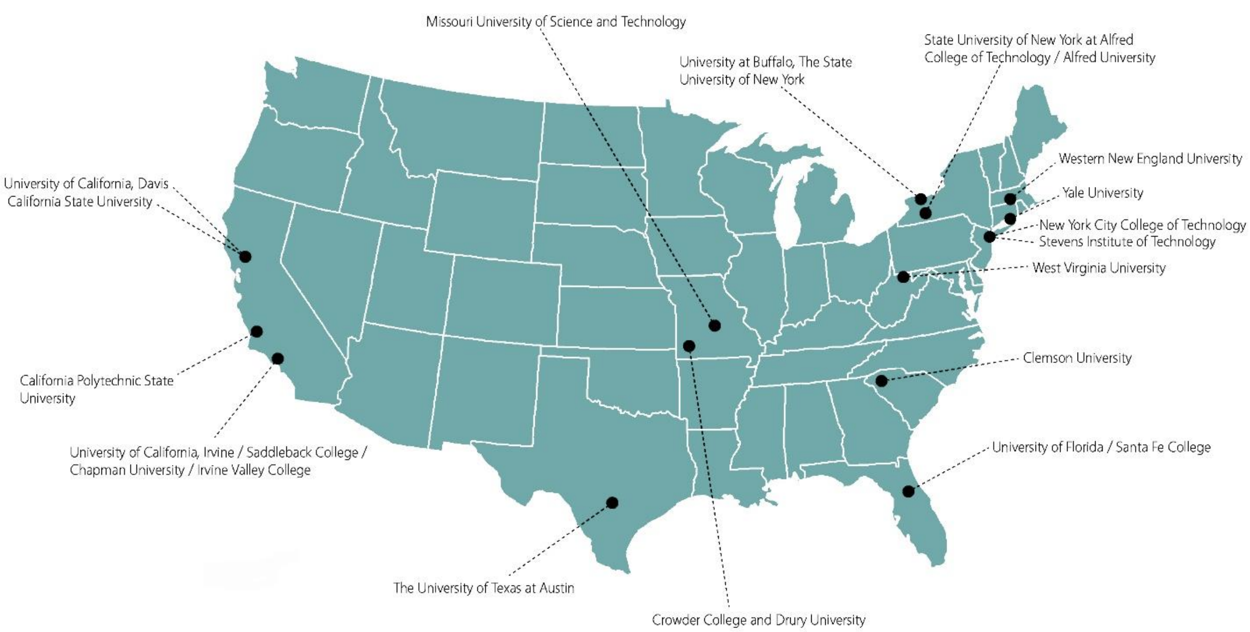

Figure 5. United States Map, Showing Locations of Universities Participating in Solar Decathlon 2015

Team Florida / Singapore

Team Florida / Singapore was organized around a core group of students and faculty at the University of Florida (UF) in Gainesville, Florida, with support from students and faculty at Santa Fe College (Gainesville, Florida) and the National University of Singapore (Singapore). The team leaders were principally graduate and undergraduate students in the UF School of Architecture, working directly with the team's Faculty Advisor, Bradley Walters AIA, and other faculty. At the conclusion of the project, the team consisted of approximately 74 students and 15 faculty.

The student and faculty team was supported by approximately 20 administrative assistants, grant specialists, public relations professionals, development officers, and researchers from the College of Design, Construction and Planning at the University of Florida. In addition, the team included an expansive network of approximately 150 supporters, including direct family members of decathletes, volunteers, and sponsors.

Student Team Members

UF College of Design, Construction + Planning

School of Architecture:

- Student 1
- Student 2
- Student 3
- Student 4
- Student 5
- Student 6
- Student 7
- Student 8
- Student 9
- Student 10
- Student 11
- Student 12
- Student 13
- Student 14
- Student 15
- Student 16
- Student 17
- Student 18
- Student 19
- Student 20
- Student 21
- Student 22
- Student 23
- Student 24 (Landscape Arch Minor)
- Student 25
- Student 26
- Student 27
- Student 28
- Student 29
- Student 30
- Student 31
- Student 32
- Student 33
- Student 34
- Student 35
- Student 36
- Student 37

M.E. Rinker School of Construction Management:

- Student 38
- Student 39
- Student 40

Department of Interior Design:

- Student 41

Sustainability and the Built Environment:

- Student 42
- Student 43 (Dual-Degree Architecture)
- Student 44 (Dual-Degree Architecture)

UF College of Journalism and Communications

- Student 45
- Student 46
- Student 47
- Student 48
- Student 49 (Advertising/Journalism)
- Student 50
- Student 51
- Student 52
- Student 53

UF College of Engineering

Dept of Mechanical & Aerospace Engineering:

- Student 54
- Student 55
- Student 56
- Student 57

Dept of Electrical and Computer Engineering:

- Student 58

National University of Singapore

School of Design & Environment

Department of Architecture:

- Student 59
- Student 60
- Student 61
- Student 62
- Student 63
- Student 64

Faculty, Staff, and Administrative Support

UF College of Design, Construction + Planning

Faculty:

- Bradley Walters, AIA, NCARB, CPHC® (Principal Investigator)
- Stephen Belton, AIA
- Lee-Su Huang
- Lisa Huang, AIA, NCARB
- Mark Andrew McGlothlin, NCARB
- Nawari O. Nawari, Ph.D., P.E., M.ASCE
- Paul Oppenheim, Ph.D., P.E.
- Robert Ries, Ph.D.
- Ravi Srinivasan, Ph.D. CEM
- James D. Sullivan, Ph.D.
- Russell Walters, Ph.D., P.E.

Leadership and Administration:

- Christopher Silver, Ph.D., Dean and Professor
- Margaret H. Carr, Associate Dean and Professor
- William L. Tilson, Assistant Dean for International Studies & Service Learning
- Andrew J. Wehle, Ph.D., Assistant Dean
- Jason S. Alread, AIA, Director, UF School of Architecture
- Robert Ries, Ph.D., Director, M.E. Rinker, Sr. School of Construction Management
- Margaret Portillo, Ph.D., Chair, Department of Interior Design
- Maria C. Gurucharri, Chair, Department of Landscape Architecture
- Joseli Macedo, Ph.D., AICP, Chair, Department of Urban and Regional Planning

University of Florida Foundation:

- Ann Baker, Director of Development
- Ramin Gillett, Assistant Director of Development

Communications, Media, and Public Relations:

- Julie Frey
- Katelyn Weber
- Brent Ferraro

School of Architecture Staff Support:

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- Brenda Barefield
- Lisa Haynes
- Becky Hudson
- Michelle Matckie

UF College of Engineering

- H.A. (Skip) Ingley, Ph.D., P.E.

UF College of Journalism and Communications

- Florida Bridgewater-Alford, APR

UF Office of Research

- Brian E. Prindle, Associate Director for Sponsored Research, Division of Sponsored Programs
- Robert J. Sessions, Jr., Research Administrator, Contracts & Grants Accounting Services

National University of Singapore

- Yunn Chii Wong, Ph.D., Head
- Abel Tablada de la Torre
- Kazuhiro Nakajima

Santa Fe College

- Dr. Edward T. Bonahue, Provost
- John McNeely, Associate Vice President
- Jane Parkin, Director, Construction and Technical Programs
- Kurt Strauss
- Justin MacDougall

Alachua Habitat for Humanity

- Scott Winzeler, Executive Director

DESIGN + TECHNICAL APPROACHES

The Solar Living House is a house for *living*. It centers on people and the activities of daily life while quietly introducing advanced design, construction, and engineering technologies. The house is a modular, 993 square-foot, two-bedroom one-bath home designed to embrace and frame an exterior courtyard space. This courtyard acts as an extension of the interior living spaces, maximizing the spatial potentials of a modest building footprint and introducing natural light into the primary living spaces of the house. Innovative solar thermal systems control humidity, increase comfort, improve air quality and reduce energy use.

Design Philosophy + House Design

> *"Because most opinion, both profound and light-headed, in terms of post war housing is nothing but speculation in the form of talk and reams of paper, it occurs to us that it might be a good idea to get down to cases and at least make a beginning in the gathering of that mass of material that must eventually result in what we know as 'house – post war.'"* [7]

John Entenza opened his editorial to the January 1945 issue of *Arts and Architecture* with the preceding statement, setting in motion one of the most recognized experiments in housing during the modern era, namely the Case Study House program. This experiment resonates for many reasons, but chief among them is how ideas of the house were questioned at a fundamental level, initiating a series of spatial and constructional speculations that aspired to keep pace with an evolving, modern American culture. By embracing the cultural shifts already underway, these houses reframed long-standing attitudes about domestic life, fusing new ways of living with the potentials offered in new materials, innovative construction systems and spatial sensibilities, resulting in visions of "house" far departed from its aging predecessors.

Inspired by mid-century modern homes and the Case Study House program, the Solar Living House is a two-bedroom home designed to embrace and frame an exterior courtyard space. Our goal is to create an elegant and disciplined house that expresses its construction in an honest and direct manner; a house that basks in the sun and harnesses the full extent of the energy it affords; a house that reflects the poetic delight of a bygone era, updated and transformed through the technological prowess of our time. We will offer a house that is at once new, yet familiar. We are looking back in order to look forward, synthesizing the clean lines, efficient spaces and material palettes of mid-century modern homes with the efficacy of new envelope strategies, energy-production systems, and novel solar-powered dehumidification systems.

[7] Entenza, John. "The Case Study House Program." *Arts & Architecture*. 01 1945: 37. Print.

Unique House Features

> *"But this program is not being undertaken in the spirit of the 'neatest trick of the week.' We hope it will be understood and accepted as a sincere attempt not merely to preview, but to assist in giving some direction to the creative thinking on housing being done by good architects and good manufacturers whose joint objective is good housing."* [8]

Our proposal for the Solar Living House is born out of the earlier ambitions of the Case Study House program. This program did not merely address the concerns of affordability or utility alone, but rather embraced modernist tenets of spatial thinking and material efficiency. Our interests in the Case Study program, and more so its position as a catalyst to mid-century housing, should be clarified as not fashionably quoting earlier architectural languages, but rather reinvesting in fundamental design principles that informed those languages, and bringing to those languages advanced technological, material, and spatial ideas that can project forward and help define an uncertain architectural future.

To accomplish this, we will build from the spatial principles and discipline of our predecessors, preserving the simple elegance of efficient and functional spaces that are beautifully proportioned and informed by the delicate play of light and shadow. We will exercise restraint and honesty in our use of materials, ensuring that the mechanics of construction are thoughtfully expressed under the trying rituals of day-to-day domesticity. We will ensure that our spaces are designed with living in mind, scaled to embrace simple activities by providing an adaptable and accommodating framework to hold the active families of the 21st century. We will make connections between inside and outside, ensuring that the house remains an open vessel for living within a place, and as such, finds a part of its identity through that place. We will address the full comforts of modern living, highlighting those moments where technology can be welcomed as a meaningful part of the larger architectural language while also offering a gentle reminder that the beautiful crafted spaces can do more than hold the material things of modern life. Our house will strive to rekindle personal interaction, to bring people together for a friendly discussion and laughter, and to offer forward the idea that the house remains an integral part of a life well lived.

[8] Entenza, John. "The Case Study House Program." *Arts & Architecture*. 01 1945: 39. Print.

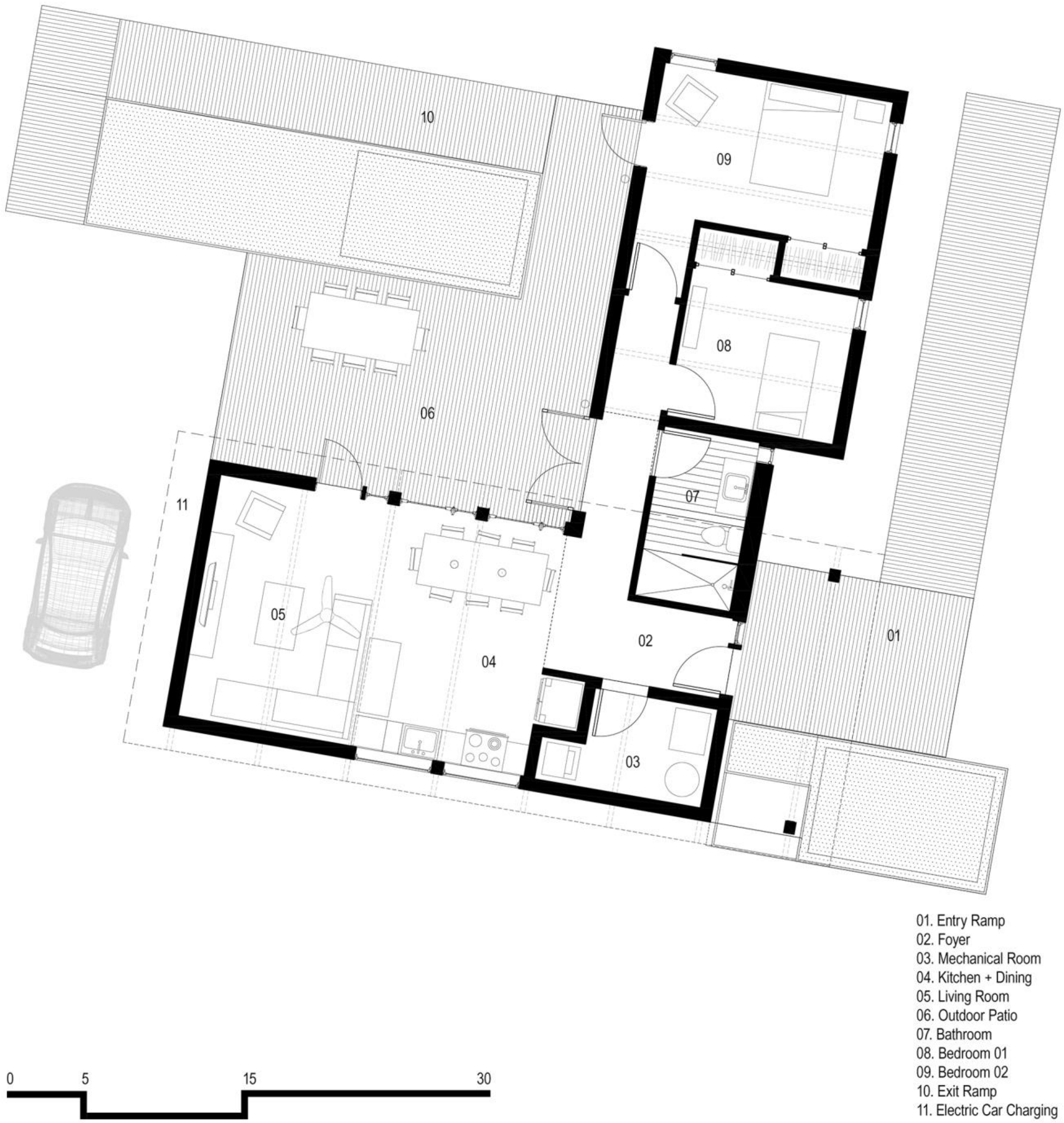
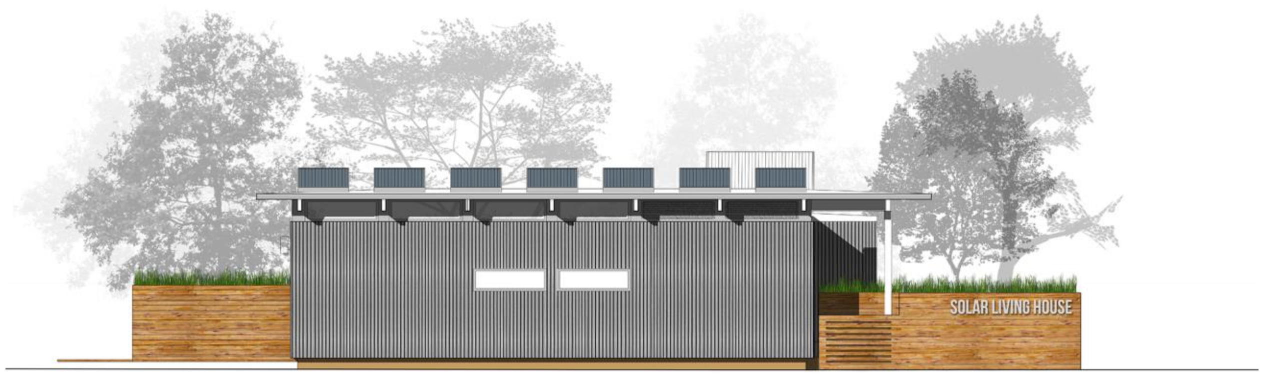


Figure 6. Solar Living House. Illustrative Floor Plan.

Figure 7. Solar Living House. Aerial View (front).

Figure 8. Solar Living House. Aerial View (rear).

East Elevation



South Elevation

West Elevation

North Elevation

Figure 9. Solar Living House. Exterior Elevations.

Figure 10. Solar Living House. Exterior view of front door.

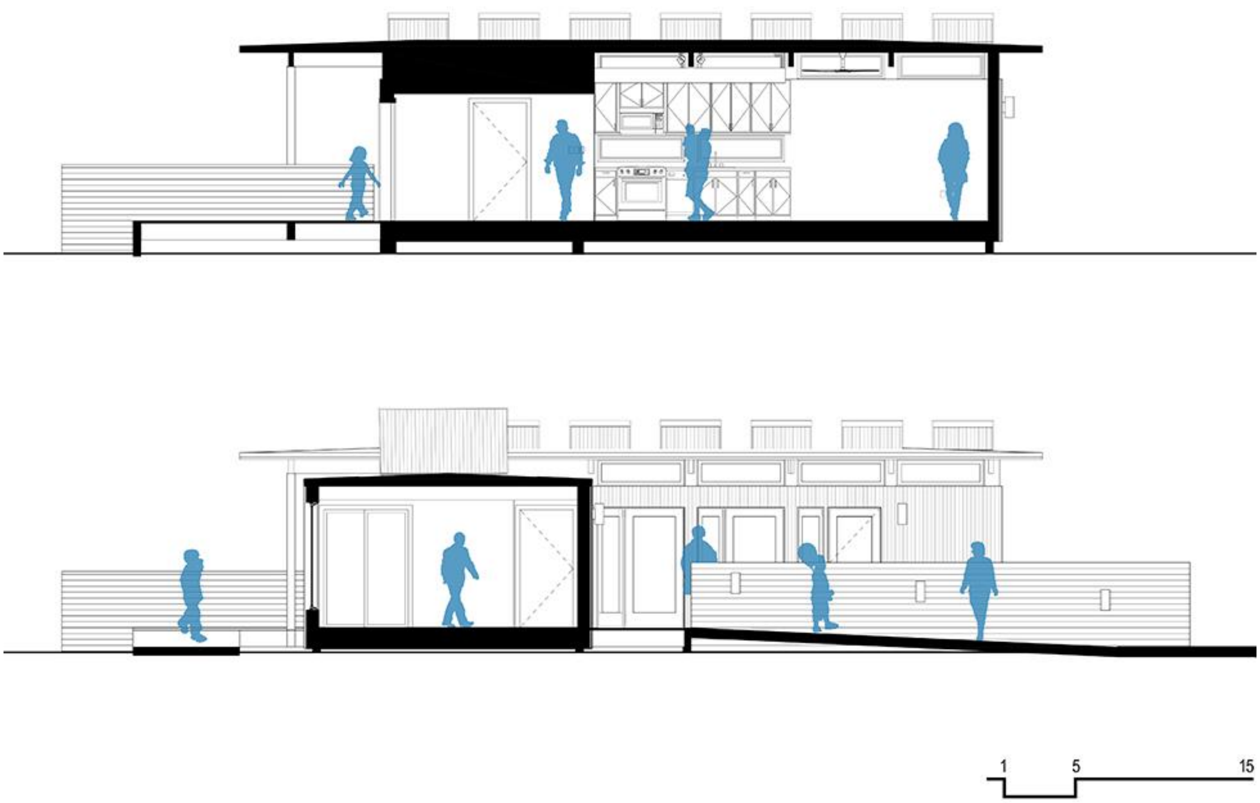


Figure 11. Solar Living House. Building Sections.

Figure 12. Solar Living House. Interior view of dining area and hallway to private wing, with courtyard just outside.

Figure 13. Solar Living House. Interior view of kitchen and dining areas, with living areas beyond.

Figure 14. Solar Living House. Interior view of living area, with kitchen, dining, and courtyard beyond.

Figure 15. Solar Living House. Interior view of master bedroom.

Design Tools and Modeling

The Solar Living House was designed using both analog and digital tools. Early design studies included hand-generated drawings, physical models, sketches, and narrative. Conceptual studies were further developed with two- and three-dimensional digital modeling tools, including Autodesk AutoCAD and Rhinoceros.

Technological Innovations

The Solar Living House aims to seamlessly integrate advanced and innovative technologies into its fabric to provide a user-friendly experience for today's busy families. The house incorporates a number of "tried and true" technologies, including solar photovoltaic panels to generate electricity, solar thermal hot water systems, an electric-powered vehicle, and low-flow plumbing fixtures. In addition, the house incorporates three principal technological innovations: wet/dry modular construction, a building automation system, and solar dehumidification systems.

Wet / Dry Modular Construction

The house is designed as a series of five modules, including one that is designated as the "wet core." The wet core consolidates the mechanical systems and bathroom into a single module to reduce plumbing runs, efficiency losses, and on-site construction time. The other four modules are designed to eliminate interior load bearing walls to allow for maximum flexibility in the reconfiguring of the space over time. The modules are designed to meet the structural challenges of both Florida's hurricanes and California's earthquakes.

Building Automation System

The house is equipped with an integrated building automation system, allowing the houses environmental systems, lights, security systems, and smoke detectors to be programmed, monitored, and controlled through any mobile or computing device. These systems allow for more precise calibrations of temperature/humidity/lighting to correspond with user needs and preferences, minimizing energy losses with economical night- or day-time setbacks.

Solar Dehumidification System

The most significant technological innovation in the Solar Living House is the solar thermal dehumidification system. This system generates hot water through two rooftop-mounted evacuated tube solar thermal collectors. The hot water is used to continually dry a regenerative solid desiccant material, typically white silica gel. The solid desiccant is used to adsorb moisture and humidity from the air without additional mechanical cooling. This strategy allows humidity to be modulated independently of air temperature, providing greater thermal comfort and reducing the opportunity for the growth of mold spores within the house while also reducing the overall energy consumption of the HVAC system.

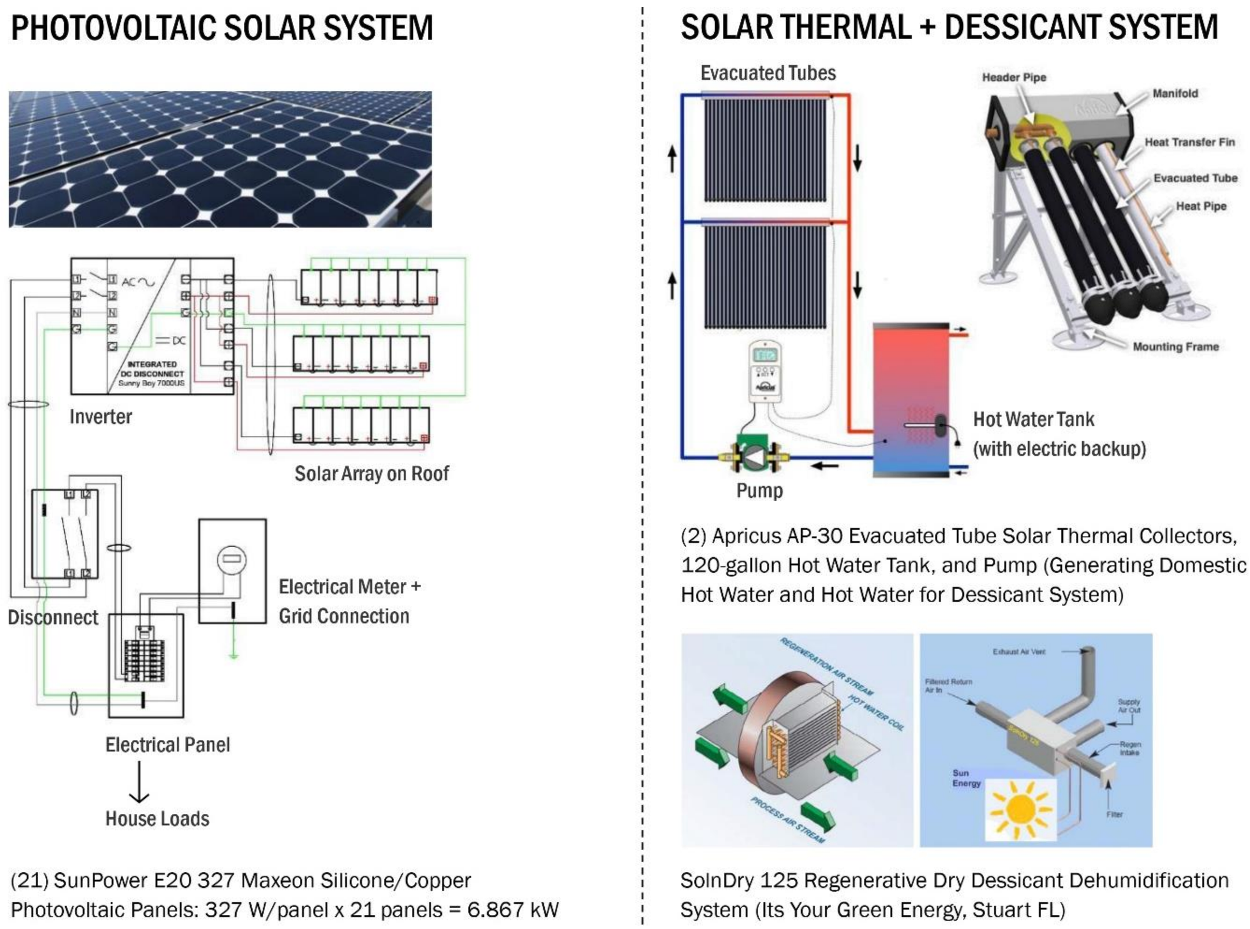


Figure 16. Active Solar Systems Incorporated in the Solar Living House

The solar dehumidification system uses regenerative solid desiccants, such as white silica gel, to adsorb water and moisture. About white silica gel:

> Silica gel is very porous and has "a great deal of internal surface area. It is a tasteless, odorless, non-toxic, non-corrosive, and chemically inert substance. It is a highly activated adsorbent that is available in numerous mesh sizes designed for many uses in industry. During adsorption, there is no chemical reaction in the silica gel, and no byproducts are created. Silica gel is non-deliquescent, and its shape and size never change. Its outer surfaces stay dry and it remains free-flowing, even when it is saturated with water."
>
> "Silica gel is a silicon dioxide (SiO_2), an amorphous form of silica which is manufactured from silicate and sulfuric acid. It is a naturally occurring mineral that is purified and processed into beaded or granular form, and is also non-corrosive and chemically inert. Much like a sponge, silica gel's interconnected pores form a vast surface area that will attract and hold water by adsorption and capillary condensation, enabling silica gel to adsorb about 40% of its weight in water vapor at 100% humidity." [9]

[9] AGM Container Controls, Inc., "About Silica Gel," http://www.agmcontainer.com/white-silica-gel.html, accessed: 22 April 2015.

Target Client

Families and living situations today are complex and varied. The Solar Living House has been designed to meet the needs of an average-sized family of 2.48 to 2.90 people, but also seeks to accommodate the single individual, a pair of young professionals, or older empty-nesters. For purposes of the competition, the target client is identified as a young family of three, residing in Gainesville, Florida, as follows:

Characteristic or Requirement	Target Client	Alternate Client 1	Alternate Client 2
Location of Permanent Site	Gainesville, Florida	Newberry, Florida	Orange County, California
Climate Zone	2A (Moist/Humid)	2A (Moist/Humid)	3B (Dry)
Housing Type	Single family	Single family	Single family
Number of Occupants	3	2	1-2
Client Demographic	Young family (mid 30's couple with infant or young child)	Upper 60's single parent with older live-at-home son/daughter	Working professionals
Client Annual Income	$80,000 - $100,000	$80,000 - $100,000	$120,000 - $140,000
Number of Bedrooms	2	2	1 (+ den/office)

The house responds to this target client and target location in a number of ways:

- The home's L-shaped configuration and private courtyard create exterior living and play spaces that are directly connected to interior spaces, providing safety and security for families with young children.
- The bedroom wing will be configured to include two bedrooms, to accommodate a couple and young child. The bedroom wing is designed with no load-bearing interior walls, allowing it to be reconfigured over time to better respond to changing bedroom, office, or den/media/gaming space needs.
- Durable, low-maintenance materials were selected to reduce life-cycle costs.
- The integrated automation systems allow for the house to be programmed and operated remotely, appealing to the tech-savvy and environmentally conscious millennial generation of home-buyers.
- Solar dehumidification systems provide thermal comfort in the moist, hot, and humid climate of Florida, where the target client is located.

Construction Costs

An independent professional cost estimator was engaged by the competition organizers to review and develop a cost estimate for the project. In their final estimate, dated 10 July 2015, Faithful + Gould estimated the overall project cost at $333,799, or $336.15 per square foot of finished floor area. By comparison, the average construction cost for a home in the United States in 2015 was $289,415, or $103.29 per square foot of finished floor area.

Solar Living House Cost Estimate

System	Description	Estimate
A10	Foundations	$7,668
B10	Superstructure	$23,754
B20	Exterior Closure	$46,563
B30	Roofing	$6,468
C10	Interior Construction	$14,961
C30	Interior Finishes	$21,467
D20	Plumbing	$47,235
D30	Mechanical	$14,488
D40	Fire Protection	$4,761
D50	Electrical	$63,954
E20	Furnishings	$0
F10	Special Construction	$28,454
G20	Site Improvement	$9,425
Total Direct Cost (Trade Costs)		$295,999
General Conditions, Overhead, and Profit		$0
Contingencies/Escalation		$14,800
Trucking (5 trucks)		$10,000
Crane time (8 days)		$13,000
Lull/fork lift (0 days)		$0
TOTAL PROJECT COST		$333,799
Finished Floor Area		993 sf
Cost per Square Foot		**$ 336.15 /sf**

2015 National Average Construction Costs [10]

System	Description	Average Cost
01	Site Work	$16,092
02	Foundations	$33,447
03	Framing	$52,027
04	Exterior Finishes	$43,447
05.Q	Plumbing	$12,302
05.R	Electrical	$12,181
05.S	HVAC / Mechanical	$12,623
05.T	Other System Rough-ins	$738
06	Interior Finishes	$85,642
07	Misc. Site Improvements (landscaping, deck, drive)	$19,567
08	Other	$1,349
Total Construction Cost		$289,415
Average Finished House Size		2,802 sf
Cost per Square Foot		**$ 103.29 /sf**

(excludes property costs and financing)

[10] Taylor, Heather. "Cost of Constructing a Home." NAHB Economics and Housing Policy Group, Special Studies, 2 November 2015, report available to the public courtesy of HousingEconomics.com. https://www.nahbclassic.org/generic.aspx?genericContentID=248306, accessed 15 July 2016.

Side-by-Side Comparisons of 2015 Solar Decathlon Houses

Rank	Team / University	Construction Cost	Finished Floor Area (square feet)	Cost per Square Foot
1	Western New England University, Universidad Tecnológica de Panamá, and Universidad Tecnológica Centroamericana	$ 120,282	680 sf	$ 176.89 /sf
2	University of California, Davis	$ 249,312	985 sf	$ 253.11 /sf
3	Crowder College and Drury University	$ 276,449	973 sf	$ 284.12 /sf
4	Stevens Institute of Technology	$ 290,776	994 sf	$ 292.53 /sf
5	The University of Texas at Austin and Technische Universitaet Muenchen	$ 268,399	915 sf	$ 293.33 /sf
6	Team NY Alfred: State University of New York at Alfred College of Technology and Alfred University	$ 268,637	881 sf	$ 304.92 /sf
7	Missouri University of Science and Technology	$ 304,684	989 sf	$ 308.07 /sf
8	Clemson University	$ 300,175	972 sf	$ 308.82 /sf
9	California State University, Sacramento	$ 332,323	996 sf	$ 333.66 /sf
10	Team Orange County: University of California, Irvine; Chapman University; Irvine Valley College; and Saddleback College	$ 330,495	984 sf	$ 335.87 /sf
11	Team Florida/Singapore: University of Florida, National University of Singapore, and Santa Fe College	$ 333,799	993 sf	$ 336.15 /sf
12	California Polytechnic State University, San Luis Obispo	$ 324,558	965 sf	$ 336.33 /sf
13	New York City College of Technology	$ 329,861	937 sf	$ 352.04 /sf
14	University at Buffalo, The State University of New York (SUNY)	$ 278,653	770 sf	$ 361.89 /sf
15	West Virginia University and University of Roma Tor Vergata	$ 347,802	881 sf	$ 394.78 /sf
-	Vanderbilt University and Middle Tennessee State University	n/a	n/a	n/a
-	Yale University	n/a	n/a	n/a
	Average	$ 290,414	928 sf	**$ 311.50 /sf**
	Median	$ 300,175	972 sf	**$ 308.82 /sf**

Identity

In establishing an identity for the project, the team decided that the concept of "living" was central to the design. Issues of livability were central to almost every design discussion. The team sought to create homes that were not simply volumes for the storage of people and things but rather spaces for living, in which people would want to linger. At the same time, issues of solar performance were omnipresent.

An advertising student at the University of Florida created a series of visual identity strategies for consideration by the larger team. The selected logo created a sunburst from a series of acute "L" shapes, drawn out of the first letter of "living."

Figure 17. Solar Living House logo (2014).

As project work continued, the graphic identity evolved to a slightly cleaner and more precise version of the early logo for better legibility. The simplified starburst was combined with a larger "Solar Living House," set in Jaapokki, a typeface developed by Mikko Nuuttila.[11]

Figure 18. Solar Living House logo (2015).

[11] http://mikkonuuttila.com/jaapokki/.

Communications + Outreach Strategies

Our team's communications strategy included a major public outreach campaign, #I AM SOLAR. This campaign concept was developed by a student team from the University of Florida College of Journalism and Communications, working under the direction of Florida Bridgewater-Alford, APR, Director of Campus Communications Outreach at the University of Florida. As a part of their course work during the spring 2015 semester, eight students created a consulting group which they named Elevate Communications Group. The Elevate team leaders were as follows:

- Student 45
- Student 46
- Student 47
- Student 48
- Student 50
- Student 51
- Student 52
- Student 53

In support of the Solar Living House project, the team conducted detailed research including a situational analysis, organizational analysis, and SWOT analysis. They identified a target audience, goals and objectives, a message platform, theory and tactics, and communication tools. The Elevate team coordinated their work with Team Florida/Singapore and Julie Frey, Communications Director for the College of Design, Construction and Planning at the University of Florida.

Elevate conducted focus group meetings, online surveys, and individual meetings to gather data and make recommendations. Their report and finalized plan, presented to the full design team in April 2015, was immensely useful in shaping the communications strategies to be used through construction, competition, and beyond.

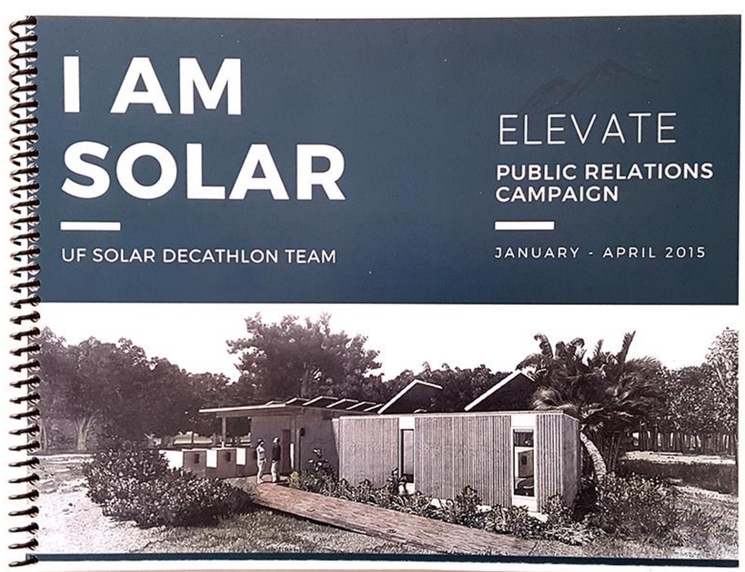


Figure 19. "I AM SOLAR" Public Relations Campaign, prepared by Elevate Communications Group, April 2015.

Our competition handout was designed to support Elevate’s Public Relation Campaign by increasing social awareness and extending the discussion started at the Solar Decathlon into the homes of friends and family members across the country. Our handout was a decal, 9.25” wide x 2.5” high, intended to find its way to laptops, water bottles, and cars across the country.

Figure 20. Team Handout: "I AM SOLAR" Decal

This messaging campaign was reinforced in the team uniform design and social media campaign planned to take place during the public exhibition and tours.

Front

Back

Figure 21. Team Florida/Singapore Uniform

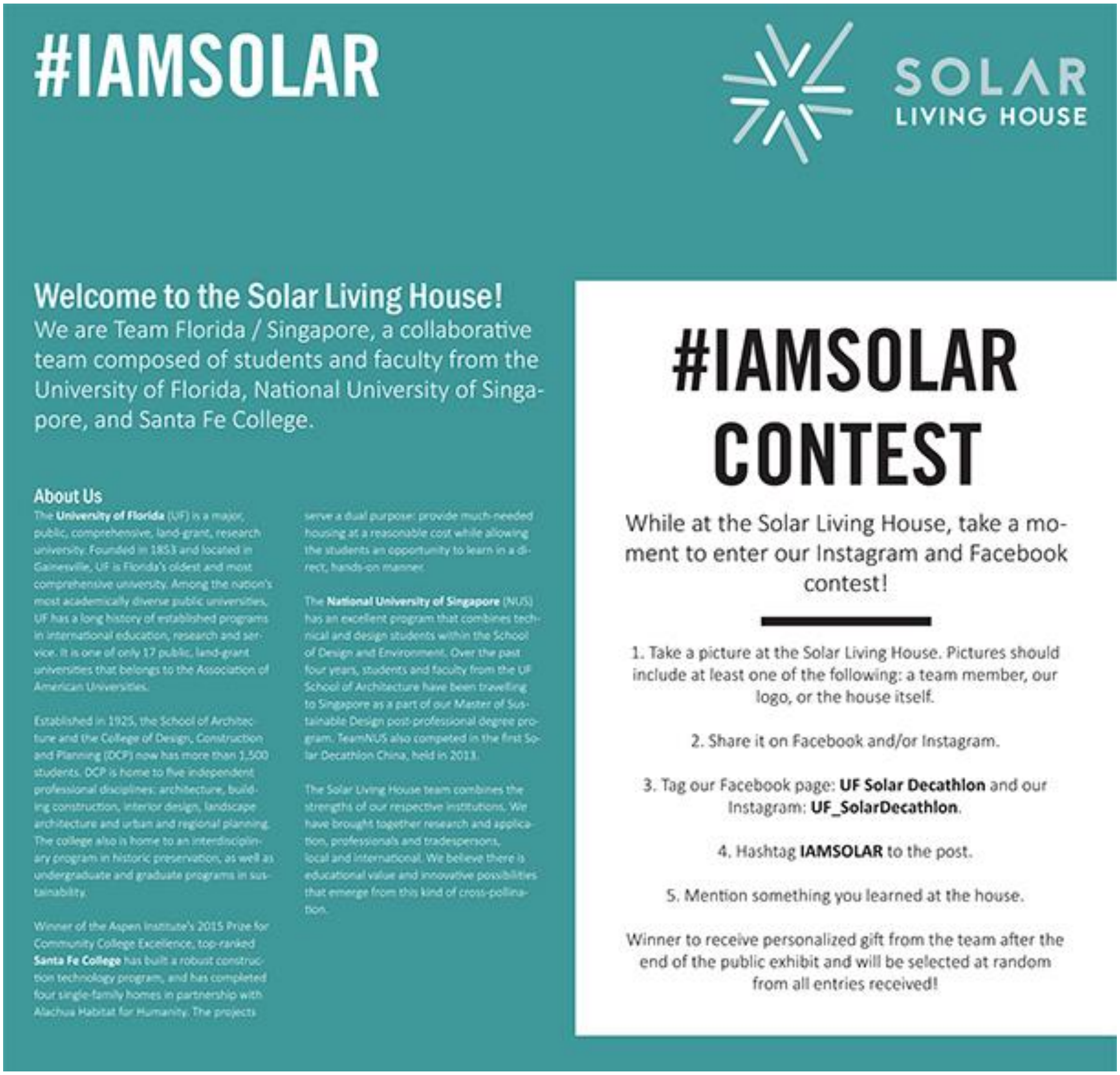


Figure 22. S02: Introductory Signage, with I AM SOLAR Social Media Campaign Information (excerpt)

For the competition, a series of graphics were created to explain the ideas behind the house to a non-technical public audience. These graphics and signage components were designed for specific locations in and around the house.

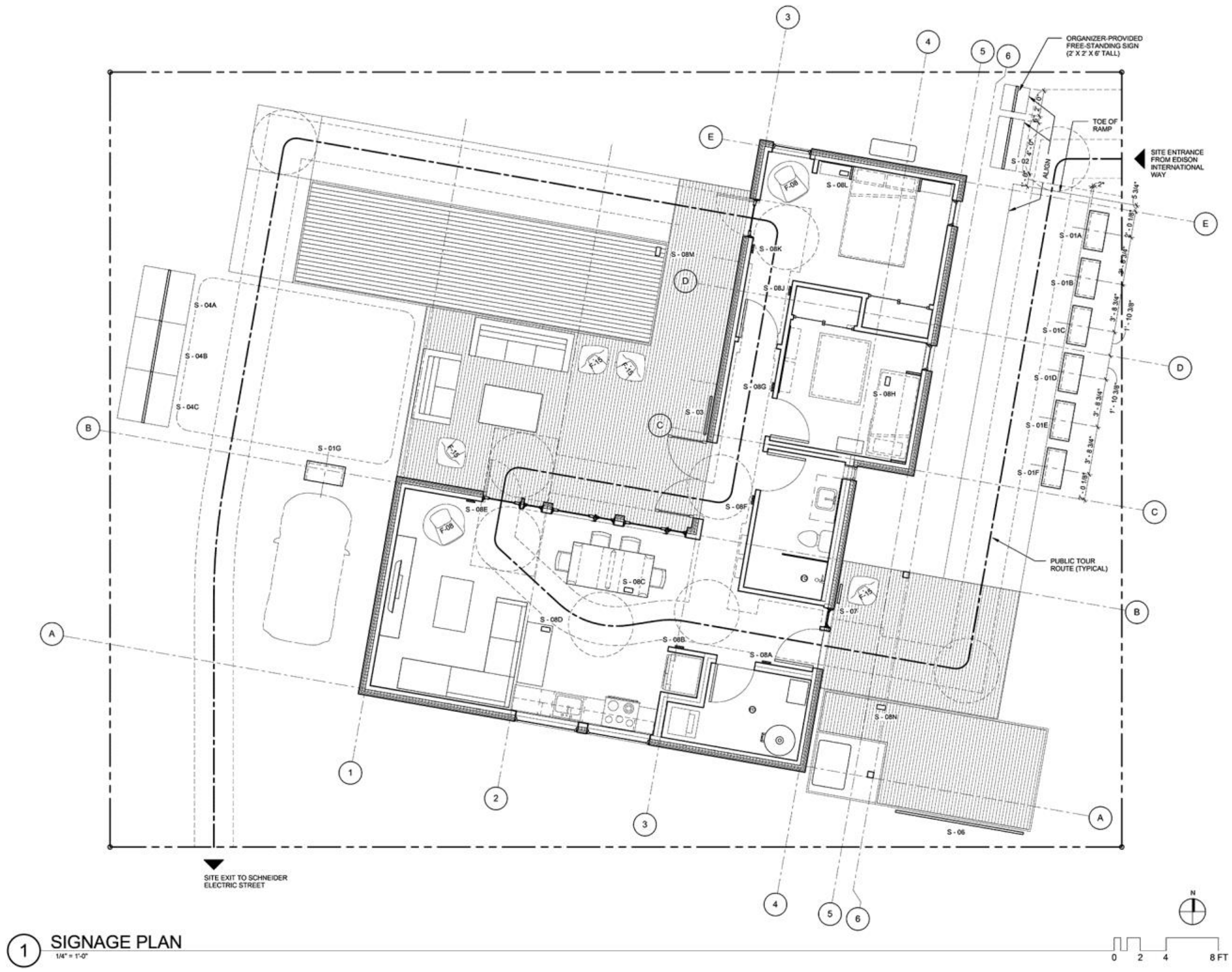


Figure 23. Signage Plan and Public Tour Route (A-141)

The signage and graphics program along the tour route began with a panel headed "Question," intended to introduce the basic premise of the Solar Living House. This panel was followed by six panels, headed Engage, Live, Adapt, Sustain, Innovate, Impact. These six panels introduced the major themes of our approach and our team's broader response to the challenges of sustainable, solar-powered dwellings in contemporary life. Each of these major themes was intended to correlate both to specific responses embedded within the project as well as ways in which everyone can participate in living more sustainably. The goal was to progressively move outside the limits of the project site, encouraging visitors to take ideas and approaches with them into their everyday lives.

These major introductory panels, displayed just outside the entry of the house, were intended to serve as a preface for the project. Visitors had an opportunity to study them in detail, while waiting in the tour queue and prior to entering the project.

Figure 24. S01A: Question

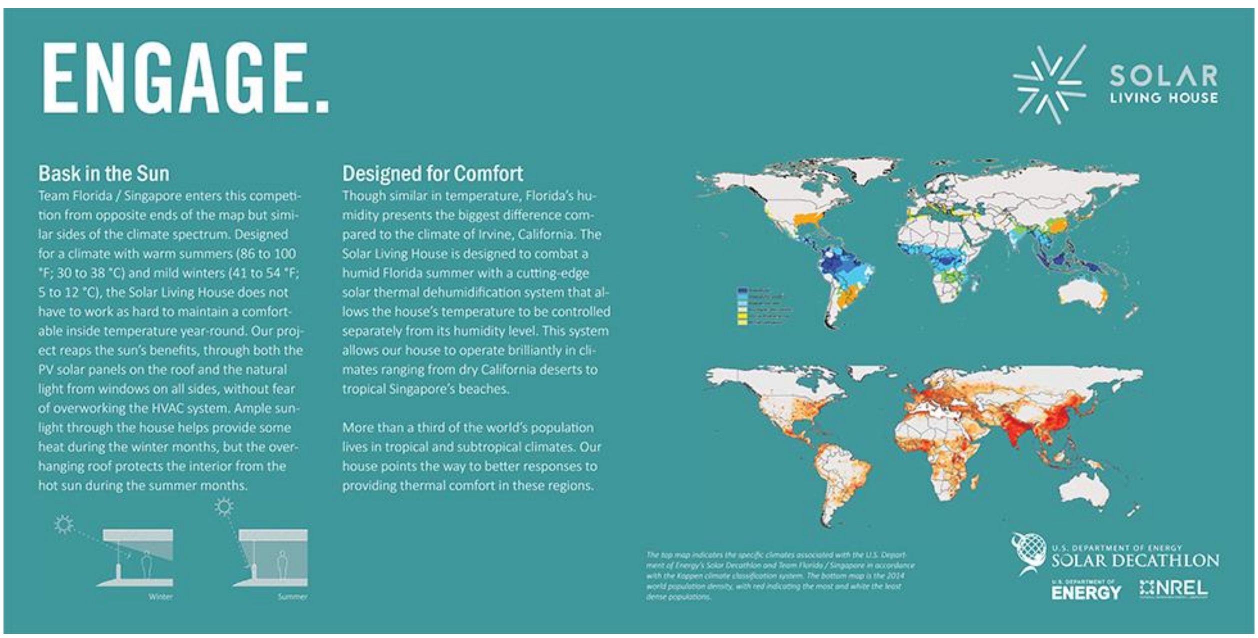


Figure 25. S01B: Engage

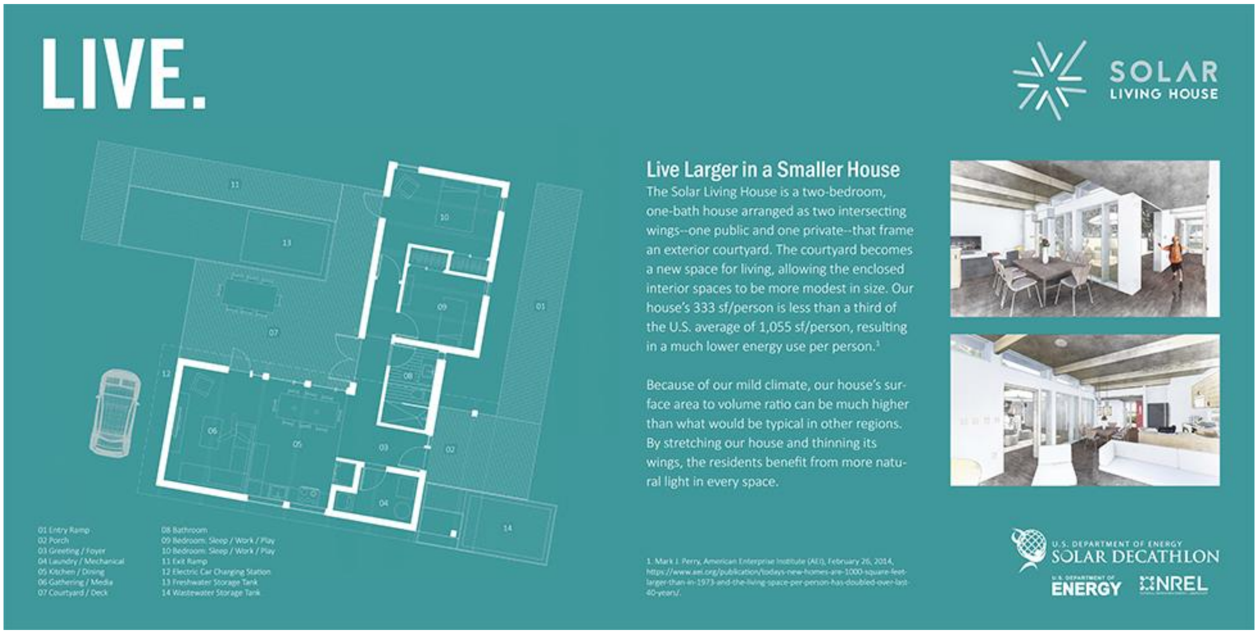


Figure 26. S01C: Live

Figure 27. S01D: Adapt

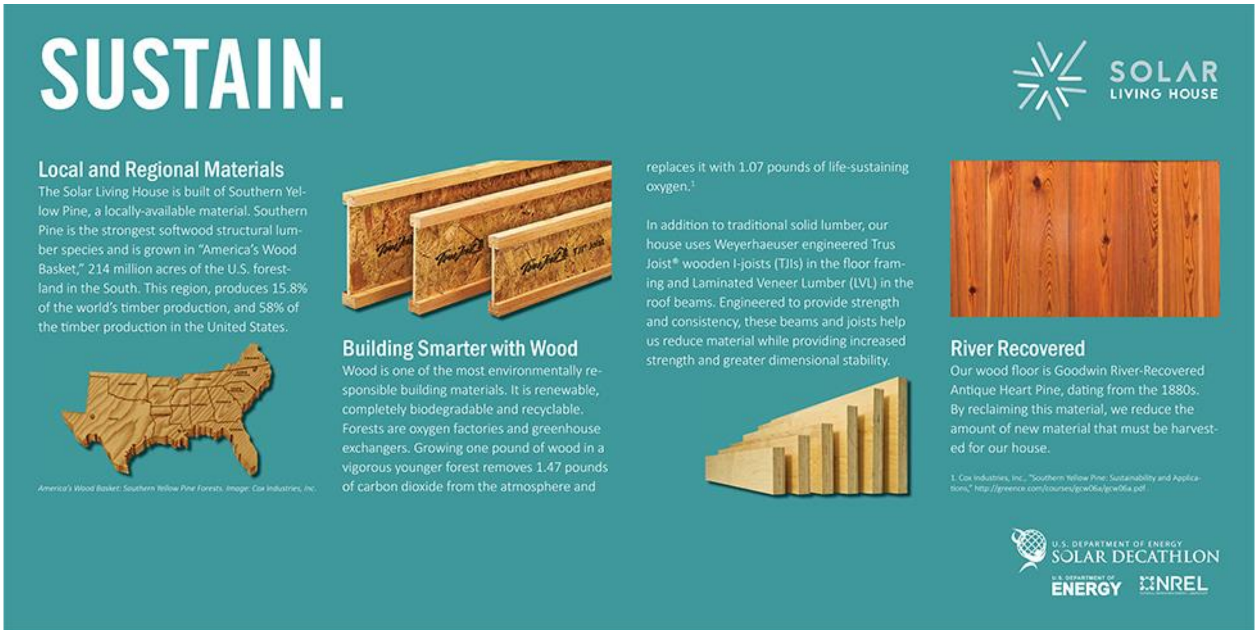


Figure 28. S08E: Sustain

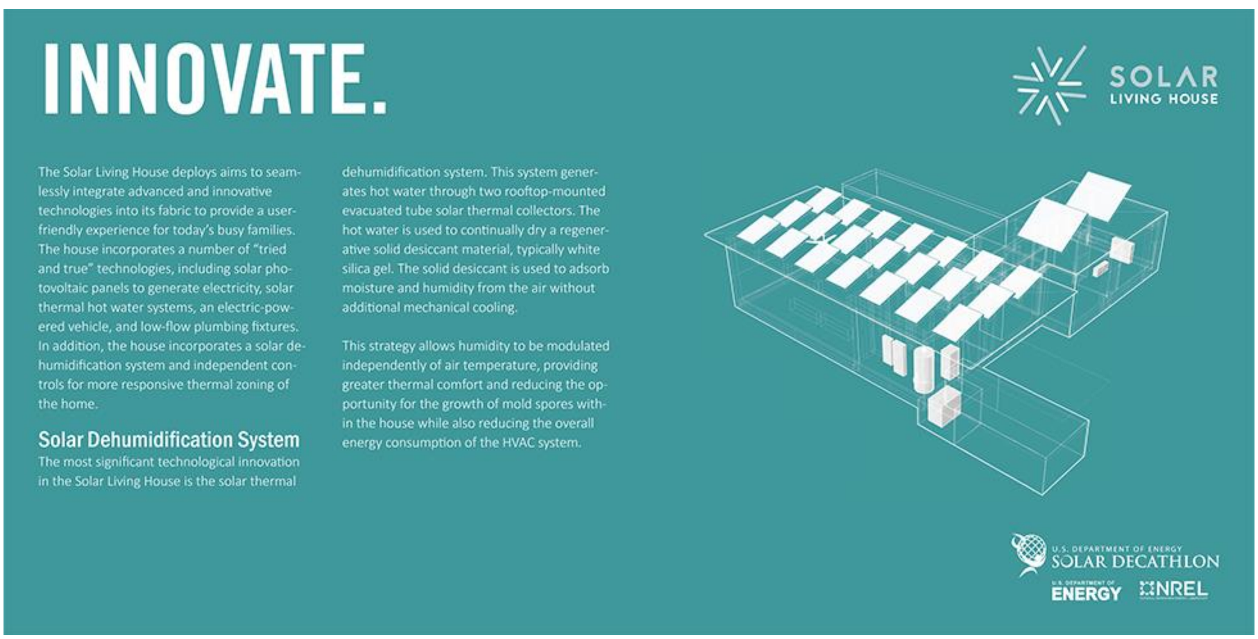


Figure 29. S08F: Innovate

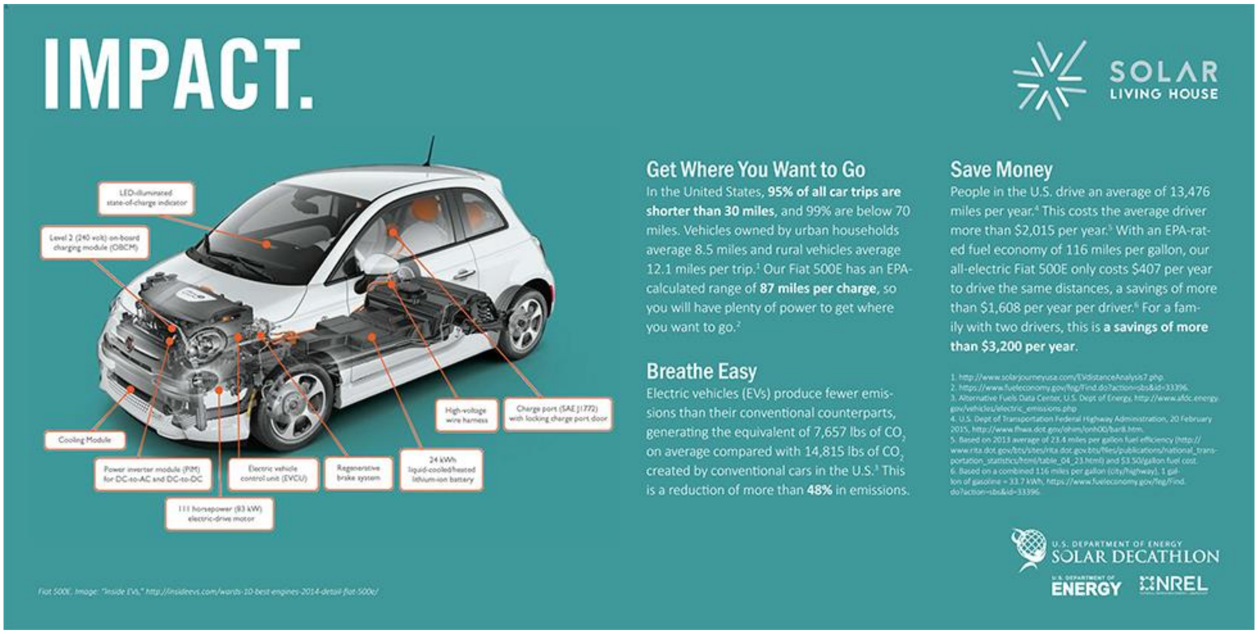


Figure 30. S08G: Impact

The ideas initiated in these introductory panels were further described through a series of small 4-inch high x 8-inch wide placards placed strategically throughout the house and along the tour route. These reiterated the central themes, and highlighted specific aspects of the project.

Figure 31. S-08A: Solar Thermal Dessicant System

Figure 33. S-08C: Moveable / Expandable Dining Table

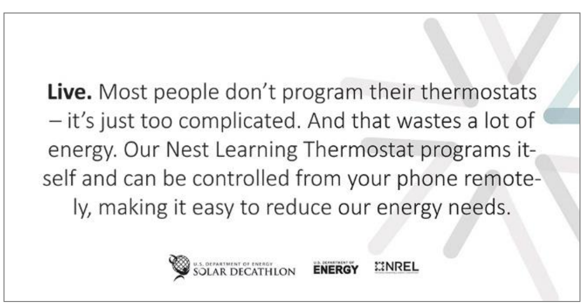


Figure 32. S-08B: Self-Programming Thermostat

Figure 34. S-08D: Moveable Kitchen Work Space

Figure 35. S-08E: Courtyard

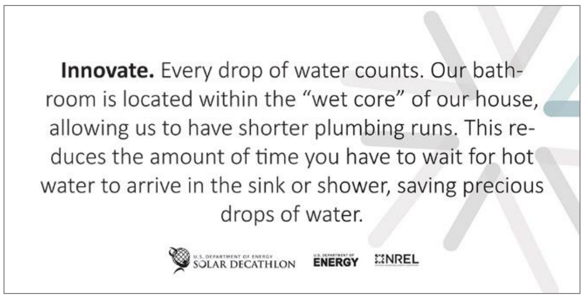


Figure 36. S-08F: Wet Core

Figure 37. S-08G: Flexible Interior Walls

Figure 38. S-08H: Bed / Desk in Bedroom 2

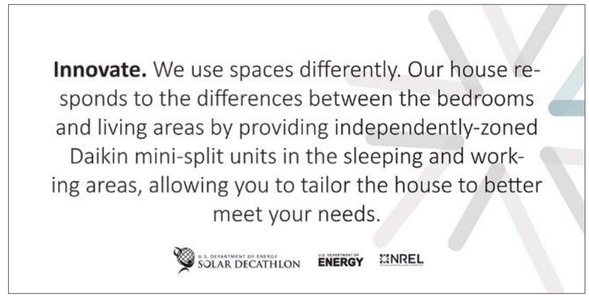


Figure 39. S-08J: Independent Thermal Zoning

Figure 40. S-08K: Courtyard

Figure 41. S-08L: Bed / Desk in Bedroom 1

Figure 42. S-08M: Climate-Specific Plant Materials

The competition messaging was augmented through a project website, Facebook page, and Twitter handle. As of 9 March 2017, the team’s Facebook page (https://www.facebook.com/solaruf) had 1,364 likes and the Twitter handle (@SolarUF) had 66 followers. The team’s website was http://solardecathlon.ufl.edu/ (now archived and no longer accessible).

LOGISTICS

The Solar Decathlon requires all project teams to erect fully-operational homes on the competition site for evaluation and public tours. This requires teams to plan for rapid assembly, limited ground penetrations, and easy/quick disassembly. The logistical issues and constraints of the project were vexing issues for the project team throughout.

Assembly/Disassembly Schedule

As set by competition organizers, the schedule allowed eight and a half (8 ½) days for on-site construction activities. This totaled 157 hours of work on site, including 19 hours per day for eight days and 5 hours for clean-up and staging on the final day.

Following opening activities, the public exhibit ran from 8-18 October (11 days), with some periods of time reserved for monitoring of house performance, jury visits, etc.

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
DAY 0 - SEPT 27	**DAY 1 - SEPT 28**	**DAY 2 - SEPT 29**	**DAY 3 - SEPT 30**	**DAY 4 - OCT 1**	**DAY 5 - OCT 2**	**DAY 6 - OCT 3**
REGISTRATION (12 p.m. - 2 p.m.; 4 p.m.-7 pm) ALL-TEAM MEETING (2 p.m. - 4 p.m.) VEHICLE STAGING (Permitted Sat. and Sun. from 8 a.m. to 6 p.m.)	REGISTRATION (6:30 a.m. - 6:30 p.m. Daily) STAND-ALONE ASSEMBLY (Begins at 7 a.m.)	IMPOUND (2 a.m. - 7 a.m.) STAND-ALONE ASSEMBLY	IMPOUND (2 a.m. - 7 a.m.) STAND-ALONE ASSEMBLY	IMPOUND (2 a.m. - 7 a.m.) STAND-ALONE ASSEMBLY	IMPOUND (2 a.m. - 7 a.m.) STAND-ALONE or GRID-TIE ASSEMBLY (Grid avaliable at 12:00 pm) GRID-TIE ASSEMBLY AVAILABLE (Grid avaliable at 12:00 pm)	IMPOUND (2 a.m. - 7 a.m.) STAND-ALONE or GRID-TIE ASSEMBLY
DAY 7 - OCT 4	**DAY 8 - OCT 5**	**DAY 9 - OCT 6**	**DAY 10 - OCT 7**	**DAY 11 - OCT 8**	**DAY 12 - OCT 9**	**DAY 13 - OCT 10**
IMPOUND (2 a.m. - 7 a.m.) STAND-ALONE or GRID-TIE ASSEMBLY WATER DELIVERY (8 a.m. - 5 p.m.)	IMPOUND (2 a.m. - 7 a.m.) STAND-ALONE or GRID-TIE ASSEMBLY (Until 12 p.m.) GRID-TIE ASSEMBLY (After 12 p.m.)	IMPOUND (2 a.m. - 7 a.m.) GRID-TIE ASSEMBLY (Unitl 8 a.m.) FINAL SITE CLEANUP, STAGING AND SIGNAGE (8 a.m. - 12 p.m.) STOP WORK FOR LAST-CHANCE FINAL INSPECTIONS* (No work to take place while teams wait for final inspections) (12 p.m.)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) REST DAY MEDIA PREVIEW (10:30 a.m. - 2 p.m.) OPENING REHEARSAL (3 p.m. - 3:30 p.m.) OPENING RECEPTION (6 p.m. - 8:30 p.m.) TEAM OPEN HOUSE (8:30 p.m. - 11 p.m.)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) CONTESTS (11:00 a.m. - Midnight) ALL TEAM PHOTO (8:30 a.m. - 9 a.m.) OPENING CEREMONY (9:30 a.m. - 11 a.m.) PUBLIC EXHIBIT (11 a.m. - 7 p.m.)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) CONTESTS (24 hours) PUBLIC EXHIBIT (11 a.m. - 7 p.m.)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) CONTESTS (24 hours) PUBLIC EXHIBIT (11 a.m. - 7 p.m.)
DAY 14 - OCT 11	**DAY 15 - OCT 12**	**DAY 16 - OCT 13**	**DAY 17 - OCT 14**	**DAY 18 - OCT 15**	**DAY 19 - OCT 16**	**DAY 20 - OCT 17**
IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) CONTESTS (24 hours) PUBLIC EXHIBIT (11 a.m. - 7 p.m.)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) CONTESTS (24 hours) JURY WALKTHROUGHS (7:30 a.m. - 12:30 p.m) and (7:30 p.m. to 9:30 p.m)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) CONTESTS (24 hours) JURY WALKTHROUGHS (7:30 a.m. - 12:30 p.m) and (7:30 p.m. to 9:30 p.m)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) CONTESTS (24 hours) JURY WALKTHROUGHS (7:30 a.m. - 10:00 a.m) and (7:30 p.m. - 8:30 p.m.)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) CONTESTS (24 hours) AFFORDABILITY & MARKET APPEAL RESULTS (10:00 a.m. - 11 a.m.) PUBLIC EXHIBIT (11 a.m. - 7 p.m.)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) CONTESTS (Midnight - 11a.m.) COMMUNICATIONS & ARCHITECTURE RESULTS (10:00 a.m. - 11 a.m.) PUBLIC EXHIBIT (11 a.m. - 7 p.m.) TEAM OPEN HOUSE (7:30 p.m. - 11 p.m.)	IMPOUND (12 a.m. - 7 a.m. & 11 p.m. - 12 a.m.) ENGINEERING RESULTS & AWARDS CEREMONY (10:00 a.m. - 10:45 a.m.) PUBLIC EXHIBIT (11 a.m. - 7 p.m.) VICTORY CELEBRATION (7:30 p.m. - 10:30 p.m.)
DAY 21 - OCT 18	**DAY 22 - OCT 19**	**DAY 23 - OCT 20**	**DAY 24 - OCT 21**	**DAY 25 - OCT 22**	**DAY 26 - OCT 23**	Last Updated On: 2014-06-09
IMPOUND (12 a.m. - 7 a.m.) PUBLIC EXHIBIT (11 a.m. - 7 p.m.) DISASSEMBLY (Begins at 7 p.m.)	IMPOUND (2 a.m. - 7 a.m.) DISASSEMBLY	IMPOUND (2 a.m. - 7 a.m.) DISASSEMBLY	IMPOUND (2 a.m. - 7 a.m.) DISASSEMBLY	IMPOUND (2 a.m. - 7 a.m.) DISASSEMBLY	IMPOUND (2 a.m. - 7 a.m.) DISASSEMBLY FINAL DISASSEMBLY INSPECTIONS (7 p.m.) ALL TEAMS OFF SITE (9 p.m.)	* Significant precipitaiton or the occurrence of an unforeseen circumstance that equally affects all teams' progress during the assembly phase may result in a postponement of the last-chance final inspections. The remainder of the schedule will remain unchanged.

Figure 43. Event schedules, excerpted from Appendix A of the Solar Decathlon 2015 Rules, dated 23 September 2014.

Immediately following the close of the public exhibit at 7:00pm on 18 October 2015, the teams were allowed to begin disassembly work. All disassembly work had to be completed in five (5) days or 95 hours of available work time.

Transportation + Assembly Strategies

When initially selected for participation in February 2014, the competition site had not yet been determined. In April 2014, a few weeks before the Schematic Design deliverable due date, the Orange County Great Park in Irvine, California was selected as the competition site. Even the shortest, most direct route from Gainesville, Florida to Irvine, California is 2,378 miles, or 33 hours at regular highway speeds without stops. The travel route crossed through eight states, each with different travel and transport regulations.

Figure 44. Land route from pre-construction site in Gainesville, Florida to competition site in Irvine, California. Source: Google.

The team evaluated a number of different approaches to delivering the project, including the following strategies:

- Stick-built: This refers to individual materials acquired and/or fabricated near competition site or transported from Florida, and most closely mirrors conventional building processes. This approach requires much more time than was allotted by the competition organizers, making it almost impossible. One strategy to speed the construction process would be to use a larger, well-orchestrated and well-managed construction team on the competition site. It also requires the resources for the team to practice building and re-building the house off-site, increasing the costs to the project team. Given that our project was entirely designed and constructed by students, we did not have access to the kind of skilled labor required for this. We also had exceedingly limited financial resources, making "practice" constructions impossible.
- Flat-pack: This approach consolidates some of the separate materials to create numerous components that can then be transported efficiently to the project site and assembled on-site. While more efficient on-site than stick-built construction, it also requires more time on-site than

some other approaches, and the project team was concerned about completing this work within the time allotted.

- Prefabrication: This approach involves the construction of the entire dwelling off-site, often in a controlled environment. The dwelling would then be transported to site as a single unit, requiring very little construction time on-site. The limitations on dimensions and geometry of the dwelling set by interstate shipping were deemed to be too constraining for this project.
- Modular construction: A hybrid between prefabrication and flat-pack strategies, this approach involves the construction of separate modules off-site. These different modules are then transported to the site and placed on or adjacent to one another to form the complete building. While individual modules are limited in their size and geometry, multiple modules can be combined to create more generous room sizes and more engaging spatial layouts.

The team decided to deploy a modular approach for the Solar Living House, where each of the separate modules would be sized to be transported via interstate roadways. In addition to facilitating construction and delivery on-site, the modular approach also allowed the team to address programmatic goals that support adaptability and responsiveness to change over time. The modules of the house can be rearranged, removed, or added-to as needed to accommodate changing interior or exterior needs over time.

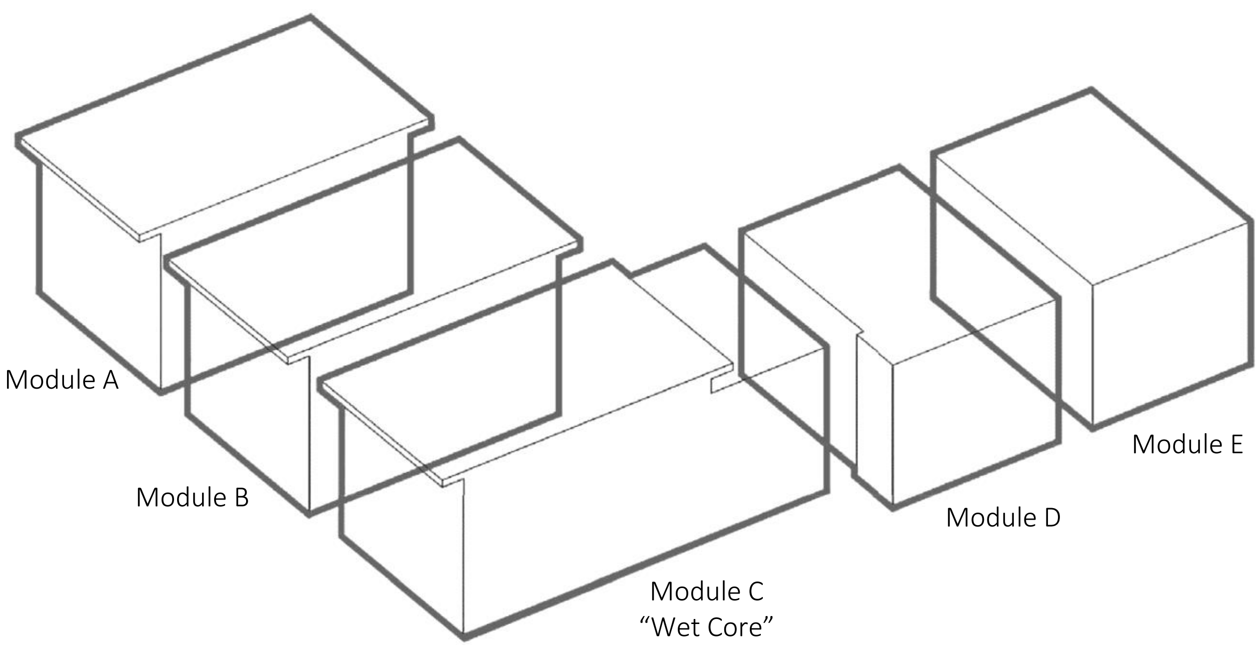
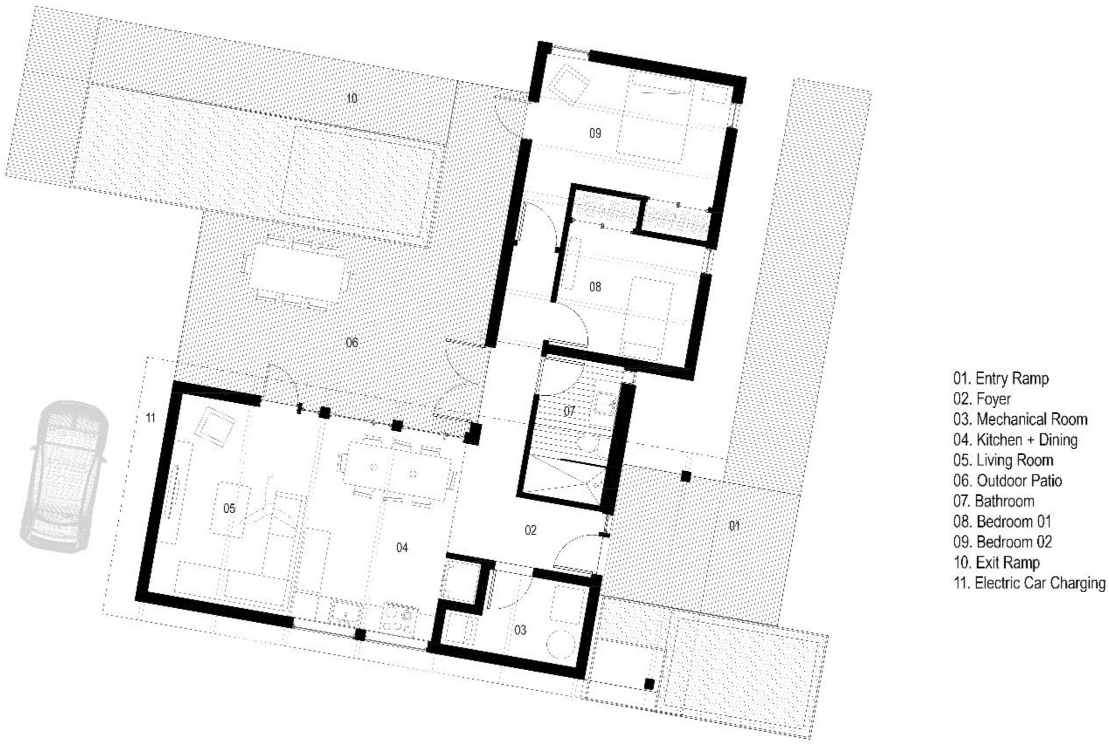


Figure 45. Solar Living House. Diagram showing five principal modules, as organized for the competition.

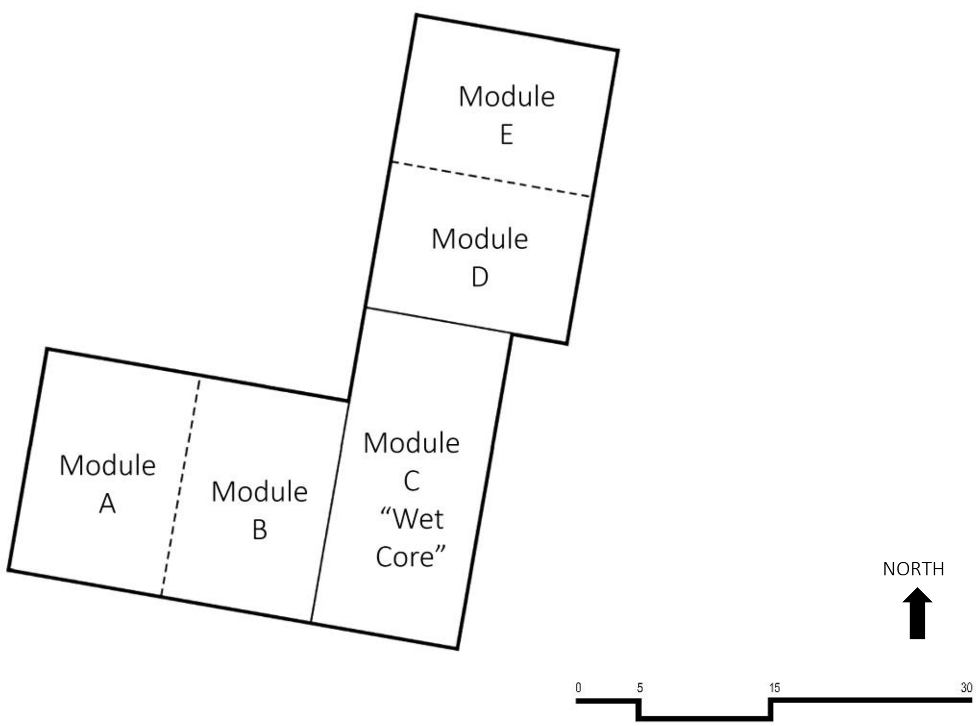
To further this concept, modules A, B, D, and E do not have interior load bearing walls or load bearing walls between them. They can be reconfigured as needed to accommodate changing needs.

Modular Construction

Illustrative floor plan:

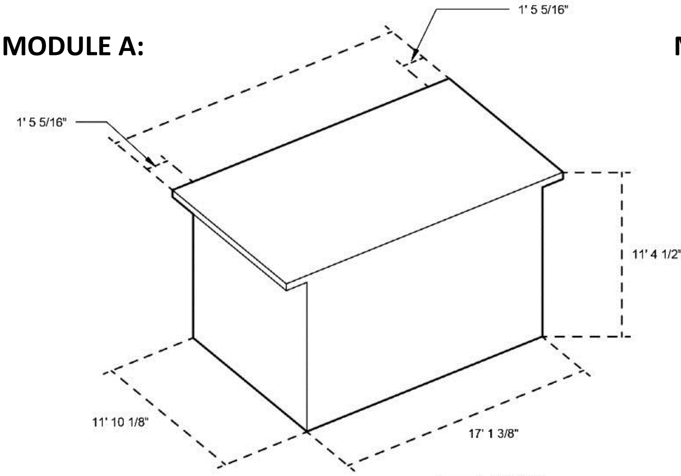


The basic module arrangement is as follows:

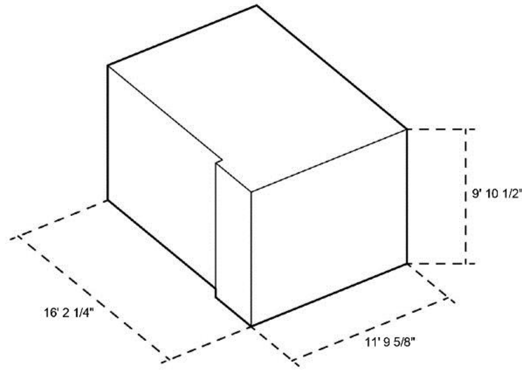


The approximate sizes and geometries of the modules are as follows (excerpted from G-003):

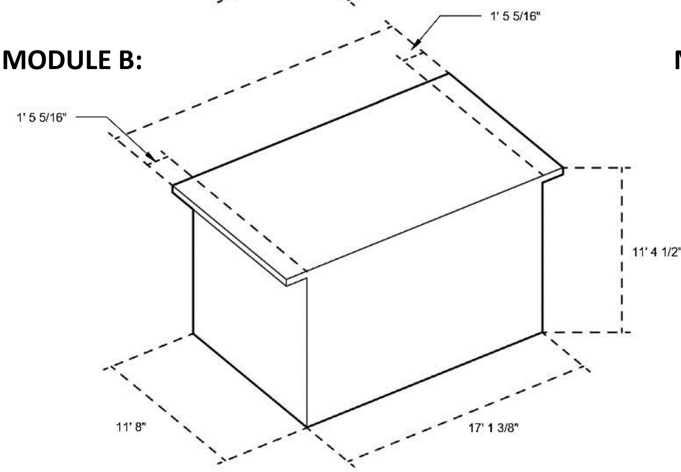
MODULE A:



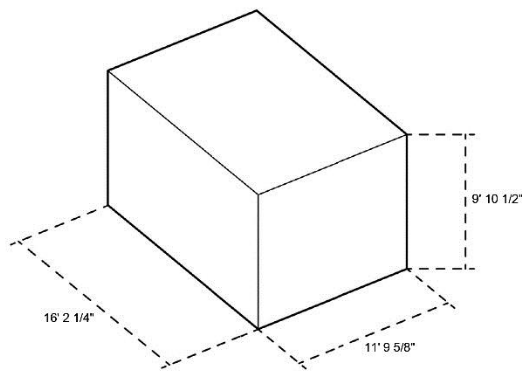
MODULE D:



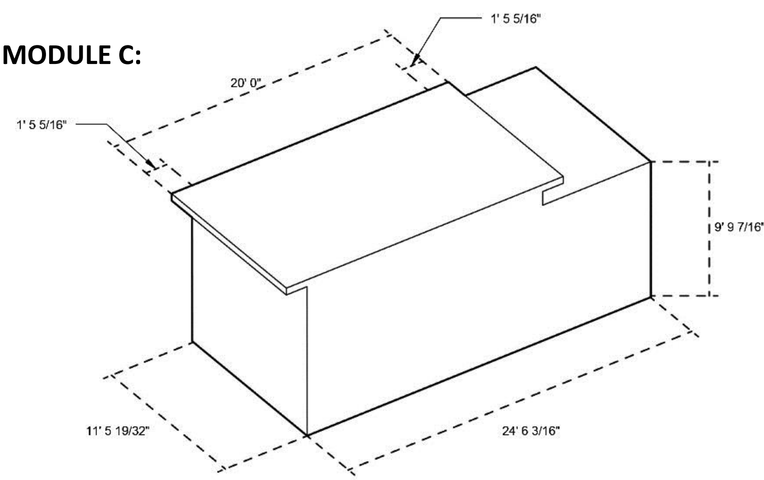
MODULE B:



MODULE E:



MODULE C:



Estimated Module Weights	
Module	Weight (lbs)
Module A	17,000
Module B	17,000
Module C	28,500
Module D	19,500
Module E	19,500

Note: These weights are generalized estimates to be confirmed by crane company prior to commencing work.

Off-Site Construction (Florida)

Principal construction activities in Florida took place at the Charles R. Perry Construction Institute at Santa Fe College. This 32,350 square foot facility includes 6,600 square foot high-bay construction studio with five-ton capacity overhead crane for lifting modular housing units, materials, and equipment.

Although the indoor construction studio was large enough to accommodate the modules, it was not large enough to allow the modules to be joined together as intended. As a result, exterior areas adjacent to the Perry Construction Institute were identified for module connection and testing areas, to be used once the separate modules were constructed and operational.

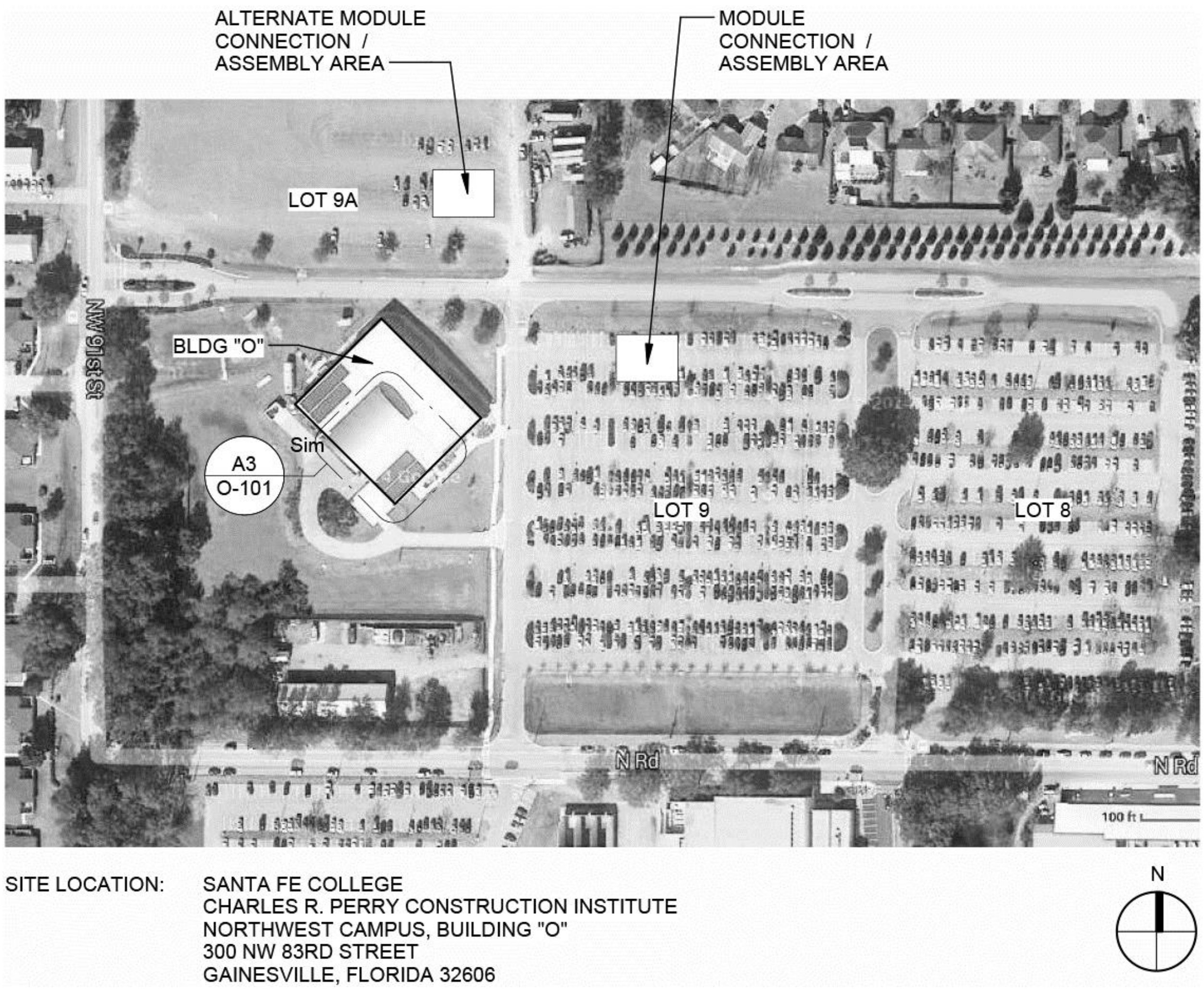


Figure 46.Principal construction locations in Florida.

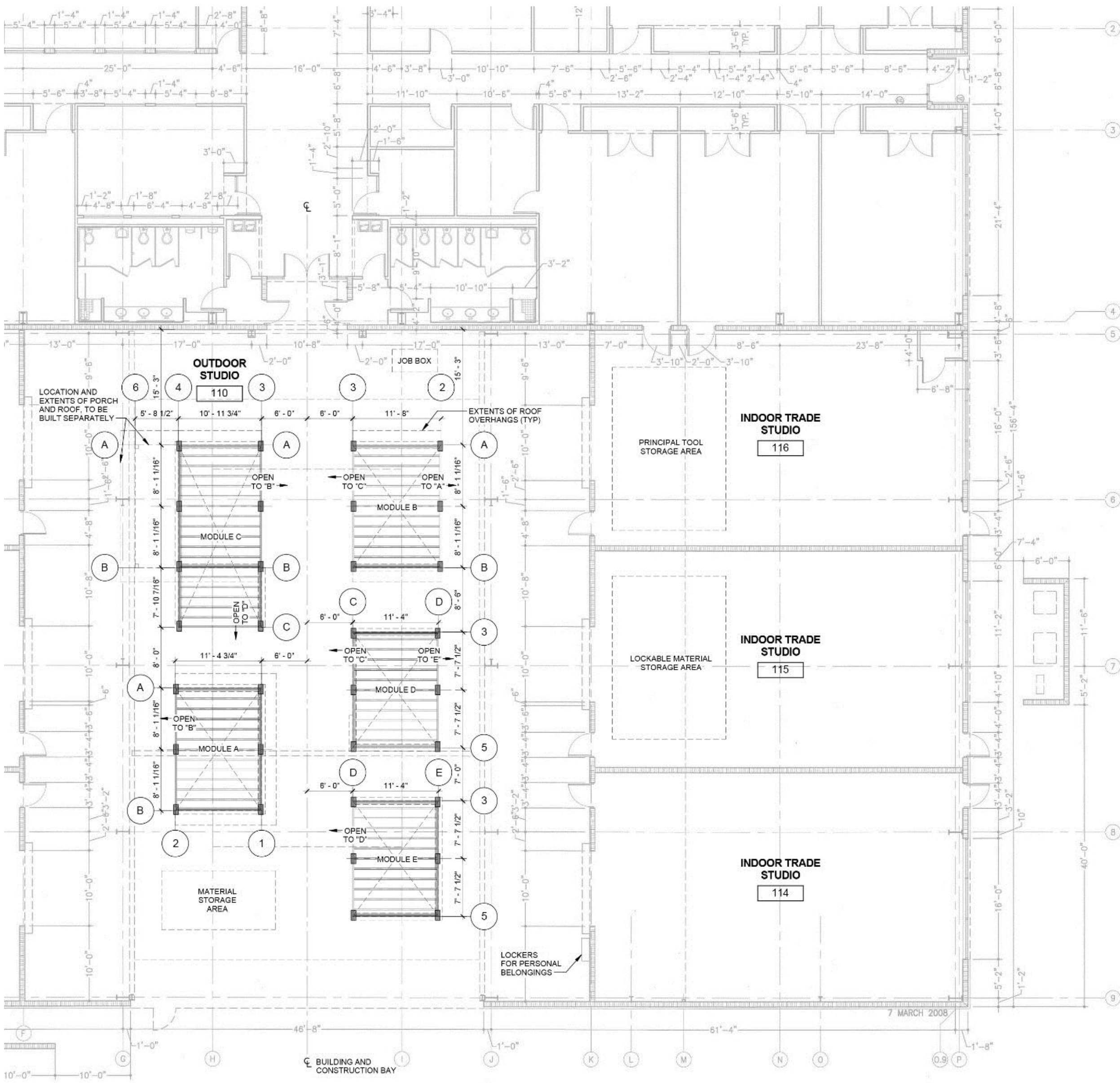


Figure 47. Partial floor plan of the Charles R. Perry Construction Institute at Santa Fe College, showing arrangement of modules in the construction studio. Adjacent trade studios were used for tool and material storage.

The modules were constructed on temporary concrete block piers, leaving sufficient space below them to allow for a truck to back under them to transport them out of the construction studio. Module framing and perimeter rim boards were designed to facilitate these movements.

Transportation to/from Competition Site

Transportation to and from the competition site proved expensive. A combination of single-drop trailers, double-drop trailers, step-deck trailers, and flatbed trailers were required.

Module Transportation Cost Estimate:

Module A:	Double-drop trailer	$ 10,000
	Tarp	$ 400
	Excess load/unload time	$ 800
	Subtotal	$ 11,200
Module B:	Double-drop trailer	$ 10,000
	Tarp	$ 400
	Excess load/unload time	$ 800
	Subtotal	$ 11,200
Module C:	Double-drop trailer	$ 10,000
	Tarp	$ 400
	Excess load/unload time	$ 800
	Subtotal	$ 11,200
Modules D+E:	Step-deck, single-drop trailer	$ 8,000
	Tarp	$ 400
	Excess load/unload time	$ 800
	Subtotal	$ 9,200
Miscellaneous	Flatbed trailer for accessories	$ 6,000
	Tarp	$ 200
	Excess load/unload time	$ 800
	Van trailer for accessories	$ 6,000
	Excess load/unload time	$ 800
	Pilot cars	$ 4,000
	Subtotal	$ 17,800
Total House Transportation Costs		$60,600

(excludes cranes, lifts, temporary structures, permit fees, etc.)

Competition Site Access and Circulation Routes

Motor vehicle operations will be necessary during the assembly and disassembly processes. Motor vehicles were also required during the competition, including vehicles moving to and from the competition site.

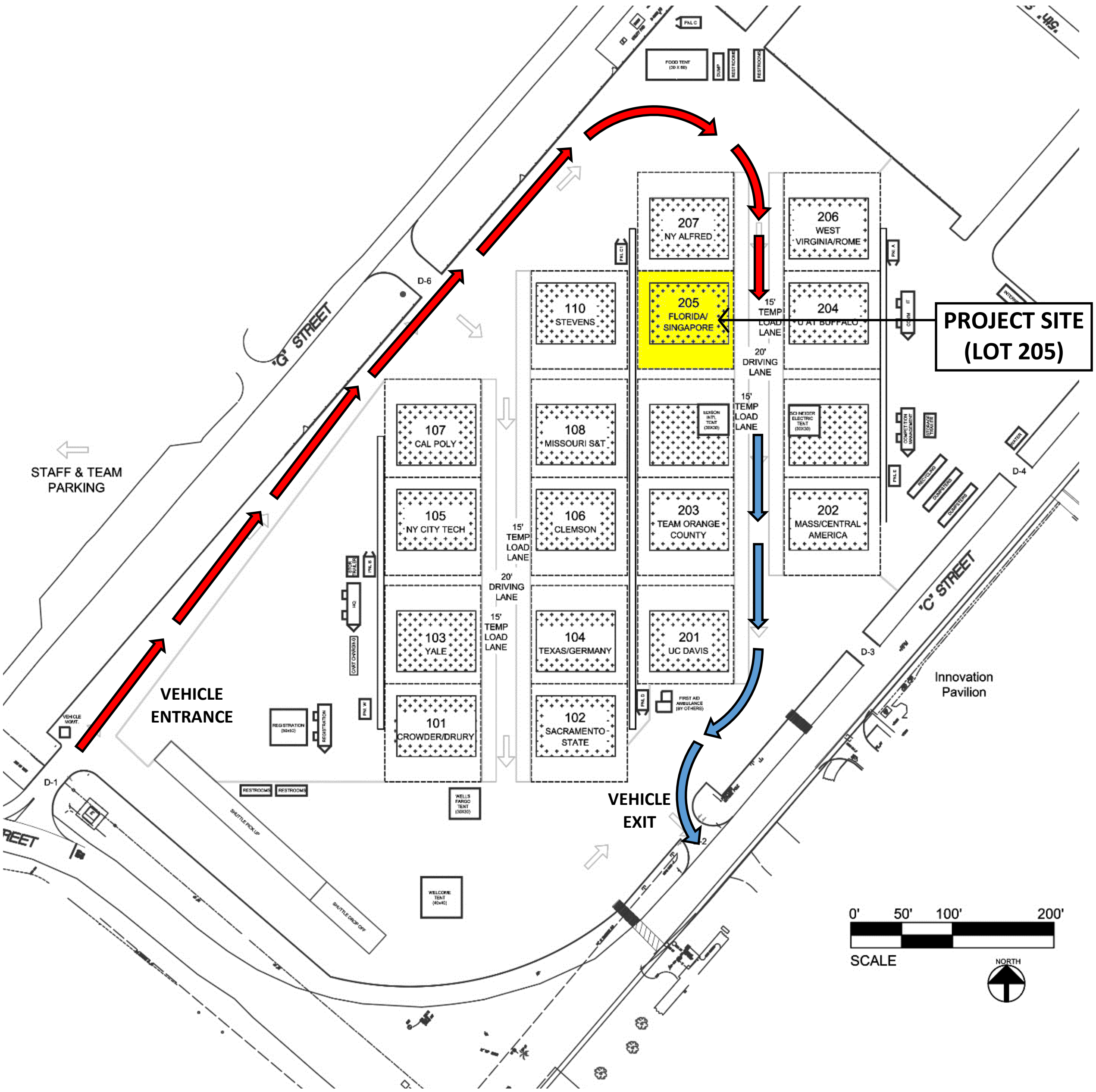


Figure 48. Competition site access and circulation routes.

Lift Plan and Assembly Sequence

On the first day of assembly and prior to the crane's arrival on site, the site will be surveyed and the house footprint laid out on the site with a series of temporary stakes, string lines, and chalk lines. A series of wood grade beams will then cut on site as required to follow the contour of the ground. They will be positioned on the ground, leveled, and anchored as shown on the structural and architectural drawings. The modules will be placed in accordance with the sequence specified on Sheet O-101. Connection details for fastening the modules to the ground are shown in Detail 1 and Detail 4 on Sheet SD-1.

Grade beam to be connected to the ground with 1" diameter A36 mild solid steel stakes (rods) driven a minimum of 36-inches into the existing asphalt. Typical spacing between rods is 24-inches on center. Refer to structural drawings for details.

Rotary hammers will be used to pre-drill to allow for the rods to then be driven into the surface.

Following placement, leveling, and anchorage of the perimeter wood grade beams, the crane will arrive on site and be located on the north side of the site, as shown on Sheet O-101. This positioning separates the crane from the designated flow of traffic on/around the site and eliminates the need to reposition the crane for a second lift. People on the active lift site will be minimized to the crane operator, crane company workers, and minimal Team Florida / Singapore members to ensure safety and reduce confusion. Pedestrian and unauthorized personnel will be prohibited from accessing the site with the use of "CAUTION" tape and temporary barricades.

Note: All of the structural connections are made from outside the footprint of the house to eliminate the need for team members to work below elevated/unstable loads.

The modules are rigged in accordance with the steps listed below and prepared for placement.

The crane will begin the lift and placement of module C and a team member will be present to instruct exact placement. After the module is set, an inspection will be completed. While module C is being lifted, the tractor trailer will exit the site and will return with module D. The riggers will then repeat the same process. Module D (and all subsequent modules) will require come-a-long brackets that will be attached when the module is close to being set down. The come-a-longs will be used to keep the second module square with the first module and keep an even gap between the two. After the lift is done, the rigging will be removed and final checks will be completed before the crane leaves. This process will be repeated for modules E, A, and B.

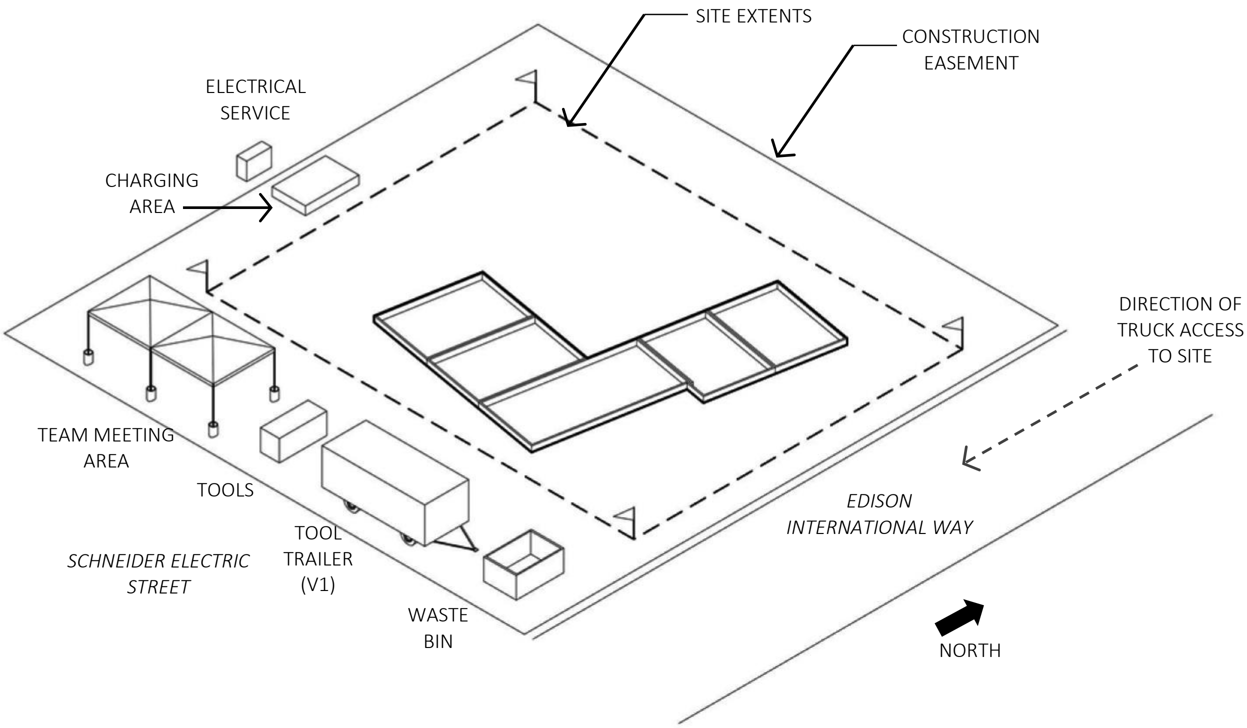
The pick points for the modules will be located approximately five feet from the end of each module or as directed by the crane and rigging company in consultation with the project's structural engineer. Grade beams and/or perimeter rim joists/beams will be notched to accept the cables/straps and to allow their removal following placement on site. We will utilize continuous steel cables or straps that are rated for the load and wrap down-under-up the module. These cables or straps have already been used in a crane lift and are designed to sustain the loads.

Rigging will involve spreader bars. The cables are free to create a natural angle when the crane hook is attached to the cables running from the hook to the spreader bars.

The movement of these components will be performed by trained and experienced professionals. Tag lines will be operated by trained crane company employees. The rigging will be performed mainly by the crane company with guidance from knowledgeable members pertaining to the lift. The crane company will provide rigging that has been properly maintained and inspected thoroughly. Sizing of the rigging will be calculated by the crane company with a large safety factor added on.

The on-site construction sequence is outlined on the following pages (excerpted from O-101).

Assembly Phase 1: Staging (Day 1)



Site Preparation:

- Team members access site
- Vehicle 1 arrives (tool trailer)
- Set up of survey equipment
- Survey of entire site recorded for use in house and deck leveling
- Set up tool zones, charging station, work area, and disposal container

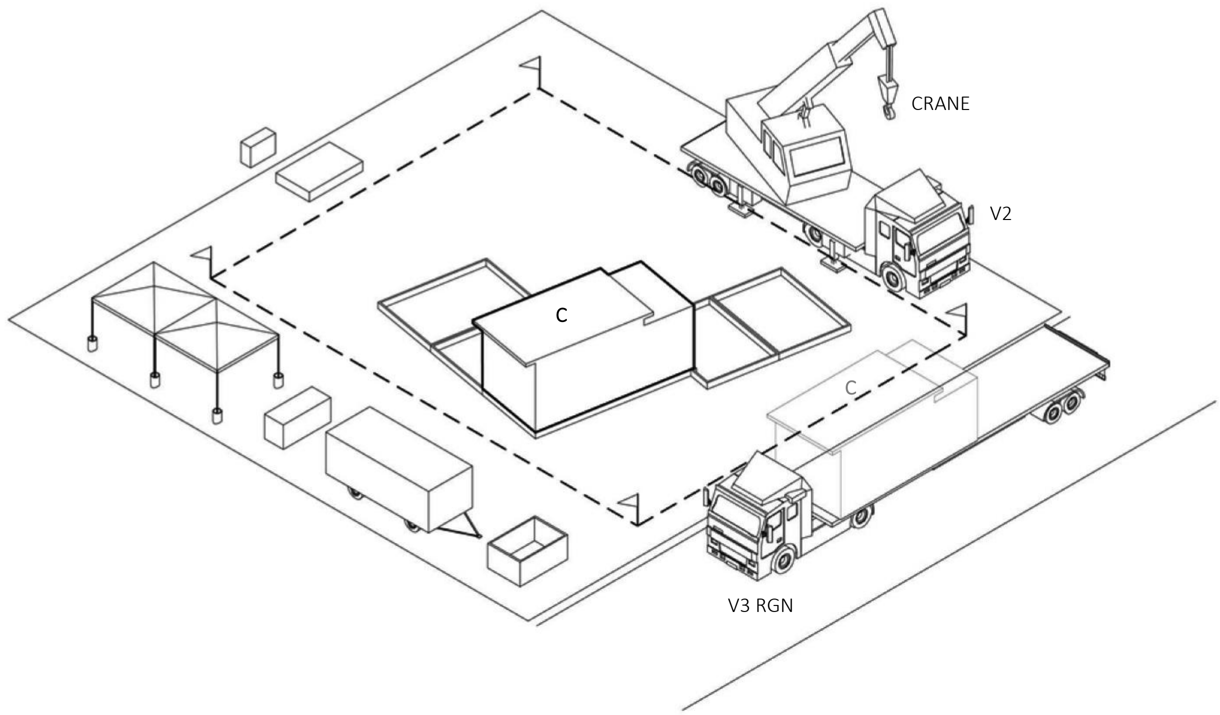
Placement of Foundation:

- Placement of grade beams (extracted from tool trailer)
- Attach steel angles to grade beams and asphalt (depending on topographical variations, the steel angles will be attached directly to the modules in some cases near the northern / uphill end of the site)

Crane Preparation:

- Prepare zone for crane access

Assembly Phase 2: House Modules + Deck + Water Tank Placement (Day 2: 7:00 am – 10:00 am)



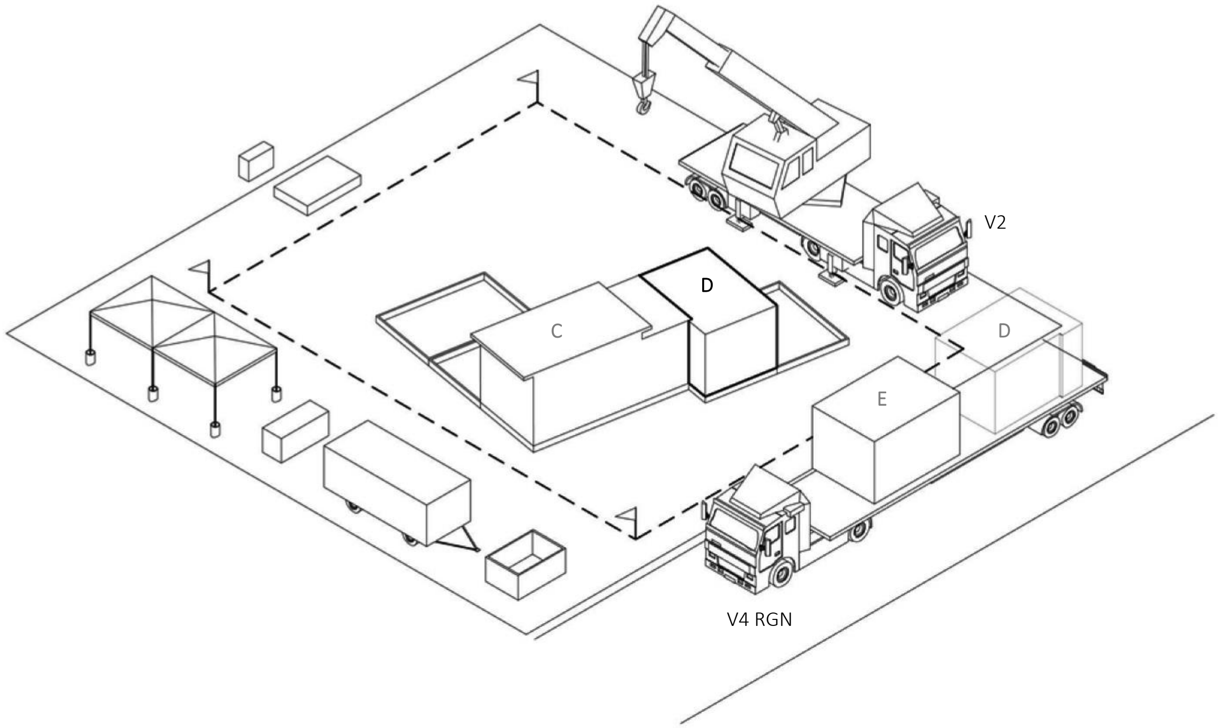
Crane Arrival:

- Crane arrives (V2) (Grove RT870) (32 tons at 60-foot reach and 50-foot height) and stages at north-east side of site.
- Estimated time to set up crane: 45 minutes.

Placement of Module C:

- Vehicle 3 arrives (RGN truck)
- Preparation of module C (wet module) for craning. Spreader bars and crane positioned to pre-determined loading points.
- Module C (wet module) is craned into place and set on grade beams (crane arm reach 40-50 feet).

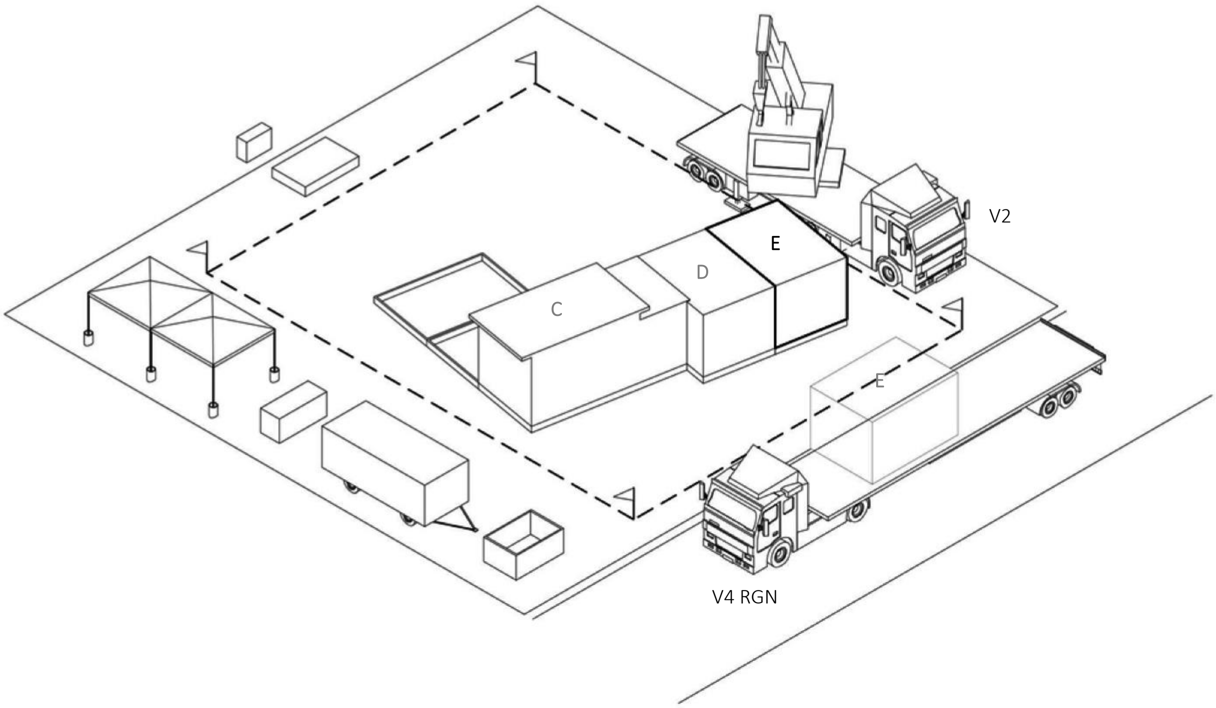
Assembly Phase 3: Day 2 (10:00 am – 2:00 pm)



Placement of Module D:

- Vehicle 4 (V4) arrives (RGN truck)
- Preparation of module D (bedroom 1) for craning. Spreader bars and crane positioned to pre-determined loading points.
- Module D (bedroom 1) is craned into place and set on grade beams (crane arm reach 20-50 feet).

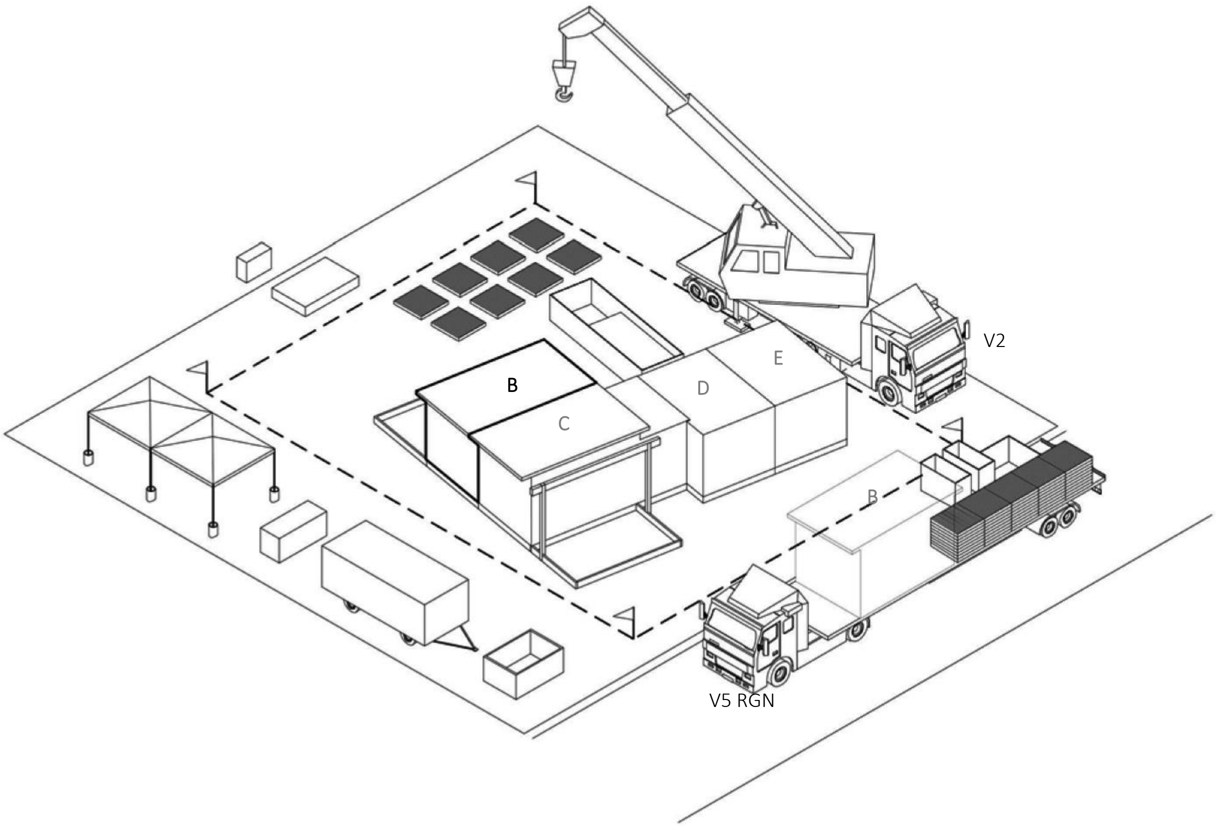
Assembly Phase 4: Day 2 (2:00 pm – 5:00 pm)



Placement of Module E:

- Preparation of module E (bedroom 2) for craning. Spreader bars and crane positioned to pre-determined loading points.
- Module E (bedroom 2) is craned into place and set on grade beams (crane arm reach 30-50 feet).
- Vehicle 4 (V4) departs.

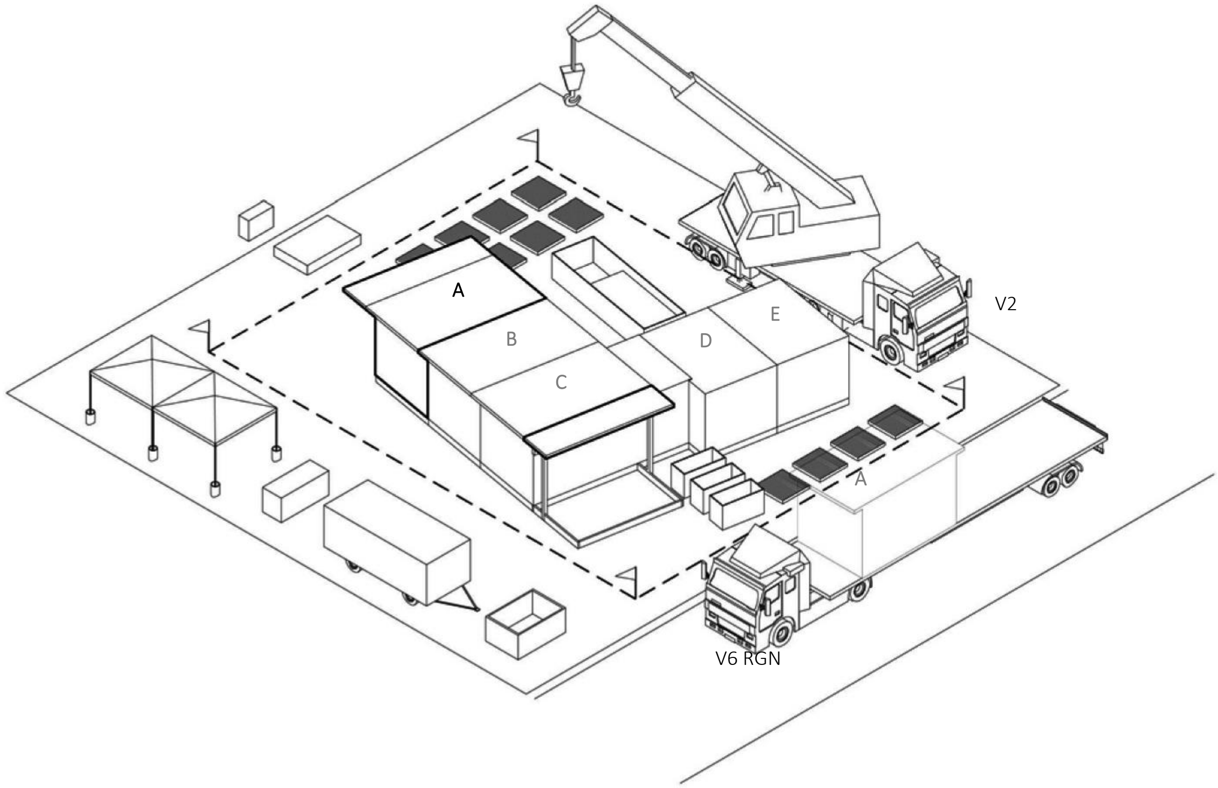
Assembly Phase 5: Day 3 (7:00 am – 10:00 am)



Placement of Module B + Back Deck + Tank Storage A:

- Vehicle 5 (V5) arrives (RGN truck).
- Preparation of module B (Living 1) for craning. Spreader bars and craning positioned to pre-determined loading points.
- Module B (Living 1) is craned into place and set on grade beams (crane arm reach 30-50 feet)
- Preparation of water tank storage units (WT A) for craning. Spreader bars and craning positioned to pre-determined loading points.
- Water tank storage units (WT A) are craned into place (northwest corner of site; crane arm reach 30-50 feet).
- Preparation of back decking units (D1) for craning. Spreader bars and craning positioned to pre-determined loading points.
- Back decking units (D1) are craned into place (northwest corner of site; crane arm reach 30-50 feet).
- Vehicle 5 (V5) departs.
- Place grade beams for front deck in preparation for Overhead A (OA).
- Place grade beams for back deck in preparation for Overhead B (OB).

Assembly Phase 6: Day 3 (10:00 am – 2:00 pm)



Day 3 (10:00 am – 2:00 pm): Placement of Module A + Front Deck + Tank Storage B:

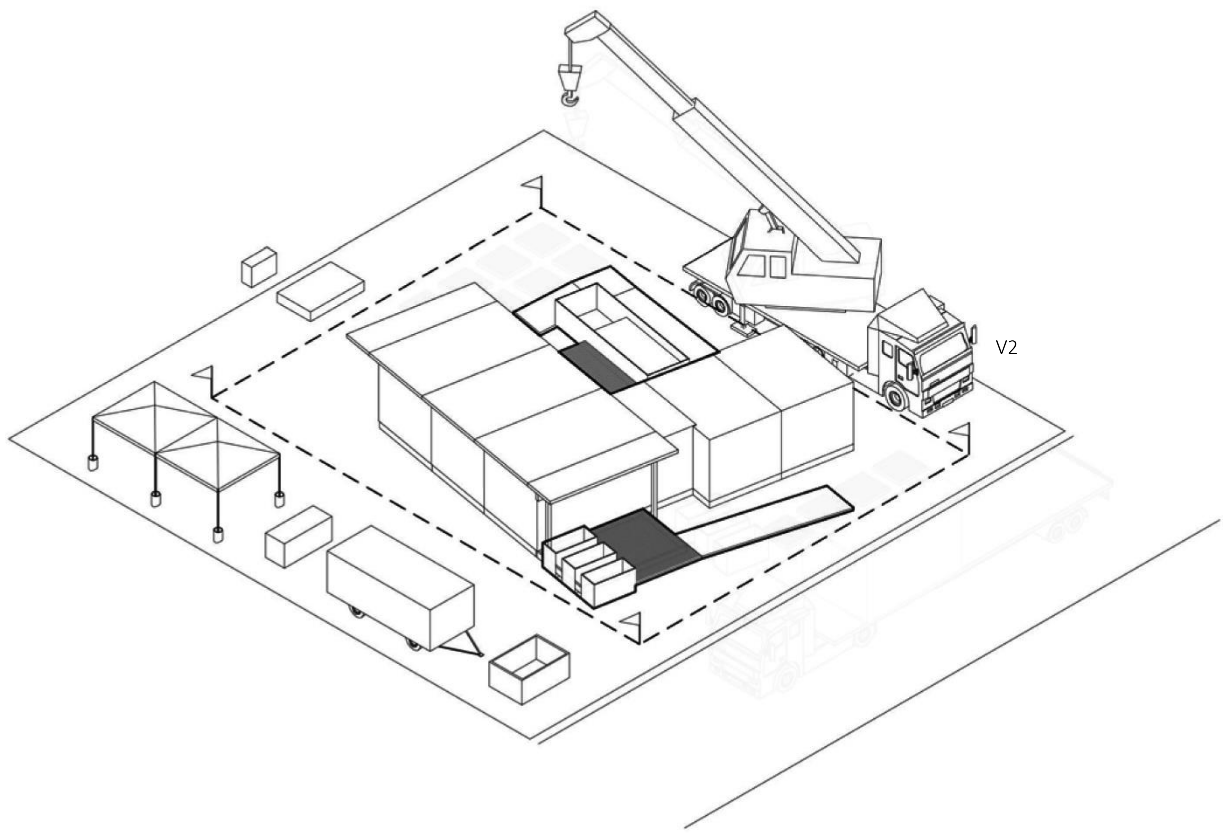
- Vehicle 6 (V6) arrives (RGN truck).
- Preparation of module A (Living 2) for craning. Spreader bars and craning positioned to pre-determined loading points.
- Module A (Living 2) is craned into place and set on grade beams (crane arm reach 30-50 feet).
- Preparation of water tank storage units (WT B) for craning. Spreader bars and craning positioned to pre-determined loading points.
- Water tank storage units (WT B) are craned into place (southeast location on the site). Crane arm reach 30-50 feet.
- Preparation of front decking units (D1) for craning. Spreader bars and craning positioned to pre-determined loading points.
- Front decking units (D1) are craned into place (southeast corner of site). Crane arm reach 30-50 feet.

Day 3 (2:00 pm – 5:00 pm): Overhead Additions:

- Preparation of front overhead addition (O1) for craning. Spreader bars and craning positioned to pre-determined loading points.
- Front overhead addition (O1) is craned into place (southeast corner of site, attached to module C). Crane arm reach 30-50 feet.

- Preparation of front overhead addition (O2) for craning. Spreader bars and craning positioned to pre-determined loading points.
- Front overhead addition (O2) is craned into place (southwest corner of site, attached to module A). Crane arm reach 30-50 feet.
- Preparation of PV system (PV) for craning. Spreader bars and craning positioned to pre-determined loading points.
- PV system (PV) is craned into place on top of living modules (crane arm reach 30-50 feet).
- Vehicle 6 (V6) departs.

Assembly Phase 7: Days 4-9



Assembly Phase 3: Modules, Envelope, Deck, and Finishes:

- Seam and join modules.
- Tighten and inspect all bolted connections.
- Foundation inspections.

Deck Installation:

- Preparation of deck installation (front and back decking + water tank storage units).
- Install electrical grounding.
- Placement of deck on grade beams (depending on topographical variations, the deck will rest on ground).
- Begin installation of deck on southwest side of the house to allow for electrical, plumbing, mechanical, and PV system installation of south deck and all ramps.

Roofing, PV, and Glazing Installation:

- Ladder positioned to guard rail to accommodate roof access.
- Team members on roof install temporary seams in roof membrane and flashing caps along roof edges.
- Team members install PV panels on roof.
- All remaining exterior finishes, screens, windows, doors, and other components are installed.

Mechanical + Electrical Installation:

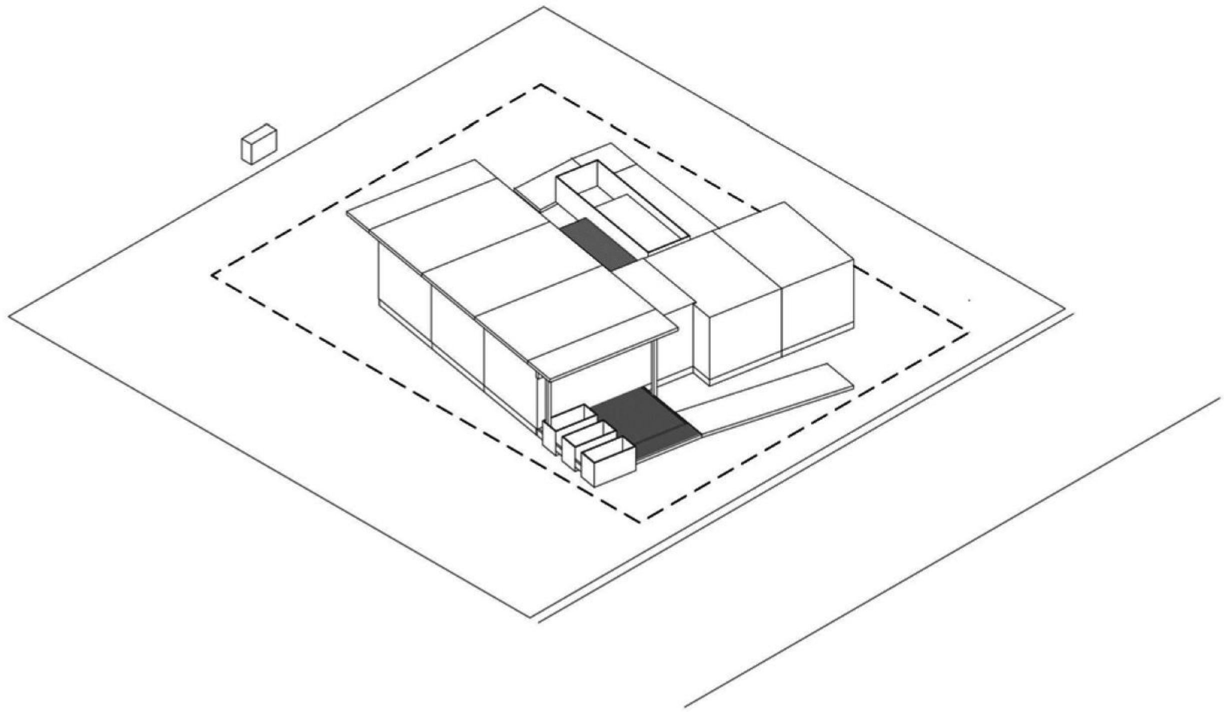
- Electrical grid tie-in under/around deck.
- Install water storage tanks under planters + water supply lines under/around deck.

Installation of Interior Finishes

Crane Departs:

- Crane departs (V2).

Assembly Phase 8: House Complete



Deck and Landscape Installation:

- Installation of all planters.
- Finish installation of deck units.

Exterior Finishing:

- Team to work with inspectors to finalize all exterior inspections.
- Team to facilitate water delivery.
- All exterior signage is installed.
- All landscaping is installed.

Interior Finishing:

- Appliances are installed.
- All millwork is installed.
- Wall panels, ceiling and floors are installed.

Site Cleanup:

- Team to work with inspectors to finalize all mechanical, electrical, and plumbing inspections.
- Team to finalize sensor and competition instrumentation.
- Systems testing and commissioning.
- Final inspections.

Site Cleanup:

- Vehicle 1 (tool trailer) departs with tools and miscellaneous supplies.
- House and site cleanup.
- Finalize preparations for competition.

Disassembly Sequence

The disassembly sequence is, in many ways, be the assembly sequence in reverse. The disassembly phase proceeds as follows:

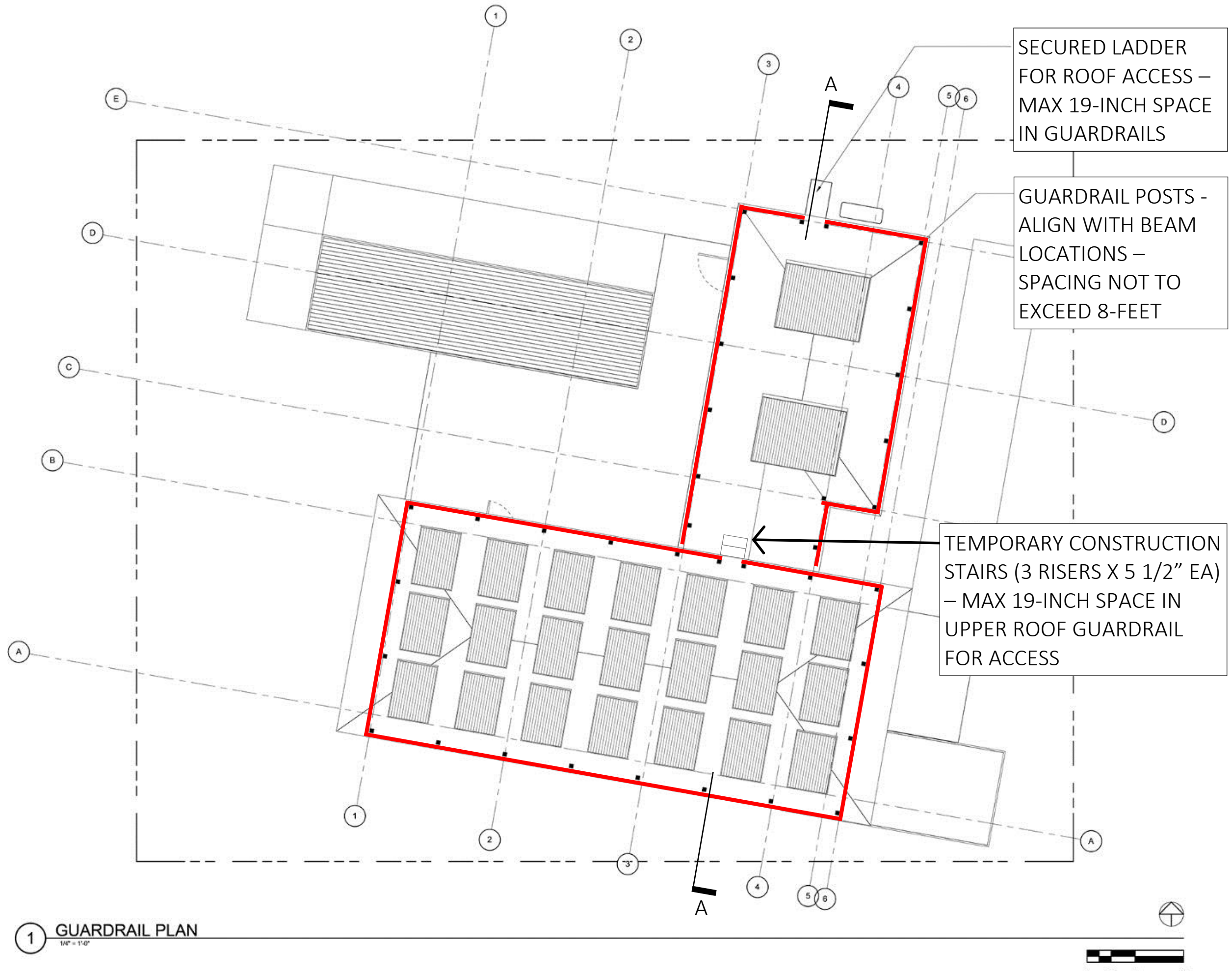
1. Remove breakable materials from walls/house. Pack furniture, housewares, etc. securely in modules.
2. Tool trailer arrives
3. Deck and landscape disassembly
4. Removal of exterior finishes where necessary for module transport or disconnecting equipment
5. Installation of guard rails at roof perimeter
6. Grid disconnection and PV removal
7. Separation of modules at roof (membrane + flashing components)
8. Removal of guard rails
9. Mechanical, electrical, and plumbing disassembly
10. Modules separated and removed
11. Remove perimeter grade beams from site
12. Empty and remove water tanks
13. Final components disassembled and removed from site
14. Preliminary review of site for with Solar Decathlon organizers
15. Site clean-up + repair of pavement if/as needed
16. Vehicle 1 (tool trailer) departs site
17. Final policing and clean-up of site
18. Turn over site to Solar Decathlon organizers

Fall Protection during Construction / Disassembly

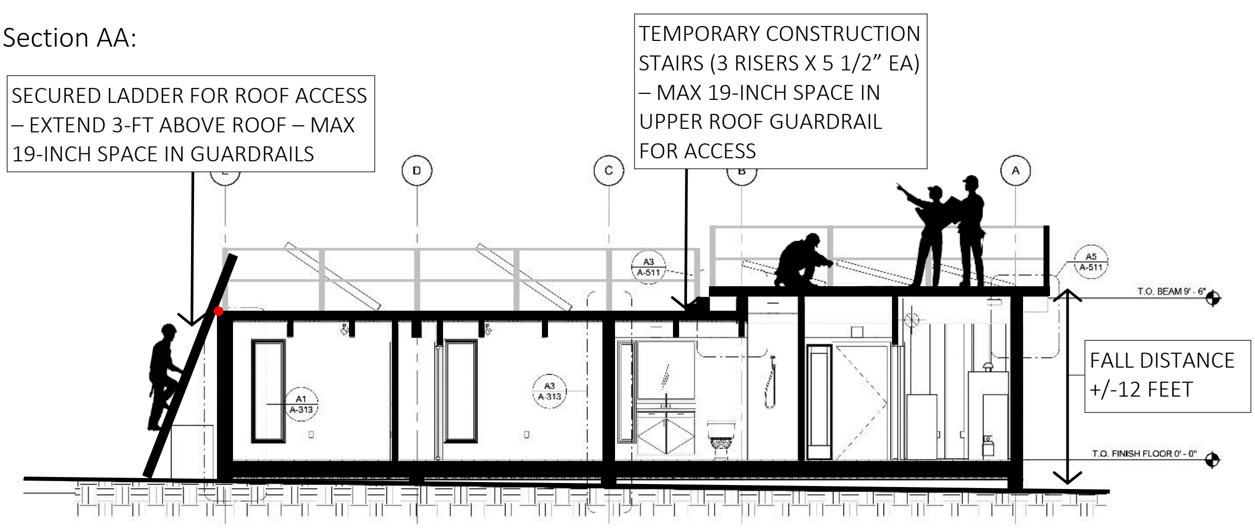
A temporary guardrail system was required at the perimeter of the roof when elevated work is being performed. The guardrail was designed to meet OSHA requirements, including height and force resistance, with posts spaced no more than 8-0” apart. As it was a manufactured system, fall protection system design certification was provided by the manufacturer. Guardrail was inspected daily by the Health Safety Officer (HSO) and repaired if needed to maintain compliance.

Access to the roof was provided through a secured ladder and temporary steps. Additional elevated work involved the use of a mobile scaffold with adjustable legs and locking castors.

Guardrail and Access Plan



Section AA:



Temporary Foundations Required for Competition Site

The competition site in the Orange County Great Park was a paved parking lot. Temporary foundations were required to limit ground disturbance at the competition site. As outlined in rule 4-3 Ground Penetration:

> *Ground penetration is permitted only for the approved method for tie-downs needed to meet wind loading and seismic requirements. Ground penetrations should be minimized and must be approved by the organizers prior to arrival at the competition site. All other ground penetrations shall not be permitted.*

In addition to minimizing ground disturbance, the temporary foundations also had to accommodate a sloping site (approximately one foot of fall across each house site). There was an interest in minimizing vertical height of foundations, to reduce the lengths of ramps and guard rails required for access.

After considering a number of options, the project team decided to use a system of wood grade beams as the temporary foundations. These grade beams, nominally 6” wide, were cut to follow the slope of the site and then anchored into the existing pavement surface with steel stakes. Approximately 162 steel stakes were required for the temporary foundations of the house.

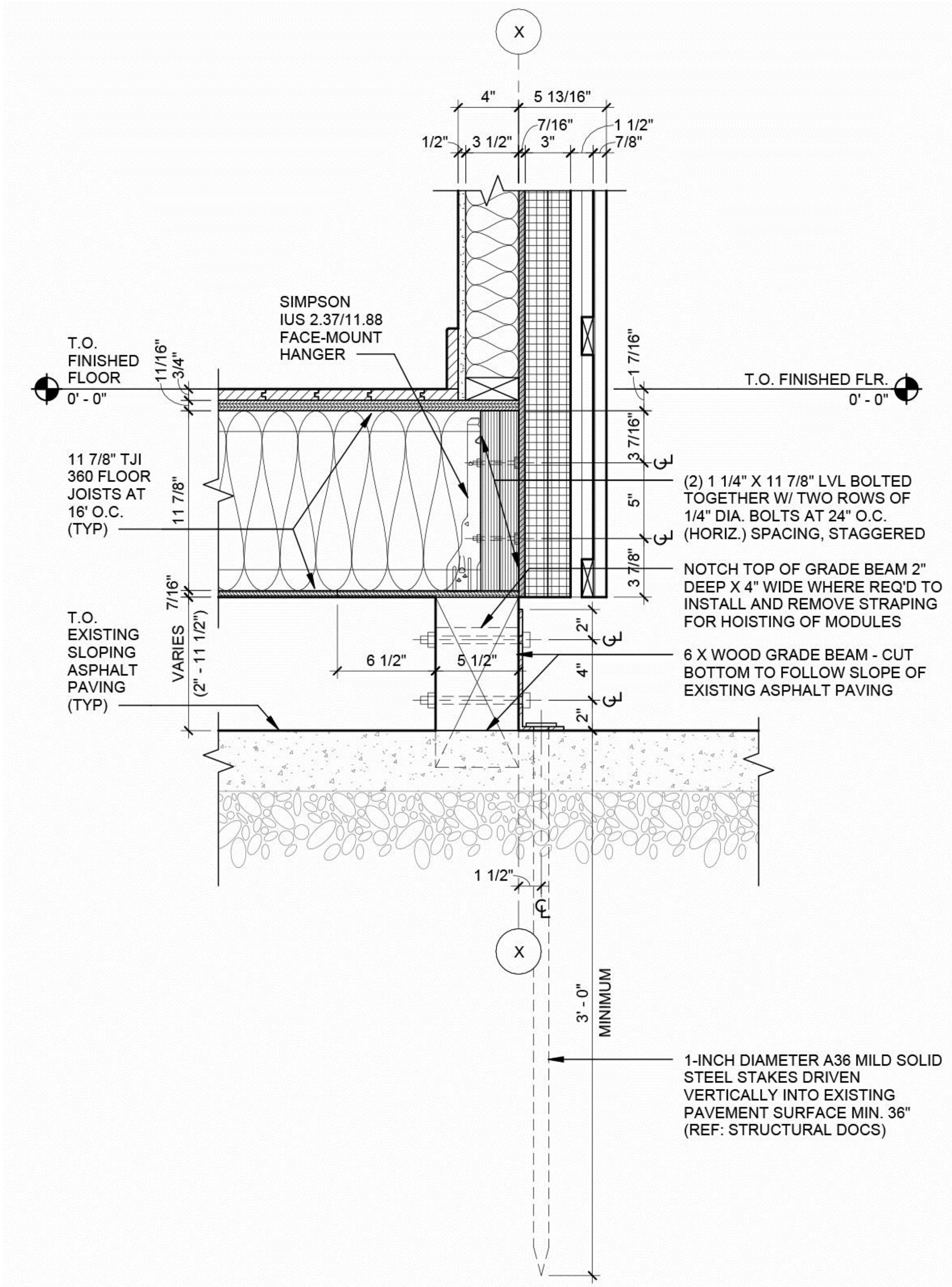


Figure 49. Temporary foundation detail showing grade beams and steel stakes (A5/A-511).

Figure 50. Temporary grade beams and foundation stakes, in plan (A1/A-105).

COMPETITION SCHEDULE + DELIVERABLES

The project was organized with two separate management structures within the DOE, one that was responsible for advancing the project itself and one that was focused on contracts and financial arrangements. Each of these different management teams had their own reporting schedules, deliverables, and meetings with the team. In addition, academic calendars did not align with competition or contract deliverables, creating an additional level of planning complexity.

Competition Deliverables / Meetings		Contract Deliverables / Meetings		University of Florida Academic Calendar	
				08/21/13	First Day of Classes – Fall 2013 Semester
		11/01/13	Funding Opportunity Announcement Posted		
				12/04/13	Last Day of Classes
				12/05/13- 12/13/13	Exams
		12/20/13	Proposal Deadline	12/14/13- 01/05/14	Winter Break
				01/06/14	First Day of Classes – Spring 2014 Semester
		02/13/14	Selection of Participating Teams and Public Announcement		
		02/21/14	Pre-Award Submission + Teleconference		
03/05/14	All-Team Teleconference	03/05/14	• Environmental Questionnaire • Detailed Budget Justification (PMC123.1) • Statement of Project Objectives (SOPO) • SF424A	03/01/14- 03/09/14	Spring Break
03/13/14	Team Excitement Video				
		03/24/14	Revised Detailed Budget Justification (PMC123.1)		
04/02/14	All-Team Teleconference Competition Site Announced				
		04/14/14	Award Document Finalized and Issued to Team		
				04/23/14	Last Day of Classes
04/24/14	Schematic Design Summary Target Construction Cost			04/24/14- 05/02/14	Exams
05/07/14	All-Team Teleconference			05/03/14- 05/11/14	Summer Break
				05/12/14	First Day of Classes – Summer A 2014
05/27/14	Schematic Design Webinar				
06/04/14	All-Team Teleconference				
				06/21/14- 06/29/14	Summer Break

Competition Deliverables / Meetings		**Contract Deliverables / Meetings**		**University of Florida Academic Calendar**	
		06/30/14	Quarterly Report 01	06/30/14	First Day of Classes – Summer B 2014
07/02/14	All-Team Teleconference				
08/06/14	All-Team Teleconference				
				08/09/14-08/24/14	Summer Break
				08/25/14	First Day of Classes – Fall 2014 Semester
		08/30/14	Continuation Application		
08/28/14	Preliminary Website				
09/03/14	All-Team Teleconference				
		09/30/14	Quarterly Report 02		
		09/30/14	Summary of Progress for Continuation Application		
10/01/14	All-Team Teleconference				
10/09/14	Design Development Documentation: • BIM Model • Drawings • Project Manual • Health and Safety Plan • Target Construction Cost				
11/05/14	All-Team Teleconference				
11/18/14	Design Development Resubmission: • BIM Model • Drawings • Project Manual				
12/03/14	All-Team Teleconference				
				12/10/14	Last Day of Classes
12/18/14	Digital Images/Animations: • Computer-Animated Walkthrough • Computer-Generated Renderings			12/11/14-12/19/14	Exams
		12/30/14	Quarterly Report 03	12/20/14-01/05/15	Winter Break
				01/06/15	First Day of Classes – Spring 2015 Semester
01/08/15-01/09/15	Design Development Meeting (Irvine CA)				
01/19/15	Estimate Clarifications Due				
02/04/15	All-Team Teleconference				
02/12/15	Construction Documentation: • BIM Model • Drawings • Project Manual • Health and Safety Plan • Target Construction Cost • Stamped Structural Drawings • Structural Calculations				

Competition Deliverables / Meetings		**Contract Deliverables / Meetings**		**University of Florida Academic Calendar**	
		02/20/15	Revised Continuation Application Submitted		
03/04/15	All-Team Teleconference			02/28/15- 03/08/15	Spring Break
03/26/15	CD Resubmission #1 Due: • BIM Model • Drawings • Project Manual • Health and Safety Plan				
		03/30/15	Quarterly Report 04		
04/01/15	All-Team Teleconference				
				04/22/15	Last Day of Classes
04/23/15	Project Summary Due			04/23/15- 05/01/15	Exams
05/06/15	All-Team Teleconference			05/02/15- 05/10/15	Summer Break
				05/11/15	First Day of Classes – Summer A 2015
05/12/15	CD Resubmission #2 Due: • Drawings • Structural Addendum • Health and Safety Plan				
		05/14/15	Revised Continuation Application Submitted		
05/28/15	Project Summary Resubmission Due				
06/03/15	All-Team Teleconference				
		06/11/15	Continuation Application Approved, allowing for purchase of materials		
06/25/15	Public Exhibit Materials Final Safety Plan Due			06/20/15- 06/26/15	Summer Break
		06/30/15	Quarterly Report 05		
07/01/15	All-Team Teleconference				
				07/21/15	Memorandum of Understanding (MOU) between UF and Santa Fe College approved, allowing construction to proceed
				07/31/15	Team Florida/Singapore notified competition organizers of their intent to withdraw from the competition, citing funding difficulties
08/05/15	All-Team Teleconference				
				08/07/15	Last Day of Classes
08/17/15	As-Built Documentation Due: • BIM Model • Drawings • Project Manual • Audiovisual Presentation			08/08/15- 08/23/15	Summer Break

Competition Deliverables / Meetings		Contract Deliverables / Meetings		University of Florida Academic Calendar	
	• Jury Narratives • Final Public Exhibit Materials • Final Website				
				08/24/15	First Day of Classes – Fall 2015 Semester
09/02/15	All-Team Teleconference				
09/27/15	All-Team Meeting (Irvine CA)				
09/28/15-10/07/15	Assembly + Opening Events (Irvine CA)	09/30/15	Quarterly Report 06		
10/08/15-10/18/15	Competition (Irvine CA)				
10/19/15-10/23/15	Disassembly (Irvine CA)				
11/20/15	Final Report Due				
				12/09/15	Last Day of Classes
				12/10/15-12/18/15	Exams
		12/30/15	Quarterly Report 07	12/19/15-01/04/16	Winter Break
				01/05/16	First Day of Classes – Spring 2016 Semester
				02/27/16-03/06/16	Spring Break
		03/30/16	Quarterly Report 08		
		04/15/16	Quarterly Report 09		
				04/20/16	Last Day of Classes
				04/21/16-04/29/16	Exams
				04/30/16-05/08/16	Summer Break
				05/09/16	First Day of Classes – Summer A 2016
				06/18/16-06/26/16	Summer Break
		07/15/16	Final Technical Report Due		

CRONOLOGICAL PROJECT PROGRESS + HISTORICAL ACCOUNTING

Conceptual Design

On 1 November 2013, the US Department of Energy issued Funding Opportunity Announcement (FOA) Number DE-FOA-0000959, FOA Type: Initial, CFDA Number: 81.086. This FOA outlined the application process that would be used for the selection of participants in the Solar Decathlon 2015. The submission deadline was set for 20 December 2013, 5:00pm Eastern Time.

In response to this FOA, a team from the University of Florida (with assistance from Santa Fe College and the National University of Singapore) prepared and submitted a proposal for consideration by the DOE.

The proposal prepared by "Team Florida/Singapore" was titled SLH #1, short for "Solar Living House," number 1. The concept envisioned this project to be the first of a number of related studies, similar to the Case Study House program decades earlier. The proposal included conceptual design studies for the project, describing an "L-shaped" house with courtyard and occupiable roof terrace.

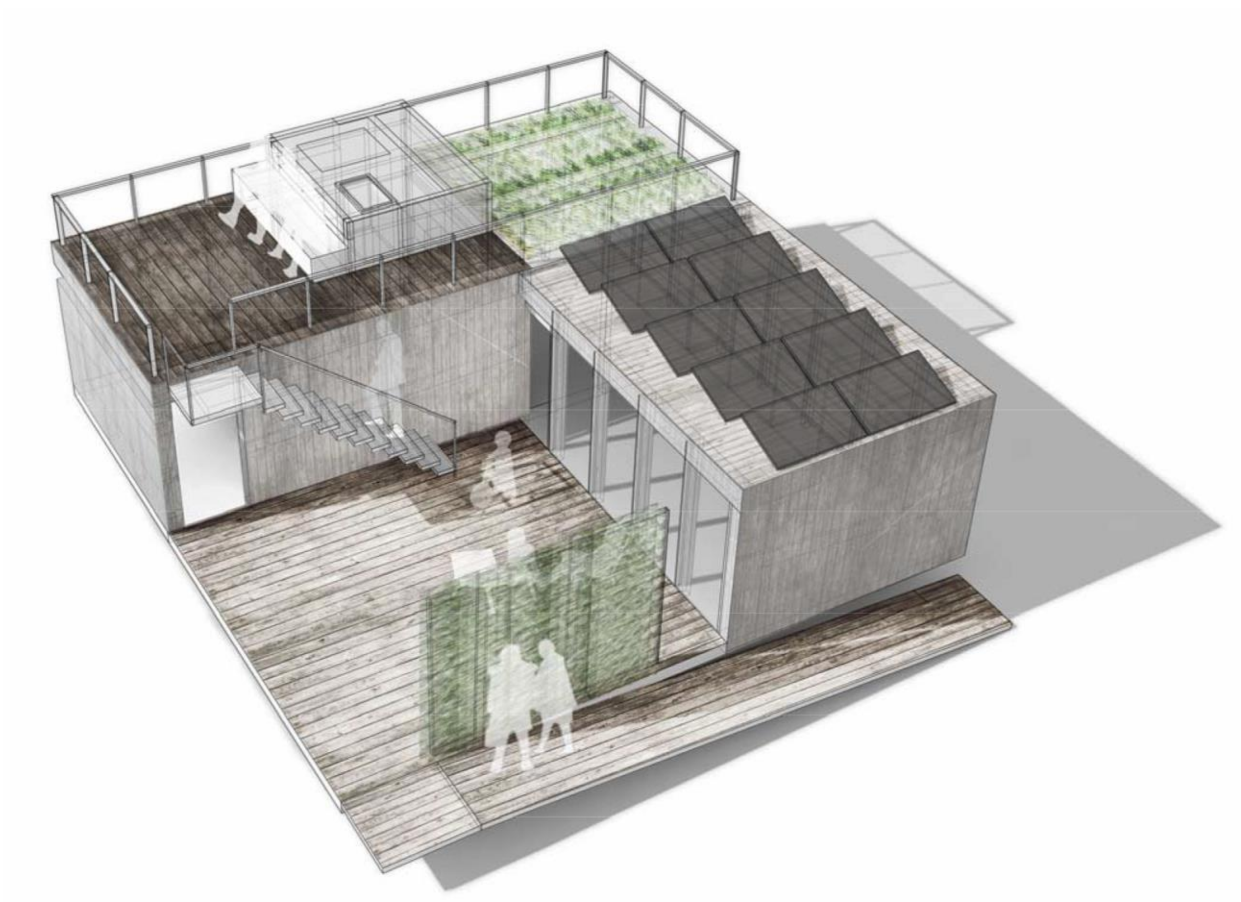
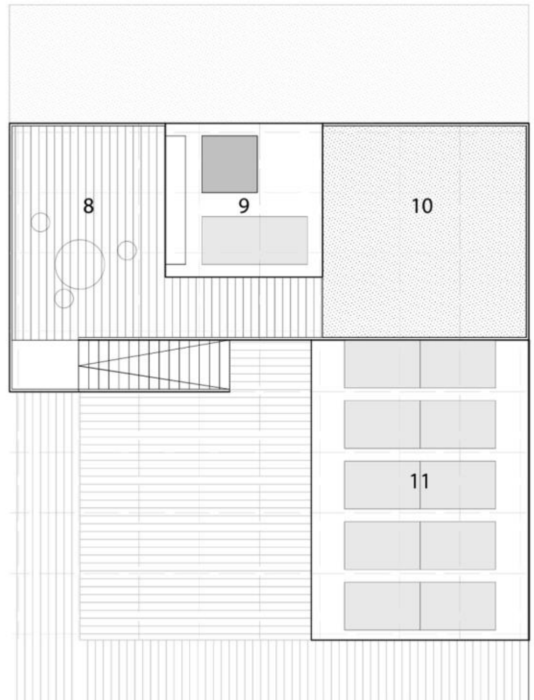


Figure 51. Solar Living House. Concept proposal, bird's eye view.

SCHEMATIC FLOOR PLANS

GROUND FLOOR PLAN

1. Entrance Ramp
2. Outdoor Living Room
3. Main Living Space
4. Dining Space
5. Kitchen/Laundry Unit
6. Bathroom/Installations
7. Bedroom



ROOF PLAN

8. Roof Deck
9. Roof Installation Core
10. Roof Garden
11. Solar PV Array

N

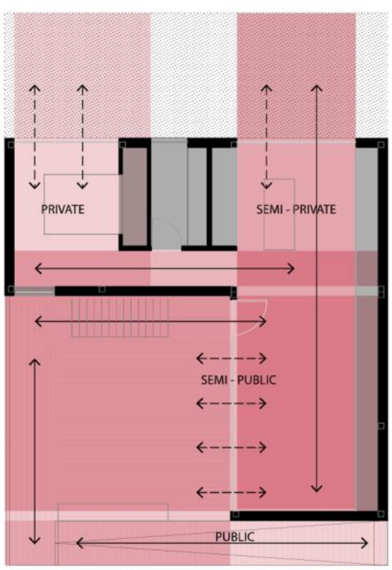


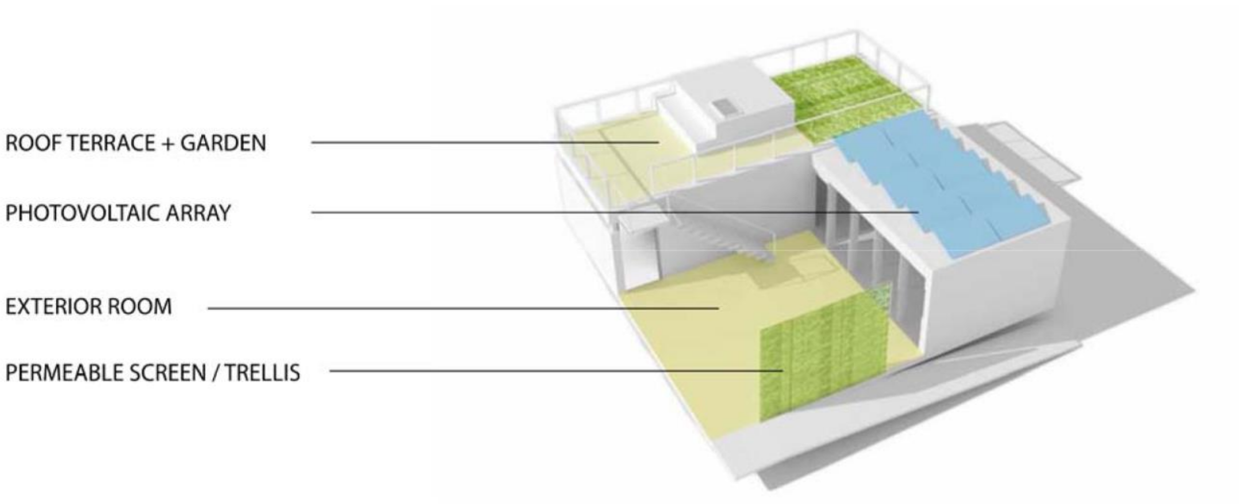
Figure 52. Conceptual design.

MOVING FROM PUBLIC TO PRIVATE

The schematic design focuses on a layered sequence of spaces that within a very limited amount of space moves progressively from the public realm to the private.

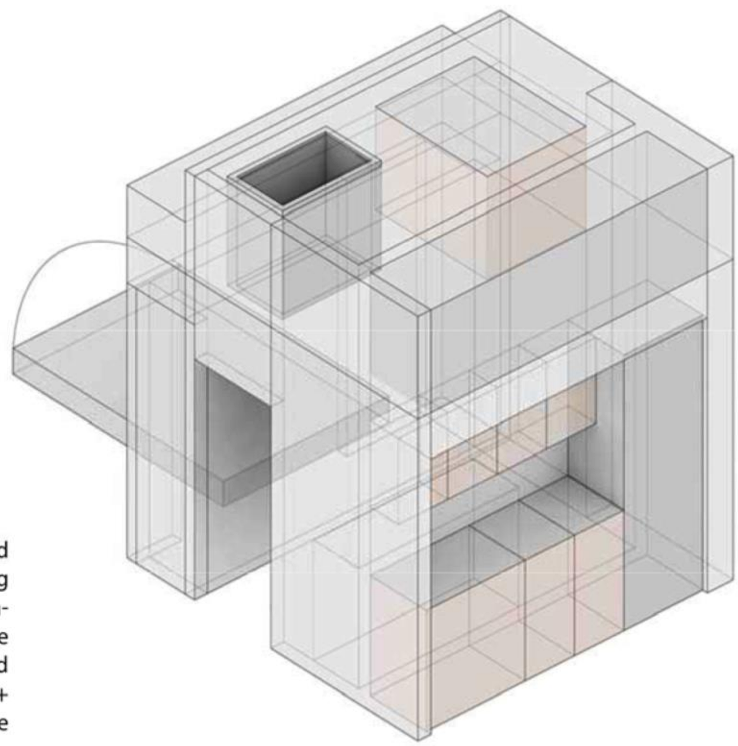
SOLAR LIVING

The design makes the most of the modest space though an open layout, the infiltration of natural daylight, maximizing the use of exterior spaces and the relation of interior spaces to them. The scheme is composed of two modules forming an L that frame an entrance courtyard filled with sunlight. This courtyard becomes an outdoor room that acts as an extension of the interior living spaces. The occupiable roof in turn completes the narrative between interior and exterior by offering and focusing a view toward the sky.



INFRASTRUCTURAL CORE

- Kitchen Unit
- Full Bathroom
- Washer/Dryer
- High Efficiency Heating + Cooling System w/ Heat Recovery
- Electrical Panel
- Rainwater Cistern
- Greywater Cistern
- Solar Water Heater w/ Cistern
- Storage
- Built-In Furniture (seating + sleeping)

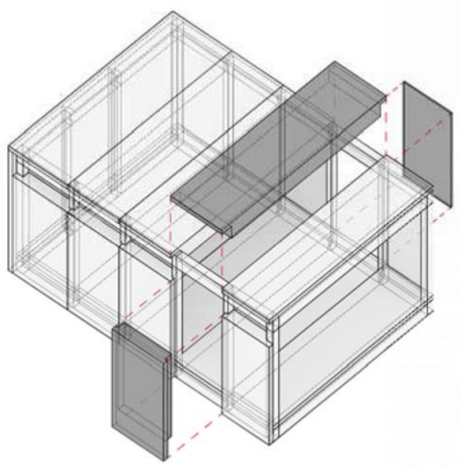


The consolidation of services into a centralized core helps reduce costs and frees the remaining spaces from the burden of installations and potential conflicts with the structural system. The remaining installations that need to be distributed throughout the house (electrical, data, heating + cooling) are able to be run through channels in the prefabricated system.

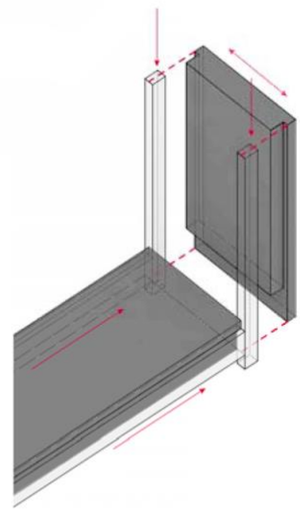
Figure 53. Conceptual design.

CONSTRUCTION SYSTEM

The house is conceived as a kit of parts utilizing digital fabrication technologies and offsite construction. This enables tolerances of 1/100" instead of 1/8" or 1/4" that is the industry standard. This results in Higher performance, better control of quality, and the opportunity that primary system elements may also fulfill the role of finish materials and surfaces. Digital fabrication also has the potential of rapid scaleability ennabling further industry cost savings. The separation of of modular system can allow for the systematic control of daylight, therby reducing overall energy usage.



FRAME + MODULE



FRAME + INFILL

MODULAR CONSTRUCTION

The approaches of modular factory construction and a robust frame system with infill panels allows for a high degree of variability to respond to a variety of considerations from site size, topography, and orientation, to client preferances. Any such configuration can be adapted over time as well to fit changing needs such as family size or live/work configurations.

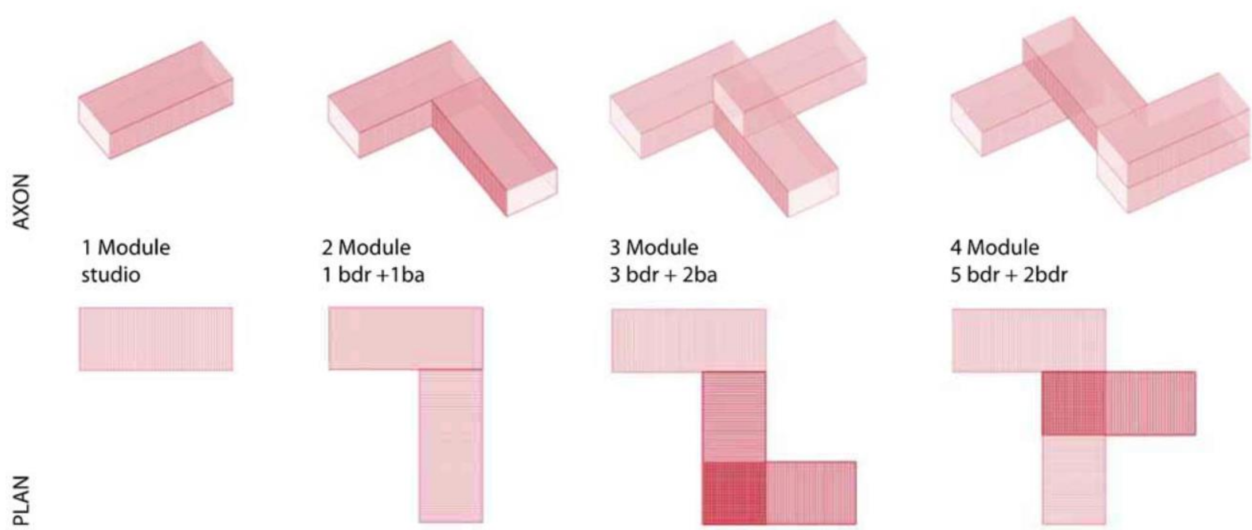
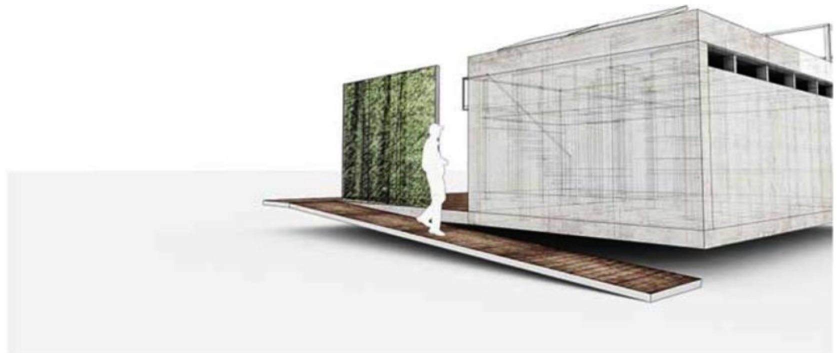
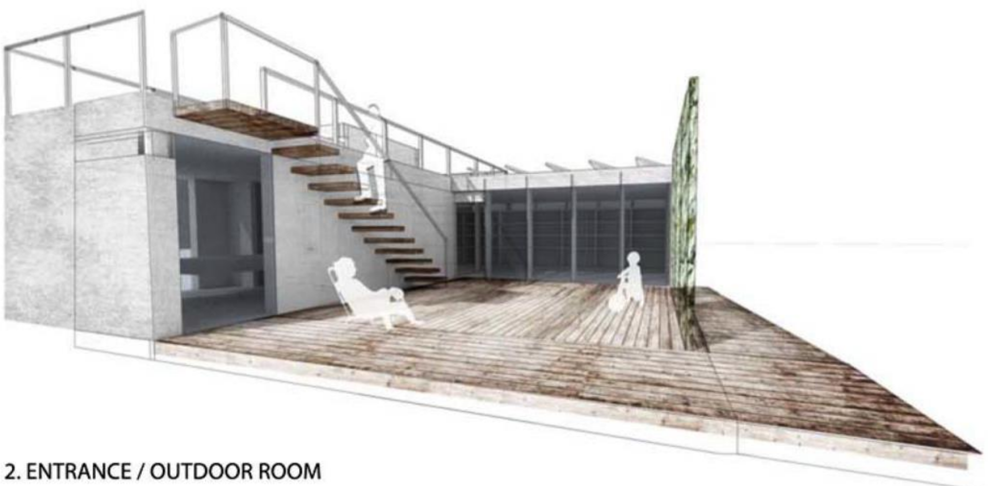


Figure 54. Conceptual design.

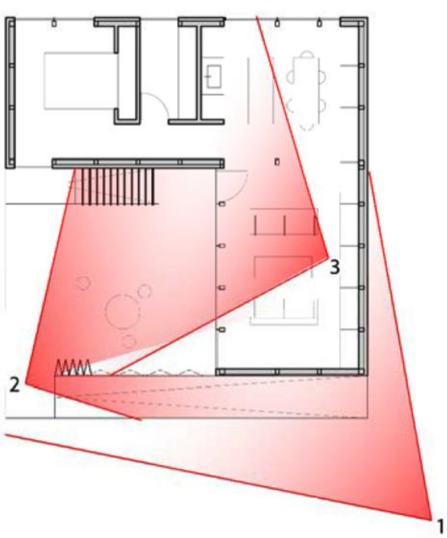
PERSPECTIVAL SEQUENCE

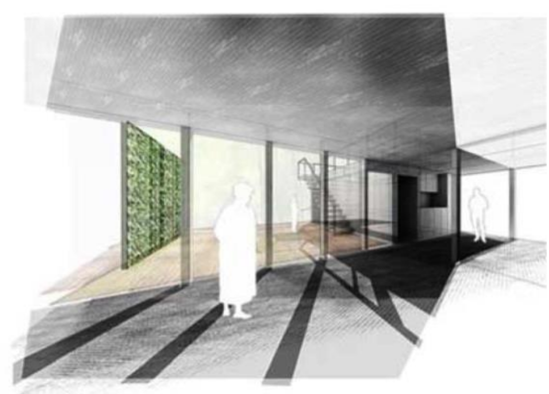


1. APPROACH



2. ENTRANCE / OUTDOOR ROOM

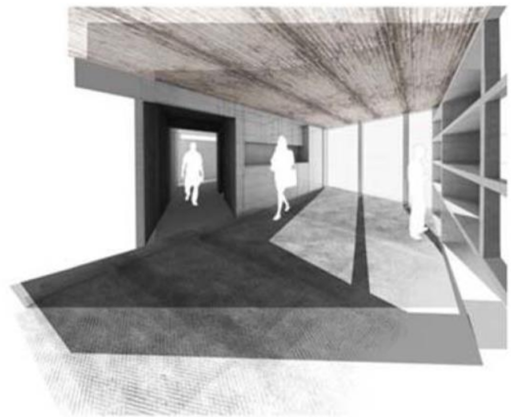




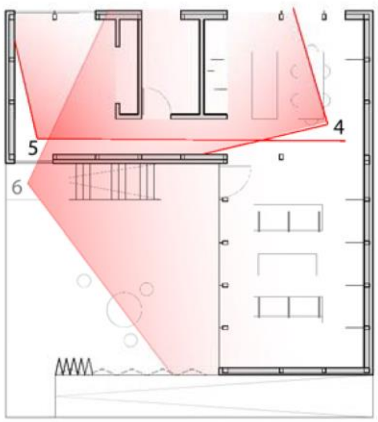
3. MAIN LIVING SPACE

Figure 55. Conceptual design.

PERSPECTIVAL SEQUENCE



4. KITCHEN / DINING



6. ROOF VIEWSCAPE

Figure 56. Conceptual design.

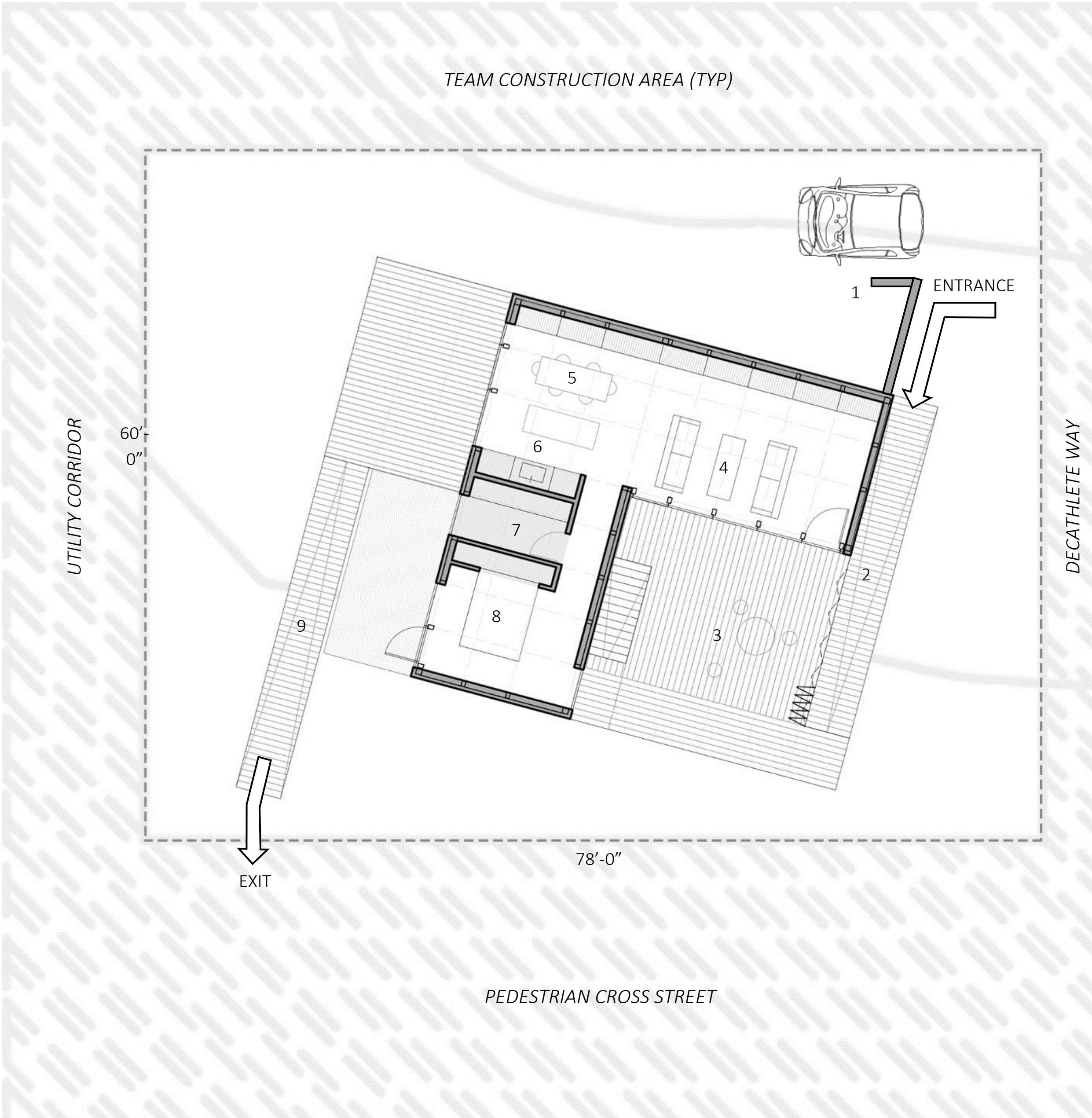
On 13 February 2014, the DOE announced that Team Florida/Singapore and nineteen (19) other university teams were selected for participation in the Solar Decathlon 2015.

Quarter 01: 1 April – 30 June 2014

During Project Quarter 01, we made significant progress in advancing the design of the house and also in developing the capabilities of our student team.

On Wednesday, 2 April 2014, the competition dates and location were announced. The site was set for the Orange County Great Park in Irvine, California, with the public exhibition scheduled for 8-18 October 2015.

Schematic Design (Task 1.0) required reviewing updated rules applicable to the 2015 competition and developing a series of design proposals in response to the specific program requirements. This task began by re-visiting and revising the assumptions made during the conceptual design / proposal phase. It was completed with the submission of the schematic design deliverable on 24 April 2014.



SOLAR DECATHLON VILLAGE: LOT #207
Orange County Great Park, Irvine California

N

GROUND FLOOR PLAN

1. Elec. Car Charging Station
2. Entrance Ramp
3. Outdoor Living Room
4. Main Living Space
5. Dining Space
6. Kitchen/Laundry Unit
7. Bathroom/Installations
8. Bedroom
9. Exit Ramp

0 8 feet

Figure 57. Schematic design floor plan.

Following completion of Schematic Design, we held a vertically integrated independent study course centered on the SD2015 project during the summer 2014 semester consisting of ten students from the University of Florida, six students from the National University of Singapore, and two dedicated faculty. Work included site visits, precedent analysis, climatic and environmental research, logistics planning, design studies, and preliminary energy modeling. Our UF team met with senior representatives from Santa Fe College and Habitat for Humanity, and also engaged industry. Outreach included attendance at the AIA Florida Convention in Miami, in addition to numerous web and phone contacts.

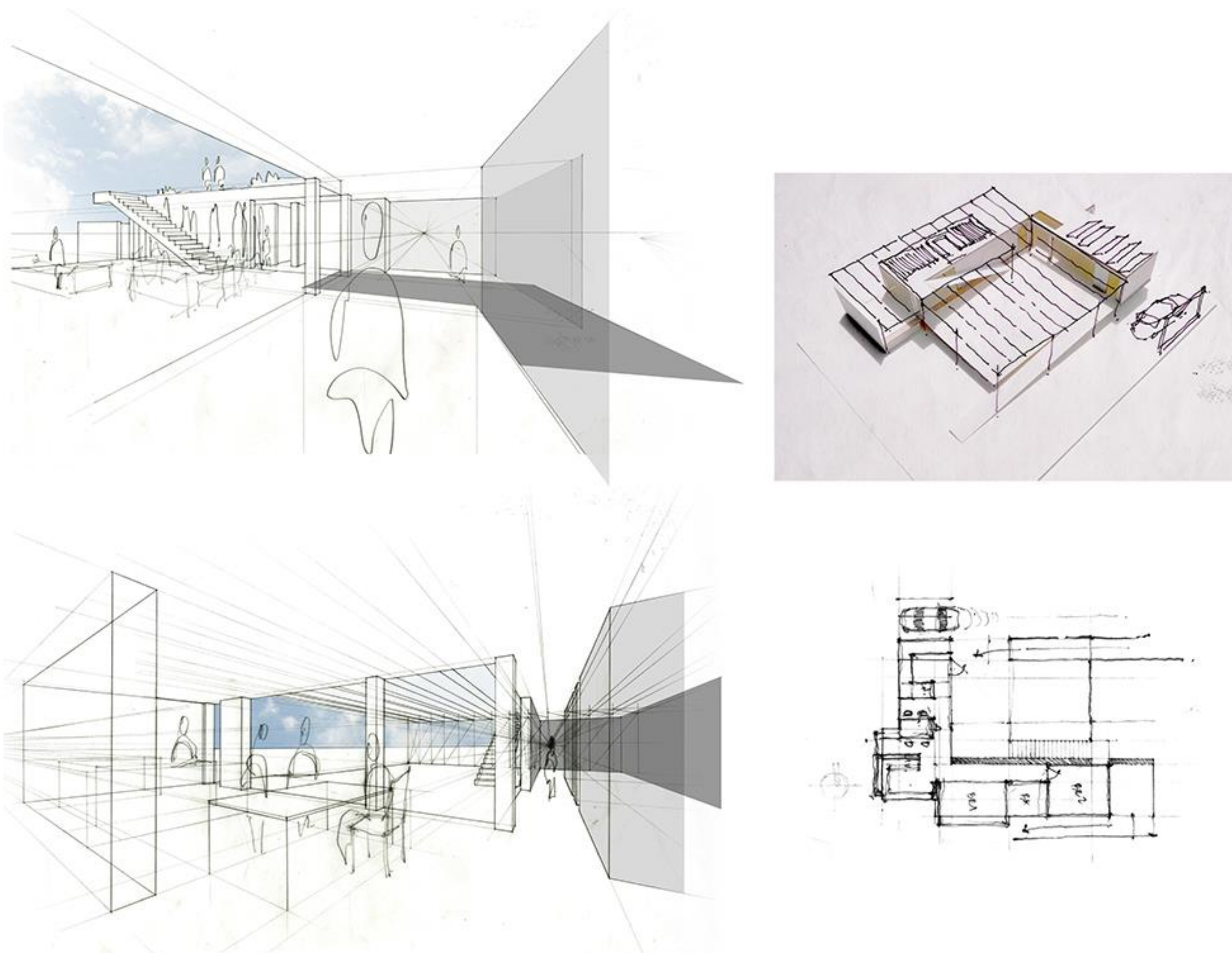


Figure 58. Design studies: Fold House.

Three students and one faculty member travelled to the Solar Decathlon Europe competition in Paris, France to benchmark best practices in preparation for the Solar Decathlon 2015.

Certain rule provisions established by event organizers required us to eliminate the stairs to the rooftop garden, which were integral to our initial design concept.

Figure 59. Design team work session, with students and faculty from Singapore and the US (Summer 2014).

Agricultural import limitations caused us to re-think certain vegetated components of the project, including a green roof and vegetated walls. We continued to work on alternative strategies that were pot-based and available in California during the event. Vegetated roofs and walls were excluded from our design development submission, pending determination of viable solutions.

The competition's limitation on maximum floor area caused some compromises for us. As a result of our market need for two bedrooms as well as the competition's definition of finished floor area, we shifted mechanical space from inside the thermal envelope to outside of it. While this will meet the competition's requirements, it will not perform as well as we believe it would if this space could be brought inside the thermal envelope. We are making provisions for it to be brought inside the thermal envelope following the competition so that the house should perform better once situated on its permanent site.

The costs for student/team travel during the competition event as well as the build and de-construction periods were significant for our team, given the distances of travel from our universities to the competition site. The costs of moving the house from Florida to California and back were also significant. Early estimates of logistical expenses during this period were in excess of $160,000. During this quarter, we pursued fundraising for these costs, in particular.

One of our co-principal investigators received an (unrelated) Fulbright Fellowship, and moved to Kuwait as a result. As he was our team's structural engineer, we worked to establish relationships with new engineers during this quarter. Assistance was provided to the team by a number of structural engineers during this period as the team searched for engineers licensed for practice in both Florida and California.

Quarter 02: 1 July – 30 September 2014

During Quarter 02, we completed the summer studio in August 2014 by preparing a draft of the design development submission and preparing the project website. During the fall 2014 semester, we organized a vertically-integrated studio consisting of one second-year graduate student, one first-year graduate student, and twenty undergraduate students in either their third or fourth year of studies. The team expanded to include students in our Bachelor of Science in Sustainability and the Built Environment (BSSBE) program, as well as Architecture and Interior Design. The work during this quarter focused intensively on the design development submission as well as communications, outreach, and fundraising.

Design Development (Task 2.0) involved developing a much more detailed comprehensive design. Several new components were introduced into the documents, including building sections, representative/critical wall sections, typical and/or key details, interior elevations, reflected ceiling plans, and line drawings of structural and MEP systems. The text-based portion of the deliverable shifted from being an assembly and component-oriented narrative (UniFormat) to a material-specific outline specification (organized by MasterFormat). The design team reviewed and updated both the schedule and project cost estimate. While most of the work for this task was completed during quarter 2, the task was scheduled to be completed with the submission of the Design Development deliverable just after the close of Quarter 02.

In our discussions with Alachua Habitat for Humanity, we tentatively identified both a family owner as well as a permanent site for the house, following the competition. In response to their requirements, the project was expanded to include provisions for a third bedroom and second bath that will not travel to the competition site but will be added to the house following its return to Florida after the competition.

Quarter 03: 1 October – 31 December 2014

During Quarter 03, we prepared and submitted the Design Development submission on 9 October 2014. This deliverable included the following: a) Building Information Model, b) Drawings, c) Project Manual, d) Preliminary Health and Safety Plan, and e) Target Construction Cost. We met requirements for a timely and complete submission with all work submitted by the deadline.

Feedback from the DOE was provided to the project team on 4 November 2014. The team revised the Design Development documents as required and resubmitted revised documents on 18 November 2014. This deliverable included the following: a) Building Information Model, b) Drawings, and c) Project Manual. We met requirements for a timely and complete submission with all work submitted by the deadline.

During this quarter, we also prepared a computer-animated walkthrough of our project, as well as computer-generated renderings. These were submitted on 18 December 2014. We met requirements for a timely and complete submission with all work submitted by the deadline.

Figure 60. Design development.

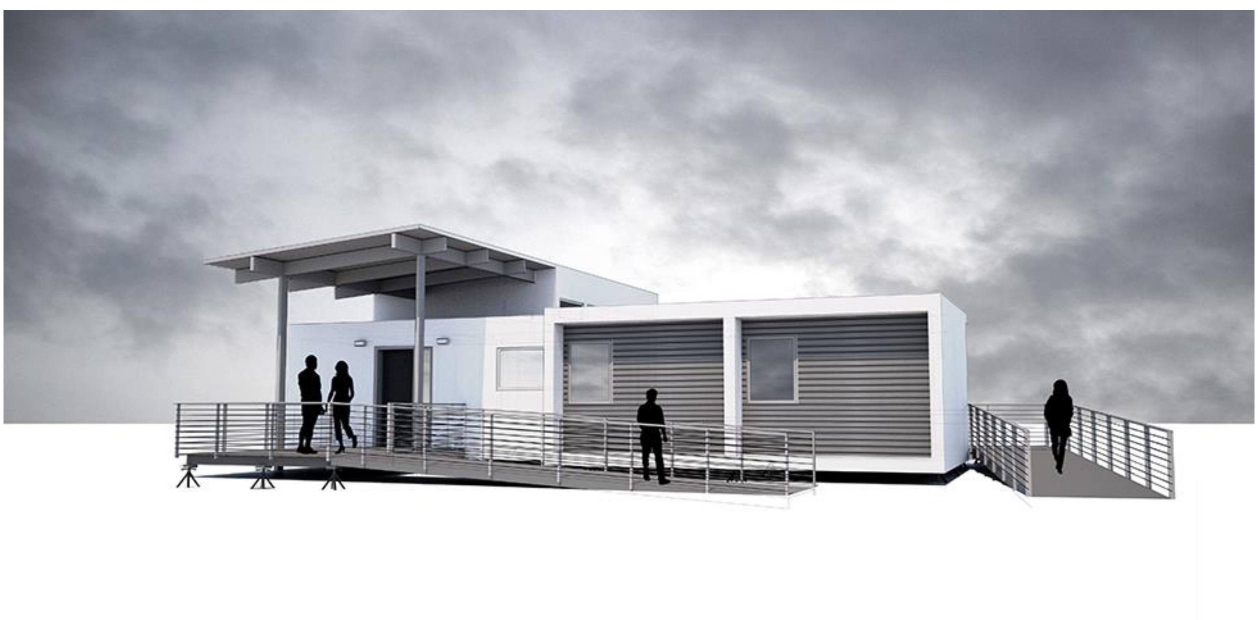


Figure 61. Design development.

Figure 62. Design development.

Figure 63. Design development.

Figure 64. Design development.

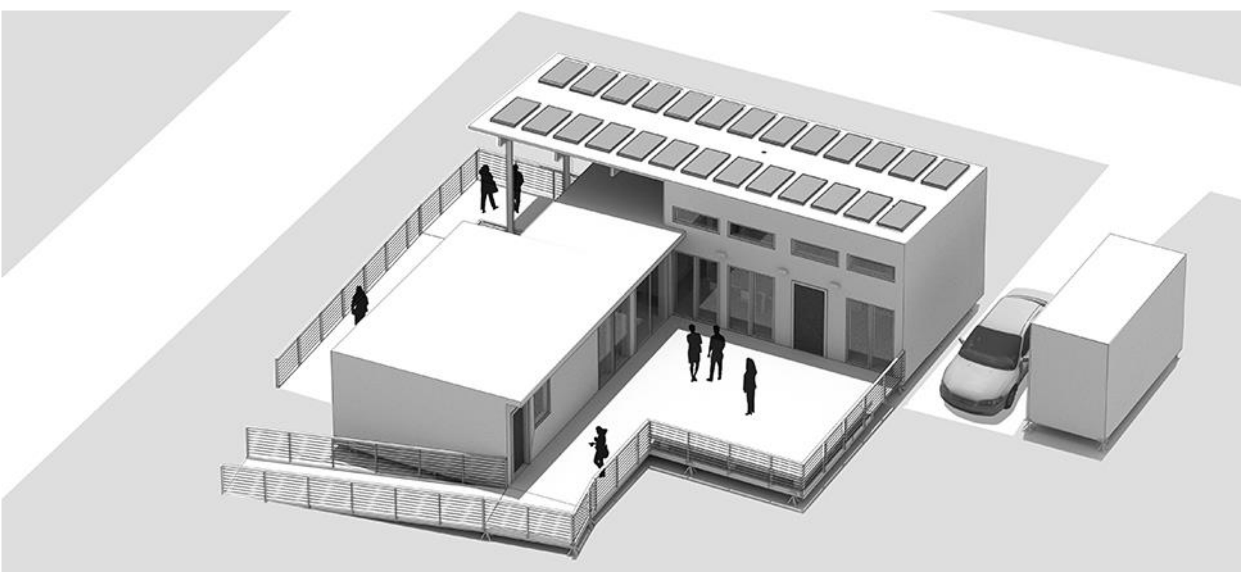


Figure 65. Design development.

Certain requirements established by the Solar Decathlon Building Code and/or Rules have increased the anticipated project costs. These include the requirements for active fire suppression/sprinkler systems, water storage tanks, water pumps, and the high live load requirements for exterior decks and ramps.

We prepared for the Design Development all-team meetings in Irvine, California scheduled for the beginning of Quarter 04 (9-10 January 2015).

Quarter 04: 1 January – 31 March 2015

During Quarter 04, ten members of our team attended the Design Development Workshop and all-team meetings in Irvine, California on 9-10 January 2015. Six undergraduate students, two graduate students, and two faculty members represented our team and participated in these meetings.

Figure 66. Members of Team Florida / Singapore on the competition site, 9 January 2015.

Certain requirements established by organizers during the DD workshop increased the anticipated project costs. These include the electrical interconnection lines as well as certain special electrical metering requirements that have been introduced.

Figure 67. Team Florida/Singapore team members at Design Development workshop in Irvine, California.

Figure 68. Construction documentation.

Figure 69. Construction documentation.

Figure 70. Construction documentation.

Figure 71. Construction documentation.

Figure 72. Construction documentation.

Figure 73. Construction documentation.

We conducted an "Integrated Project Delivery (IPD)" studio during the spring 2015 academic semester. This studio included eleven architecture students (including two dual-majors in Sustainability and the

Built Environment and one minor in Landscape Architecture), three construction management students, and three mechanical engineering students. This core project team was further assisted by approximately fifty undergraduate and graduate volunteers from across the university.

We partnered with Gouvis Engineering Consulting Group, Inc. of Newport Beach, California to assist with the Structural Engineering for the project. Significant development of the structural design was completed during this period.

The temporary support structures for the house were revised from jacks to perimeter grade beams, allowing the house to be lowered. This eliminated the needs for perimeter guard rails. The slopes of the ramps were reduced, changing these to sloped surfaces (1:22 slope), eliminating the need for handrails. The heights of the structure were lowered to eliminate “topper” modules that were planned to be attached to the open tops of lower modules. The re-designed modules should meet dimensional requirements for interstate travel by truck.

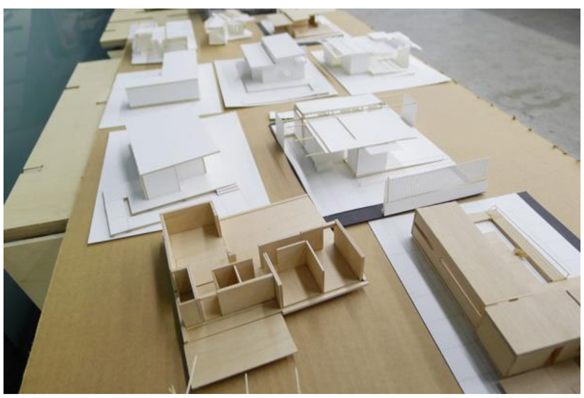


Figure 74. Physical model studies.

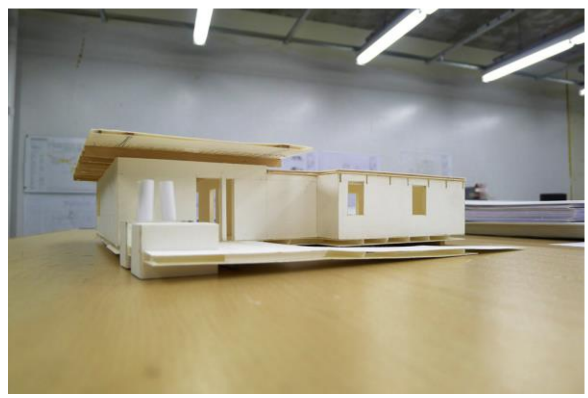


Figure 76. Physical model studies.

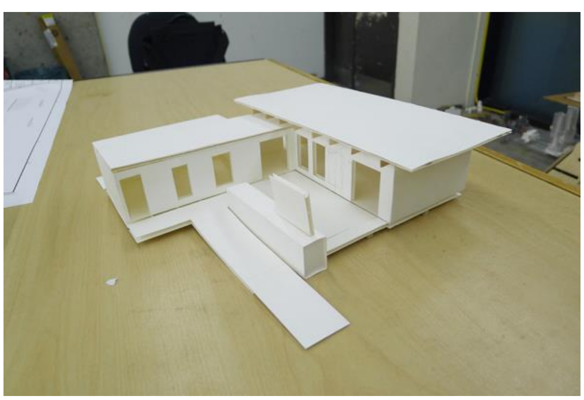


Figure 75. Physical model studies.

Figure 77. Physical model studies.

We identified a number of improvements to the building systems, including a regenerative solar thermal solid desiccant system that was incorporated into the project.

A group of eight students and one faculty member from the University of Florida College of Journalism and Communications joined the project team to work on developing the communications, marketing, and outreach aspects of the project.

On 19 January 2015, we prepared and submitted a "Design Development Estimate Dispute/Clarification Narrative" in response to the Design Development Estimate prepared by Faithful+Gould (F+G), dated 5 January 2015. We received and reviewed a subsequently-revised estimate from F+G, dated 26 January 2015.

We prepared and submitted the Construction Document submission on 12 February 2015. This deliverable included the following: a) Building Information Model, b) Drawings, c) Project Manual, d) Health and Safety Plan, e) Final Target Construction Cost, f) Stamped Structural Drawings, and g) Stamped Structural Calculations. We met requirements for a timely submission with all work submitted by the deadline.

Feedback from the DOE was provided to the project team on 15 March 2015. The team revised the Construction Document submission as required and resubmitted the revised documents on 26 March 2015. This deliverable included the following: a) Building Information Model, b) Drawings, c) Project Manual, and d) Health and Safety Plan. We met requirements for a timely submission with all work submitted by the deadline.

Due to concerns about incorporation of new technologies, warranties, long-term maintenance questions, and homeowner reluctance, the relationship with Alachua Habitat for Humanity was terminated during this period. Alternative plans for future uses of the project were researched, including a possible donation of the house to other groups/families and/or sale of the house to a family in California or Florida.

Twenty-three (23) students and two faculty completed an OSHA 10-hour safety training course conducted by Russell Walters, Ph.D., P.E. The course was held on 16 March and 23 March. In addition, fourteen (14) students and one faculty member completed an OSHA 30-hour safety training course conducted by Dr. Walters.

Quarter 05: 1 April – 30 June 2015

This quarter started near the end of the academic semester. As a result, one of the first accomplishments was the conclusion of the Integrated Project Delivery (IPD) studio and final reviews with external critics on Tuesday, 21 April. The Journalism and Communications Team also presented their final outreach and communications plan on the same day. Many members of the project team graduated and/or left campus to work on internships in professional practice.

Figure 78. Solar living house studio design presentations at the University of Florida on 21 April 2015.

We prepared and submitted the “Project Summary” deliverable on 23 April 2015. As outlined in the Rules appendix D-9, this deliverable included: a) Overview (10-page summary .pdf document), b) Team Photograph, c) Team Logo (web and print versions), d) Computer-Generated Renderings (four elevation views, two birds-eye perspective views, and four interior views), e) Competition Prototype Graphic Floor Plan (.pdf document), and f) Dinner Party Menus and Recipes (.pdf document).

We reviewed additional comments and questions from competition organizers as outlined in 17 April 2015 email and discussed by phone on 22 April 2015. Project team prepared revisions to the Environmental, Health and Safety Plan (EHSP), drawings, and structural details as requested and resubmitted these materials for review on 13 May 2015. On 14 May 2015, our resubmitted documents were approved with commendations from reviewers.

On 14 May 2015, we received comments from organizers noting required revisions to our project summary submission. Revised documents were submitted on 27 May 2015.

After months of back-and-forth discussions between the US DOE and the project team, the Continuation Application for Budget Period 2 was approved on 11 June 2015, allowing the project team to proceed with the purchasing of materials.

In June, our partners at Santa Fe College completed construction of their fifth Habitat for Humanity House and moved it off campus onto its permanent site. This allowed construction preparations to begin for the Solar Decathlon project.

On 25 June 2015, we submitted the "Public Exhibit Materials" for review by competition organizers. As outlined in Rules appendix D-10, this deliverable included: a) Team handout, b) Signage, c) Team uniform design, and d) Plan drawing of team site depicting public exhibit material locations and tour route at 1:48 scale. On 25 June 2015, we also submitted the Final Environmental, Health and Safety Plan (EHSP), as required.

During this quarter, there was a significant amount of time spent working out the particulars of the Memorandum of Understanding (MOU) between the University of Florida and Santa Fe College. A formal written document was drafted in February and March 2015 and was sent to the legal counsel of each institution for review and/or revisions as required. At the end of Quarter 05, legal revisions were still underway. We anticipated that the agreement would be finalized no later than 14 July 2015 to allow it to be voted on during the 21 July 2015 Santa Fe College Board of Trustees meeting. Construction activities would be allowed to proceed following an affirmative vote of the Board of Trustees.

The extended legal reviews required to finalize the MOU delayed the project by four months and dramatically constricted construction activities. Based on an anticipated 21 July 2015 approval and authorization to proceed, we would have only 50 calendar days for construction of the house prior to shipping it to California. Complete assembly of the modules and whole-house testing of systems would no longer be possible before the competition, given the compressed construction schedule. The project team was concerned about the impacts this would have on the house's performance in California.

We continued fundraising and logistics preparations for the competition. Funding became a significant concern for the project team. Although we were aggressively pursuing cash and in-kind donations for the project over the past year and a half, the team had only managed to secure approximately $56,000 in in-kind donations/commitments and about $74,000 in grants/cash commitments. We estimated that we would need approximately $300,000 to $330,000 in additional contributions to complete the house and participate in the competition. This included an anticipated $120,000 in logistical costs to ship the house to California and back as well as $48,000 to fly the team of students and faculty to California and house them for a month.

Faced with funding difficulties, the project team evaluated a number of strategies to reduce the funding required. Aggressive cost-cutting measures considered included elimination of a module (compromising the market appeal of the house), reducing deck area, reducing exterior insulation/window performance (compromising energy performance), shipping one-way to California, and reducing the team size from sixteen to ten. Implementing all of these measures, we still anticipated a minimum of $200,000 in additional funding would be required to complete the house and participate in the competition. The project team worked aggressively to resolve this funding issue to allow continued participation in the competition.

Unable to secure funding for travel and lodging, the student and faculty team from the National University of Singapore was not able to participate in design and construction activities during this Quarter. It also became clear that there was no funding in place to support their participation in the competition events in California.

The team had a number of discussions about the permanent location of the home following the competition, but did not make any final decisions.

Quarter 06: 1 July – 30 September 2015

Figure 79. Concrete block piers in the construction studio of the Charles R. Perry Construction Institute, ready for framing of modules (6 July 2015).

On Friday, 31 July 2015, we notified the competition organizers that Team Florida/Singapore was withdrawing from continued participation in the Solar Decathlon 2015 Competition. The principal constraint was funding.

At that time, we estimated that we would need approximately $300,000 to $330,000 in additional funding to complete the house and participate in the competition. This included an anticipated $120,000 in logistical costs to ship the house to California and back as well as $48,000 to fly the team of students and faculty to California and house them for a month.

Even after considering a number of aggressive cost-cutting measures that would compromise the performance of the house in the competition, we anticipated that $200,000 to $250,000 in additional funding would be required to complete the project. We were not able to secure funding to complete the project, in either its complete or compromised form.

Construction activities were placed on hold. Other sponsors, project supporters, and team members were notified of this decision and all work was suspended.

Quarter 07: 1 October – 31 December 2015

During Quarter 07, administrative reporting requirements were completed as required. No additional was completed during this quarter.

At the competition in Irvine, California, Stevens Institute of Technology won top honors overall. The University at Buffalo, The State University of New York, took second place, followed by California Polytechnic State University, San Luis Obispo, in third place.

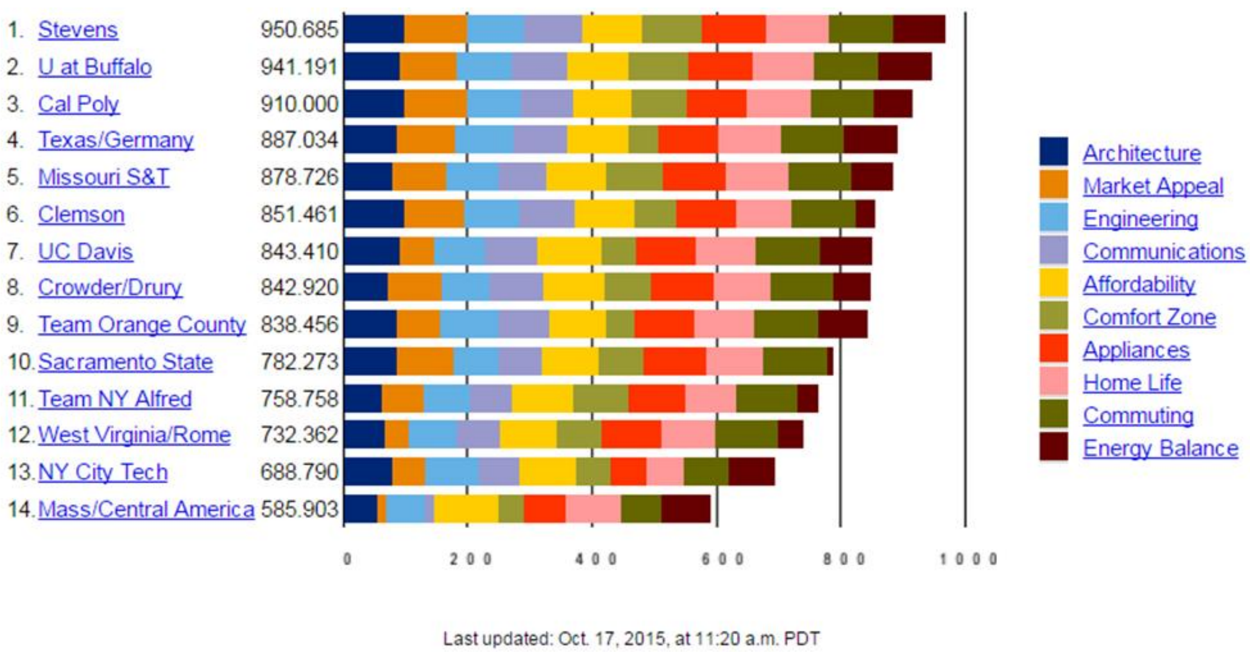


Figure 80. Solar Decathlon 2015 final team standings and scores. Source: http://www.solardecathlon.gov/2015/competition-scores.html.

Quarter 08: 1 January – 31 March 2016

During Quarter 08, administrative reporting requirements were completed as required and team leaders attended the DOE Closeout WebEx on 23 March 2016. No additional work was completed during this quarter.

Quarter 09: 1 April – 15 April 2016

During Quarter 09, administrative reporting requirements were completed as required following the end of the Period of Performance.

PUBLICATIONS / PRESENTATIONS / TRAVEL

Publications

A. Refereed Peer-Reviewed Proceedings:
   1. McGlothlin, Mark and Bradley Walters. 2014. “Between the End and the Beginning: Design-Build Teaching Through the Lens of the Solar Decathlon.” In *Working Out: Thinking While Building: Papers from the 2014 Fall Conference*, conference co-chairs Ted Cavanaugh, Ursula Hartig, and Sergio Palleroni, 515-522.Washington, DC: ACSA Press. ISBN 978-0-935502-94-7.
   2. McGlothlin, Mark and Bradley Walters. 2014. "Ends and Means: Inquiries Into the Role of the Solar Decathlon in Architectural Education." In *Living & Learning: Proceedings of the Second International Conference of the Association of Architectural Educators*, edited by Rosie Parnell et al, 30-34. Sheffield UK: University of Sheffield.

Presentations

A. Invited International Symposium
   1. McGlothlin, Mark and Bradley Walters. 2014. “The Weight of Things.” Topical presentation at the *Second International Conference of the Association of Architectural Educators* (AAE), University of Sheffield, Sheffield UK, September 5.

B. Refereed Paper Presentations
   1. McGlothlin, Mark and Bradley Walters. 2014. "Between the End and the Beginning: Design-Build Teaching Through the Lens of the Solar Decathlon." Paper presented at the *2014 Association of Collegiate Schools of Architecture (ACSA) Fall Conference*, Dalhousie University, Halifax NS Canada, October 17.
   2. McGlothlin, Mark and Bradley Walters. 2014. "Ends and Means: Inquiries Into the Role of the Solar Decathlon in Architectural Education." Paper presented at the *Second International Conference of the Association of Architectural Educators* (AAE), University of Sheffield, Sheffield UK, September 4.
   3. McGlothlin, Mark and Bradley Walters. 2014. "The Weight of Things." Paper presented at the *2014 National Conference of the Beginning Design Student*, Illinois Institute of Technology, Chicago, Illinois, April 5.

C. Invited Lectures and Seminars
   1. Walters, Bradley, Gabby Heffernan, and Adiel Benitez. 2015. "Solar Living House." Invited Speaker at *Green Caffeine*, Organized by USGBC Heart of Florida Chapter, Volta, Gainesville, Florida, April 1.
   2. Walters, Bradley. 2015. "Building Research: Solar Living House." Invited Speaker at the *2015 Gwendolen M. Carter Conference: Schools of Architecture | Africa: Connecting Disciplines in Design + Development*. University of Florida School of Architecture, March 13.
   3. Walters, Bradley. 2015. "Building Research: Solar Living House." Presentation made as a part of the *2015 Inquire Create Inform: Research Symposium*, University of Florida College of Design, Construction, and Planning (DCP), Gainesville, Florida, January 29.

D. Invited Panelist
   1. Walters, Bradley. 2015. "People in Glass Houses." Invited Panelist for *Constructive Conversations: Architecture Film Series and Public Dialogue*, Organized by Gainesville Modern, The Hippodrome Cinema, Gainesville, Florida, January 31.

E. Refereed Project Presentations
   1. Walters, Bradley. 2015. "Solar Living House." An Interactive Lab Presentation at TEDxUF, University of Florida, Gainesville, Florida, March 21.

F. Lectures and Seminars
   1. Walters, Bradley. 2015. "Making it Real: The Solar Decathlon." Invited Guest Lecturer for ARC 2461 *Materials and Methods of Construction 1*, Instructor: Stephen Belton, March 24.
   2. Walters, Bradley. 2014. "Getting Dirty + Learning Through Making: The Solar Decathlon." Invited Guest Lecturer for ARC 1000 *Architecture and Humanity*, Instructor: John Maze, December 4.

Travel

A. During Quarter 01 (2014 Quarter 2), three students and one faculty member travelled to the Solar Decathlon Europe competition in Paris, France to benchmark best practices in preparation for the Solar Decathlon 2015.
B. During Quarter 04 (2015 Quarter 1), ten members of our team attended the Design Development Workshop and all-team meetings in Irvine, California on 9-10 January 2015. Six undergraduate students, two graduate students, and two faculty members represented our team and participated in these meetings.

COMPARISON OF ORIGINAL GOALS AND OBJECTIVES AND ACTUAL ACCOMPLISHMENTS

	Project Goals and Objectives	Actual Accomplishments
A.	<u>Project Objective</u> *(from EERE 165 Statement of Project Objectives)*: The fundamental goal of this project is to develop and demonstrate cost-effective solar powered homes. We intend to build on the legacy of the Case Study House program to re-think the spatial and formal components that constitute house, as well as construction methodologies. The goal is to find or create economies in the building design while also creating a higher-performance envelope. A tighter envelope will allow us to reduce our overall power needs, thereby reducing the size and scope of our active solar systems.	This objective was partially met through the design development and documentation work. Unfortunately, as the project was not able to continue through construction, the team was not able to fully demonstrate and communicate these issues to the public at large.
B.	<u>Project Objective</u> *(from EERE 165 Statement of Project Objectives)*: A principal goal for the project is to create a family of building components, wall assemblies, and modular units that can fundamentally influence the manner in which homes are built and occupied.	This objective was partially met through the design phases of the project's development.
C.	<u>Technical Scope</u> *(from EERE 165 Statement of Project Objectives)*: The project will include a series of interrelated activities, ultimately leading to the construction of a home for a family in Gainesville, Florida. Along the way, the house will be designed, modeled, built, tested, transported, occupied, measured/evaluated, transported, assembled, commissioned, and, finally, lived in.	This objective was not fully met as the project was not able to be constructed as planned.

	Project Goals and Objectives	Actual Accomplishments
D.	Project Management *(from EERE 165 Statement of Project Objectives)*: The project team will use Integrated Project Delivery (IPD) methods, integrating design, engineering, and construction considerations at early stages in the project's development. The team will meet in person as well as via web-based tools at weekly or bi-weekly intervals, depending on the stage of the project's development. In addition, a password-protected project worksite will be used for sharing of project-related documents, including design and engineering models.	This objective was met, and these management systems were used throughout the project's development.
E.	Technical Innovation #1 *(from Technical Proposal)*: Deploy "lean construction" to reduce material use, mass, weight, and cost. Advanced framing or optimal value engineering (OVE) is not new, and has already been demonstrated to reduce framing material use by as much as 40%. Because of the reduced thermal bridging in the exterior envelope, heating and cooling costs can be reduced by as much as 30%.[12] We intend to implement the best practices of OVE but also to test further material reductions through digitally fabricated members that may remove excess material and cost while improving thermal performance. Our goal is to reduce material use by at least 10% beyond OVE, or 50% reduction in material use as compared with traditional building methods, while still meeting Florida's stringent Hurricane building code. We anticipate being able to measure this through comparisons with the earlier houses built by Santa Fe College for Habitat for Humanity.	The design team encountered difficulties in meeting this goal. The difficulties were principally building code requirements and high costs associated with performance testing of alternative construction systems. Given the rapid schedule of the Solar Decathlon and the limited financial resources available to the team, this goal was not met by the project team.

[12] Green Building Advisor, http://www.greenbuildingadvisor.com/green-basics/energy-efficient-framing-aka-advanced-framing.

	Project Goals and Objectives	Actual Accomplishments
F.	<u>Technical Innovation #2</u> *(from Technical Proposal)*: Test Passive House standard for applicability in hot + humid climates. The Passive House standard is amongst the most aggressive energy standards in use today, reducing building energy use by as much as 80% over traditional, code-compliant construction. The standard centers on design and construction of tight, super-insulated building envelopes that eliminate opportunities for thermal bridging. Through the Solar Living House, we would like to reduce energy use by 80% over conventional construction.	The design team planned for increased insulation requirements, high-performance glazing, and continuous air-barriers. Unfortunately, the passive house criteria were compromised by logistical issues associated with modular construction and impermanent construction necessitated by the competition. In addition, budget constraints required compromises to the glazing systems. The design team was not able to meet this goal.
G.	<u>Technical Innovation #3</u> *(from Technical Proposal)*: Deploy regenerative desiccant systems and/or Conditioning Energy Recovery Ventilator (CERV) units to address humidity concerns of the tropics and sub-tropics. Latent loads are primary in the tropics and sub-tropics. By addressing them independently of ventilation air (with dessicants) or in combination (with the CERV) we seek to dramatically reduce energy use overall.	This goal was met through the incorporation of innovative solar thermal and regenerative desiccant systems.
H.	<u>Technical Innovation #4</u> *(from Technical Proposal)*: Create a vegetated roof garden that can be used to test and measure the impacts of vegetated roofs on stormwater quantity and quality, as well as their impacts on the thermal performance of building envelopes. The vegetated roof on the Solar Living House will be designed in parallel with non-vegetated components, allowing direct and meaningful comparative measurements to be taken.	During schematic design, rule provisions established by event organizers required us to eliminate the stairs to the rooftop garden, which were integral to our initial design concept. In addition, agricultural import limitations caused us to eliminate vegetated components of the project, including a green roof and vegetated walls. This goal was not met by the project team.

	Project Goals and Objectives	Actual Accomplishments
I.	Technical Innovation #5 *(from Technical Proposal)*: Create modular "wet core" component units to allow for more efficient installations of plumbing and mechanical systems.	This goal was met through the incorporation of centrally-located "wet core" module. The efficiency of consolidated plumbing systems were compromised somewhat by the competition's requirement for a sprinkler system to be installed in the home. The competition's requirements to locate water tanks outside the footprint of the house also compromised the efficiency of our water-distribution network, adding additional piping and pumps to the project.
J.	Technical Innovation #6 *(from Technical Proposal)*: Create modular, replicable and expandable frame and panel system for building structure and thermal enclosure.	This goal was partially met, as the project did incorporate a frame and panel system. The flexibility of the system was compromised somewhat by both lateral bracing/earthquake requirements and budget limitations.
K.	Target Construction Cost *(from Technical Proposal)*: Our target market is the median Florida family, and our target construction cost will be $138,710.	This goal was not met. The final project estimate anticipated that the total construction cost would be $333,799, or $336.15 per square foot of finished floor area. This is more than 2.4 times the target construction cost.

FINDINGS, REFLECTIONS + CONCLUSIONS

Work on the Solar Living House and Solar Decathlon 2015 offered our student team unparalleled learning opportunities. Because of the duration of the project, a number of students participated at different points in their education, from first year undergraduates all the way through to advanced graduate students. The opportunity for collaboration with students and faculty from the National University of Singapore was also extraordinary, allowing for a sharing of technical knowledge and cultural exchange. As a part of this project, some members of our student team travelled to Versailles, France for Solar Decathlon 2014, others travelled to Irvine, California to participate in the Design Development Workshop. Student travel to France was made possible through the generosity of the Bosch Community Fund.

In terms of technical innovations, the regenerative solar thermal solid desiccant system that was incorporated into the project was the most significant aspect of the project. A highly efficient solar thermal system was used to dry silica desiccants, allowing them to be regenerated and reused for humidity control. This is an important technology for the tropical and semi-tropical regions where our universities are located.

During the project's development, a number of issues required the team to adjust course. While this is a part of almost every design and construction project to some extent, it is worth noting some of the issues encountered:

- Site location in Irvine, California added considerable logistical constraints and additional funding requirements that would not have been as significant with sites on the east coast.
- Sites were identified near the end of the schematic design phase of work, requiring changes to earlier design decisions.
- The sloping competition site required revisions to public tour routes, foundations, and construction systems.
- Conflicts between competition schedules, contract reporting, and academic calendars led to project management complexities. The misalignments between competition schedules and academic calendars were the most troublesome, as deadlines would often conflict with course requirements and/or break schedules. The competition events, requiring students and faculty to miss as much as a month of coursework in multiple classes, caused some scheduling difficulties.
- Complex financial management processes led to delays in the approval of our team's continuation application. This impacted some purchasing and construction timelines.
- The competition's prohibition of steps on site (even if not intended for use by the touring public) eliminated certain design possibilities and required a redesign of certain project components.
- Requirements for multiple ramps (entrance/exit) for access to deck areas added to the scope and cost of the work.
- High live load requirements for exterior decks and ramps required a more robust structure than originally anticipated.
- Fire sprinkler systems, as well as associated water storage tanks and pumps, are not typical in single-family homes in our region. These systems added considerable cost and technical complexity to the project. They also compromised the efficiency of the modular approach chosen for our project.
- Agricultural import limitations led to the elimination of the green roof and vegetated walls that were included in our conceptual design.
- Maximum floor area limitations required certain mechanical spaces in our project to move from inside the thermal envelope to outside of it, compromising the efficiencies of both the units and the air/thermal barriers.
- Maximum building height limitations eliminated some design possibilities that could have better integrated section and building massing into discussions of solar and thermal performance.
- Fundraising difficulties were a critical issue for our project team. In particular, our Foundation closely manages high-potential donors, directing them towards particular projects of significant value to the University. The Solar Decathlon project team was unable to sufficiently justify the value of the project to the University, given competing needs for educational and research spaces.

- Design and construction limitations set by Habitat for Humanity eliminated certain material possibilities while also requiring three bedrooms and two baths within tight area limitations. Our team was unable to compete with the very low first-cost construction strategies already being deployed by Habitat. There was no mechanism within Habitat to value or account for lower operational and maintenance costs over the life of the structure, placing undue emphasis on first-costs above all else.
- Logistical difficulties associated with modular construction were considerable. Redundant structural members, temporary enclosures, transportation costs, and mechanical / plumbing / electrical systems were some of the many difficulties encountered with this modular approach.
- Above-grade water storage tanks, located outside the extents of the house and deck, required more piping and pumps than was anticipated.
- Electrical interconnection lines and special electrical metering requirements were more extensive than anticipated.
- Delays in finalizing the Memorandum of Understanding (MOU) between the University of Florida and Santa Fe College led to delays in construction.

Unfortunately, we were unable to complete construction of the Solar Living House and participate fully in the on-site competition events, due to funding difficulties. On Friday, 31 July 2015, we notified the competition organizers that Team Florida/Singapore was withdrawing from continued participation in the Solar Decathlon 2015 Competition.

At that time, we estimated that we would need approximately $300,000 to $330,000 in additional funding to complete the house and participate in the competition. This included an anticipated $120,000 in logistical costs to ship the house to California and back as well as $48,000 to fly the team of students and faculty to California and house them for a month. Even after considering a number of aggressive cost-cutting measures that would compromise the performance of the house in the competition, we anticipated that $200,000 to $250,000 in additional funding would be required to complete the project. We were not able to secure funding to complete the project, in either its complete or compromised form.

Construction activities were placed on hold. Other sponsors, project supporters, and team members were notified of this decision and all work was suspended.

In the year since our team's withdrawal from the competition, team leaders went on to complete construction of the Quinlivan Net-Zero Energy Home on a site in Gainesville, Florida. This site-built home avoided many of the constraints and complications listed above, allowing it to be built for a much more modest budget. Where the competition prototype was estimated to cost $336.15 per square foot, the two-bedroom two bath 1,800 square foot Quinlivan home was constructed for $135.39 per square foot. The Quinlivan project included active photovoltaic solar systems, careful attention to continuity of the air barrier, increased insulation levels, and permanent site constructions (driveway, walkways, etc.).

For more information about that project, see: https://studiowalters.com/portfolio/quinlivan-net-zero-energy-house/.

Figure 81. Quinlivan Net-Zero Energy House, completed in 2016. Photo by Bradley Walters.

Figure 82. Quinlivan Net-Zero Energy House, completed in 2016. Photo by Bradley Walters.

The fact that the larger, more formally complex Quinlivan project was completed for less than half of the construction cost budget of the Solar Living House suggests that it is possible to build affordable high-performance houses. But it also offers an important critique of both the Solar Living House and the larger Solar Decathlon program

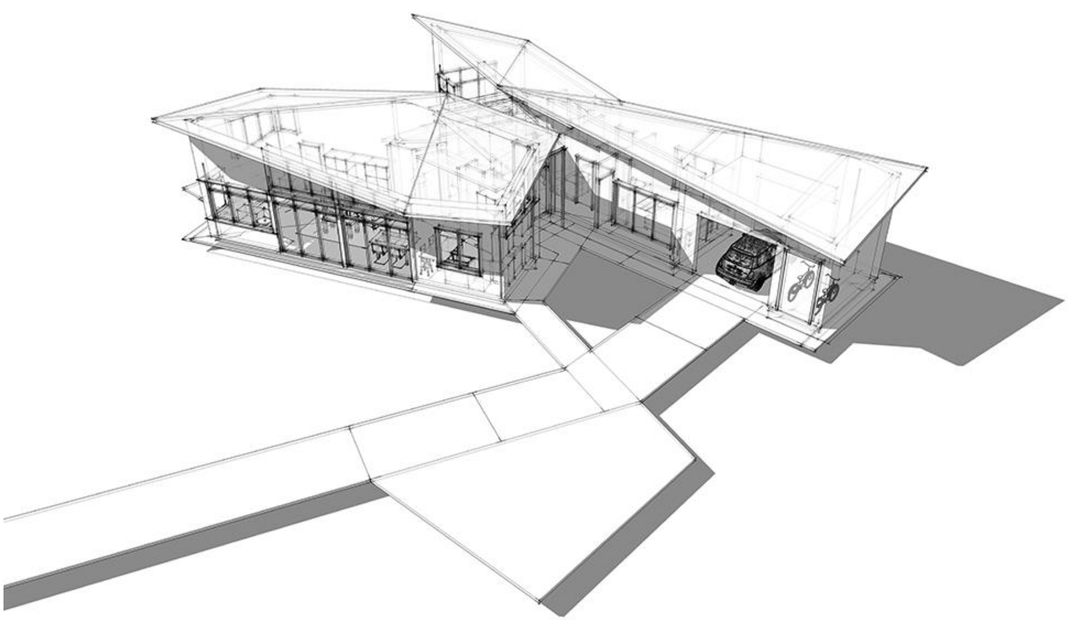


Figure 83. Quinlivan Net-Zero Energy House, completed in 2016. Drawing by Bradley Walters.

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