744. Interdisciplinary Partnering / Integrated Design: Georgia Tech's Entry in Solar Decathlon 2007

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ABSTRACT

This paper will present an overview of Georgia Tech's entry in Solar Decathlon 2007 ~ an international, multi-disciplinary competition between twenty universities to design, build, transport, and commission an 800sf solar-powered house on the National Mall in Washington, DC in October 2007. The competition was sponsored by the U.S. Department of Energy with the support of BP Solar, Sprint, the National Association of Home Builders, the American Institute of Architects, and ASHRAE. Contest rules required that each house generate enough energy from the sun to operate a household, a home-based business and an electrical vehicle.

Keywords: Interdisciplinary Collaboration, Integrated Design, Solar Power

1.0 INTRODUCTION

1.1 Building Ecology and Emerging Technologies

The rapidly changing context within which architecture and construction are practiced necessitates focused research in building technology such as material research, building ecology, envelope and cladding technologies, digital fabrication processes, and mechanical and environmental systems.

Georgia Tech's participation in Solar Decathlon 2007 began as a research proposal in a new Master of Science [MS] track in the College of Architecture. "Building Ecology and Emerging Technologies" [BEET] is a one-year post-professional degree housed in the PhD Program of the College of Architecture. MS/BEET is one of nine Master of Science tracks that foster interdisciplinary and collaborative study. [1]

The focus of MS/BEET is critical and rigorous research in emerging architectural technologies, particularly those engaged with issues of ecological importance. Interdisciplinary, research oriented, and design focused, this program offers specialization in the design, critique and analysis of architectural processes, paradigms and building systems developed in response to the global diminishment of natural resources.

1.2 Solar Decathlon

Georgia Institute of Technology was one of twenty universities selected to participate in Solar Decathlon 2007. Sponsored by the U.S. Department of Energy, the Solar Decathlon is a two-year international competition that brings student teams from universities across the world to compete in designing, building and operating highly energy efficient, completely solar-powered houses. The teams assembled their houses on the National Mall in Washington, DC in late October 2007. Contest rules required that each house generate enough energy from the sun to operate a household, a home-based business, and an electric vehicle. [2]

Fig. 1. Southeast Corner, Georgia Tech Solar Decathlon House, 2007

1.3 Leadership Team

Georgia Tech's team was highly collaborative and interdisciplinary. The project was initiated by College of Architecture professors Ruchi Choudhary, Chris Jarrett, and Franca Trubiano. Within a year, professor Russell Gentry joined as the fourth major leader on the project. The project leaders served as managers of an ever-increasing interdisciplinary team of 100 students and faculty from the Colleges of Architecture, Engineering, Management, and Sciences. Departmental partners included the PhD Program (Building Technology), Electrical and Computer Engineering, Mechanical Engineering, School of Biology, College of Management, as well as number of research center partners.

2.0 Research Center Partners

2.1 University Center for Excellence in Photovoltaics

Over a decade ago, the U.S. Department of Energy (DOE) established a University Center of Excellence for Photovoltaics Research and Education (UCEP) at Georgia Tech, one of two such centers in the United States. The Center's mission, under the direction of Dr. Ajeet Rohatgi, seeks to 1) improve the fundamental understanding of the science and technology of advanced PV devices, to fabricate record high efficiency solar cells; 2) provide training; 3) enrich the educational experience of students in this field; and 4) give the U.S. a competitive edge by providing guidelines to industry and DOE for achieving cost-effective and high-efficiency PV devices.

The faculty and student expertise at UCEP helped the team secure delivery of 41 Sunpower 210 and 215 PV modules to the project. In addition to general consultation, UCEP was instrumental in the specification, installation and operation of the PV and Inverter systems.

Fig. 2. PV Panels and Shade Screens, Georgia Tech Solar Decathlon House, 2007

2.2 Advanced Wood Products Laboratory

To effect an envisioned transformation of the wood products industry, the College of Architecture developed and operates the Advanced Wood Products Laboratory (AWPL). The AWPL utilizes computer-aided designing and computer aided manufacturing (CAD/CAM) to drive automated machining and manufacturing equipment.

The laboratory provided extensive support in the fabrication and construction of the Solar Decathlon house. The labs' computer-numerically-controlled (CNC) 3-axle and 5-axle machines enabled fabrication of the rotational "wing structure" in the roof that supports the photovoltaic panels and polycarbonate shade screens. It also enabled the fabrication of the shade screen on the south elevation and the luminous polycarbonate paneling throughout the interior of the house.

2.3 Center for Assistive Technology and Environmental Access

The Center for Assistive Technology and Environmental Access (CATEA) develops, evaluates, and utilizes assistive technology - technologies or devices designed to allow or improve performance of activities of daily living or work - in the design and development of accessible environments.

CATEA helped the team integrate accessibility as part of the vision of the house, as well as provide the design standards to implement the vision. The lab also provided valuable feedback in the selection of materials, technologies and appliances in support of the highest standards of accessibility, from floor surfaces, lighting, under and above-counter dimensions and finishes, various equipment and products, and bathroom accessibility including a roll-in shower.

2.4 Institute for Sustainable Technology Development

A university-wide advocate on sustainability, the Institute of Sustainable Technology and Development (ISTD) at Georgia Tech has developed a comprehensive agenda for enhancing curriculum, research programs, and campus management in support of sustainability. ISTD is an alliance of research and educational centers addressing specific issues relevant to creating a more prosperous and sustainable campus and society.

ISTD advocated for Georgia Tech's participation in Solar Decathlon 2007. They provided invaluable linkages to a range of sponsors and researchers inside and outside of Georgia Tech. They also helped the team secure start-up funding, strategic financial planning, and fundraising support that ultimately led to large donations to meet the costs of the project.

2.5 Center for Biologically-Inspired Design

The Center for Biologically Inspired Design (CBID) facilitates, develops infrastructure for, and promotes interdisciplinary research and education in biologically-inspired design at Georgia Tech. CBID develops tools and methods that facilitate interactions between biologists and other scientists and engineers.

CBID provided early, systems-thinking support based on biomimetic design. CBID helped define the original mission of the house, namely to extend the biological concept of homeostasis in the design of the project. The challenge the team set for themselves was to build a house whose internal environment would be capable of self regulation across a dynamic set of states, the most important constraint being energy input.

3.0 Decathlon Contest Summation

3.1 Architecture: 200 pts

The Architecture contest incorporated three facets: Firmness (suitability of skin, materials), Commodity (facility of program integrated with function), and Delight (comprehensive impression of originality). The interaction and collaboration of these three factors were judged based on which team had designed the most innovative and attractive green house design.

3.2 Engineering: 150 pts

Energy Analysis and Engineering Design and Implementation were used to decipher the technological advancements in the competition houses. For the Energy Analysis contest, students were required to fabricate a model predicting the annual energy performance of their house. The jury observed how this model improved the form and technology utilized in the Decathlon house. In the Engineering Design and Implementation contest, the teams were assessed based on metrics of the building envelope, indoor environmental control, mechanical, electrical, and plumbing systems.

3.3 Market Viability: 150 pts

The competition, in general, "encouraged all participants to act responsibly when making energy choices." Within this broader goal existed the opportunity to make solar technology and innovation applicable to the common consumer. This contest focused on market appeal. The teams were evaluated based on the potential for mass production, facility of sale, and broad consumer interest. In addition, the jurors assessed energy production in relation to cost efficiency.

3.4 Communications: 100 pts

Web site development and public relations experts assessed each teams' creative and effective delivery of information about their house. The judges evaluated each team for their clarity of information, consistent design message, and facility in interactive web an in-situ applications. In addition, the judges sought a connection between the vision, process, and results of each team's solar house throughout their two-year development process.

3.5 Comfort Zone: 100 pts

Given the delicate balance in which indoor environments comfortably operate, the Solar Decathlon teams were charged to design their houses to remain environmentally steady, uniform, comfortable throughout the competition period. Teams had to effectively achieve the predetermined target temperature and humidity. The tight temperature range of 72*F/22.2*C - 76*F/24.4*C) and relative humidity of (40% - 55%) were defined as the optimal comfort zones. The competition was judged by experts in building heating, cooling, and ventilation.

3.6 Appliances: 100 pts

A strict list of domestic requirements awaited the teams on the lawn of the National Mall. Each house was responsible for 1) washing and drying twelve towels for two days; 2) cooking and serving three meals a day, then washing the dishes after each meal for four days; and 3) running a TV/video player for up to six hours and a computer for up to eight hours for five days. The judges ranked the teams through calculations that rate the efficiency and completion of each task.

3.7 Hot Water: 100 pts

Like the Appliances competition, the Hot Water competition was based on the completion of a task, namely running a shower with a water pressure of fifteen gallons in ten minutes or less. The water had to be running at a temperature of 110*F/43.3*C in order to qualify for this contest.

3.8 Lighting: 100 pts

Through luminance measurements and professional experience, the jury determined which house used the appropriate type and proportion of light for each particular space, as well as which used innovative and functional energy efficiency techniques. Aesthetics, variety of light (ambient versus direct or electric versus "daylighting"), and function were also considered.

3.9 Energy Balance: 100 pts

The competition is called the Solar Decathlon in part because it requires the innovative design and utilization of solar panels to generate the bulk of electricity for the house and the car. Judges awarded full points if the energy collected from the solar panels is at least as much as the energy used during the competition.

3.10 Getting Around: 100 pts

For this contest teams were supplied with a standard street-legal (and commercially available) electric vehicle. They were given the task of balancing how much excess energy they think they consume by running the car. Judges awarded points proportional to the amount of miles driven during the competition period.

Fig. 3. Electric Vehicle provided by U.S. Department of Energy, Georgia Tech Solar Decathlon House, 2007

4.0 Design Strategies

4.1 Design Concept

Georgia Tech's Solar Decathlon House harnesses and celebrates the sun's power. As in the Greek tale of the architect Daedalus and his son Icarus who embarked on a flight to the sun, so too the modern fascination with building "lighter" and more "transparent" buildings is presumed to be at odds with "energy conservation." And yet, at no other time in the history of construction have advances in materials technology and energy systems design rendered Icarus' vision more realizable. Exploring the paradox of "lightness" and "energy conservation" was the inspiration that guided the design and construction of Georgia Tech's Solar Decathlon House. [3]

4.2 Light Roof

The roof design integrates 27 PV panels providing 6.5 KW of electricity to power the energy systems and appliances of the house. The panels are located on an adjustable rack that allows the panels to pivot and optimize their solar orientation. A portion of the south wall contains 12 PV panels providing an additional 2.0 KW of electricity to help power the house and an electrical vehicle.

Fig. 4. Adjustable PV Panels, Georgia Tech Solar Decathlon House, 2007

Shading minimizes unwanted heat gain and provides UV protection resulting in longer-lasting materials and reduced maintenance. The PV's on the roof are supported by a light-frame, adjustable rack system that optimizes the angle of the PV panel with the angle of the sun while shading the roof from direct sunlight and unwanted heat gain.

Rainscreens, or ventilated cavities, utilize the pressure of the wind to dissipate the energy of driven rainwater. As a result, rainscreens diffuse the premature decay of building materials in homes while keeping the water out. Rainscreens have been used on the roof and on the south wall, as part of a building-integrated photovoltaic (BIPV) panel strategy for deterring rainwater and moisture intrusion. [4]

Translucent materials allow diffused light to pass through but one cannot see through them. The roof is composed of a double translucent skin with an upper rainscreen and a lower panel. Made from ETFE film, the panel is inflated like a pillow and filled with aerogel insulation ~ the lightest substance known. The translucent double skin roof is "light weight" and "emits light" while being thermally-efficient.

Fig. 5. Translucent Double-Skin Roof, Georgia Tech Solar Decathlon House, 2007

Clerestory: Clerestory is an architectural term that originated in the temples of Egypt that denotes an area of glass in the roof that provides additional light. Here, the clerestory wraps the entire perimeter of the house providing abundant amounts of daylight while offering panoramic views of the sky from inside the house.

4.3 Light Materials

Nicknamed frozen smoke, Aerogel is a low-density material derived from gel but replaced with gas. The result is an extremely low-density flexible solid with remarkable insular properties that reduces thermal bridging. This semi-transparent material is light-weight, strong, durable, and known for the way "light scatters within the material." Aerogel insulation has been incorporated into the polycarbonate walls and translucent roof of the house. [5]

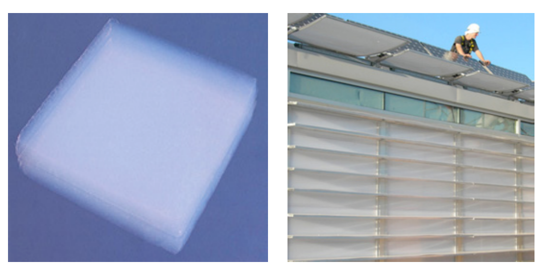

Fig. 6. Aerogel; Polycarbonate Wall w/ Aerogel, Georgia Tech Solar Decathlon House, 2007

Structurally-insulated panels (SIP's) are composed of energy-efficient expanded polystyrene insulation. The panels are factory made, sized to order, and easy to erect. SIP's improve quality, speed and economy in construction. The solid walls of the house are composed of SIP's, and on the west and north walls are finished with "light gauge" metal panel siding.

Bio-based insulation is a spray foam derived from soy beans that has excellent insular properties and provides a tight seal to keep air and moisture out. Traditional fiberglass insulation requires a large amount of energy to produce and creates harmful fumes when burned. Bio-based insulation is an eco-conscious insulating alternative that improves energy performance. The entire floor of the house is insulated with bio-based insulation.

Polycarbonate is a polymer-based product that is temperature resistant, thermally-efficient, extremely durable with good acoustical properties and is 1/100th the weight of glass. Polycarbonate is typically used in eyeglasses, headlamps, bottles, and housewares. The east and south walls incorporate a system of polycarbonate panels that "emits light" while being thermally efficient. [6]

Fig. 7. Polycarbonate Screen, East Wall, Georgia Tech Solar Decathlon House, 2007

ETFE (ethylene-tetrafluoraethylene) is an innovative, polymer-based, translucent film with high corrosion and temperature resistance. This material is very thin and lightweight and has enormous strength. ETFE has been used in large-scale buildings, including the stadium for the 2006 World Cup in Germany and the Aquatics Center for the 2008 Olympics in Beijing. It has also been used in the Eden Project, an environmental science center in England. ETFE is used in air-filled cushions in the roof and introduces the first residential application in the U.S. [7]

4.4 Light Technologies

Evacuated tubes convert the sun's energy into heat for purposes of heating water. Each evacuated tube consists of two glass tubes. The space between the two glass tubes is a vacuum. The vacuum helps to retain the heat from the sun. The insulation properties are so good that while the inside tube may be 150°C / 304°F, the outer tube is cold to touch. As a result, evacuated tube water heaters can perform well even in cold weather. A set of 20 glass tubes provide all the domestic hot water needed for the house. The tubes are easy to install and may be part of the building skin or, as in this house, part of the outdoor landscape.

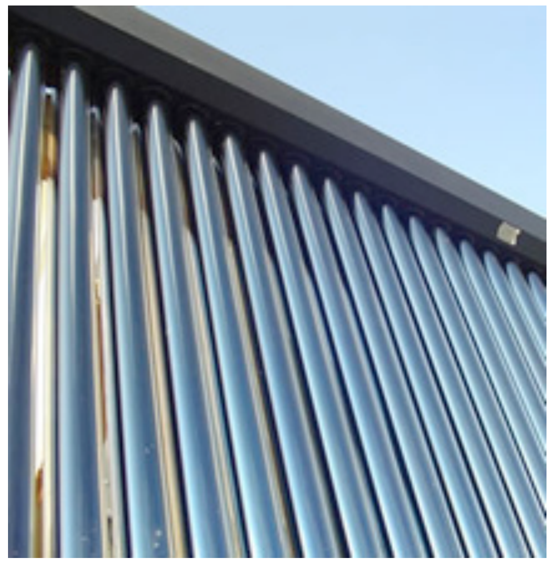

Fig. 8. Evacuated Tubes, Georgia Tech Solar Decathlon House, 2007

A split heat pump provides individual control of air-conditioning the different spaces in the house without ductwork. The outdoor unit is connected to the inside fan coil units by small refrigerant lines that cycle the refrigerant to heat or cool the air inside the house. A split heat pump is very quiet, efficient, and cycles quickly between heating and cooling mode. Its "slow cooling" mode also allows the user to control the humidity in the house.

This house is controlled and operated by software that continuously assesses the solar power available against the energy demands of the house. The software not only predicts energy balance over the next week, but also warns the user about expected operation of the house when solar power is limited. In this manner, the house becomes a dynamic living environment that can be continuously adjusted or balanced under varying uses and weather conditions.

The energy recovery ventilator conditions incoming air using the temperature and humidity of the outgoing exhaust air from the house. An energy wheel rotates within the ERV unit and transfers the energy of the exhaust air to the incoming air. This easy-to-install, off-the-shelf technology reduces air-conditioning energy by recovering what would otherwise be wasted. [8]

Rainwater harvesting cools machines in the house. In 1902, Willis Carrier invented air-conditioning to cool machines, not people. This is because machines are most efficient when they are at optimum operating conditions. For example, the efficiency of photovoltaic panels or an outdoor heat pump unit would increase if they were cooled. This house uses the rainwater collected in 20" PVC pipes under the deck to spray water on various machines that need cooling, including the solar panels themselves.

4.5 Light Lighting

Daylighting is the practice of using natural light to illuminate space. Rather than relying on electric lighting during the day, daylighting is the result of an integrated design process to illuminate the interior of the house with natural light. Daylighting reduces energy loads and provides excellent illumination while connecting people to the outdoors.

LED's (light emitting diodes) are essentially tiny light bulbs that fit easily into an electrical circuit. Unlike traditional incandescent bulbs, LED's contain no mercury nor filament that will burn out, and they don't get especially hot. LED's are found in all kinds of everyday objects like alarm clocks, appliances and traffic lights. LED's are extremely energy efficient, lasting up to 25 times longer than traditional incandescent light bulbs. LED flood strips are integrated into the design of the walls in the bedroom, producing a luminous effect that can be continuously dimmed to suit one's visual comfort or to decrease lighting energy demands.

Fluorescent light uses electricity to excite a vapor that produces a fluorescence. Fluorescent lighting is more efficient than incandescent light because a greater proportion of the energy used is converted to usable light and a smaller proportion is converted to heat. The living areas of the house use fluorescent lighting that is modulated by zoning the light circuits.

Solar technology is also showcased in this house at night. Small solar lights, self-sufficient with their own battery, line the outdoor deck. These small lights are charged with solar energy during the day and provide outdoor deck lighting at the night.

Photosensors are placed in each functional area of the house. The LED's use relay switching panels that communicate over a network with the house's building automation system. This allows the optimal controller to monitor and communicate lighting performance to the homeowner over the internet. The fluorescent lighting is modulated by zoning the light circuits and also tuned by the optimal controller. The interior of the house demonstrates the integration of LED and fluorescent light technology for ambient lighting in residential applications.

5.0 CONCLUSION

5.1 Project Scope Summary

The Solar Decathlon 2007 competition challenged students to think in new ways about energy and how it impacts their everyday lives. In a quest to stretch every last watt of electricity that's generated by solar-electric panels, the students absorbed the lesson that energy is a precious commodity. The students strove to innovate, using high-tech materials and design elements in ingenious ways. Along the way, they learned how to collect material supplies, talk to subcontractors, raise funds, communicate across disciplines, stretch their energy budgets, shop for energy-saving appliances, design energy-efficient lighting, and build an off-the-grid solar-powered house. Ultimately, the aim of this project was to provide students the opportunity to learn responsible actions when making energy choices and to show the world what they have learned. [9]

6.0 REFERENCES

[1] To view program descriptions of various Master of Science tracks in the College of Architecture, go to: www.coa.gatech.edu/ms.

[2] For more complete information on the Solar Decathlon, go to: www.solardecathlon.org, as well as www.solar.gatech.edu.

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