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No Compromise

the integration of technology and aesthetics

Solar technology is burdened with a stigma that contradicts a sense of proportion and beauty in building. Arbitrarily attached to new or existing construction, the technology is often associated with a small clique of individuals disenfranchised from the mainstream. This project is designed to challenge these perceptions and reestablish the ideals of solar energy by integrating architecture and technology. It pushes existing paradigms by proposing architectural form that celebrates solar power while obtaining a high level of system integration. As each technical decision was measured against its contribution to spatial effect, the project attained a simultaneous sense of the sustainable and the beautiful.

Introduction

Since the 1970's production costs of photovoltaic systems have steadily declined and better efficiency is making solar technology a viable source of energy for many building applications. The focus of this project centers on research of alternative energy and sustainable systems and its applicability to architectural practice, academia, the construction industry and ultimately the general public.

The increasing demand and rising costs for energy contrasted against the goal to reduce consumption of fossil fuels are competing trends of significant influence on daily life styles. In an effort to reduce the use of electricity, the U.S. Department of Energy is actively promoting the use of renewable energy sources. Energy consumption in residential and commercial buildings accounts for about 37 percent of our nation's energy budget. Buildings typically operate at less than 50 percent overall efficiency. With the nation's energy security and future in mind, collaborations between private industry, practice and academia are pivotal to address systemic issues of architecture and building technology. This project is one such effort to

research, realize and test building components that will reduce the nations demand for energy while improving the quality of architectural space.

The housing industry has been reticent to experiment with new techniques that could make buildings less energy intensive. Houses

constructed by small, local trades have not changed their construction techniques in decades. The panelized housing industry and prefabricated factory built processes represent some improvement in speed and waste reduction, but overall the results are conservative and energy saving is minimal. To transform the industry radical changes



1. View of the 2005 Virginia Tech solar house looking from dining towards living room and entry.



2. Scene on the Mall in Washington, D.C. during set-up of the Solar Decathlon Village.

are needed. This project proposes the use of alternative technologies and new materials to adapt to new lifestyles and the changing patterns of the ways people live and work. Ideas from the areas of material science and product development stimulate new territories of opportunity for the practice of architecture. Though the object was to produce a functioning house, the long-term research goal is to make buildings more efficient, affordable, and livable.

The Solar Decathlon

The program was derived from the International Solar Decathlon Competition sponsored by the Department of Energy. The charge was to design, build and operate the most effective and efficient house powered solely by the sun. The goal of the DOE is to provide to the public information about solar energy through interest in the residential market. Innovative, energy efficient houses from 19 major research universities attracted hundreds of thousands of visitor to the Mall during the three week event

In addition to design and construction, the house had to be transported to Washington, D.C. for testing and exhibition. The complexity of the task could not be met by any single discipline acting in isolation. Nor could success be achieved if each specialty group contributed its expertise in a linear sequential fashion. The process had to be integral from the start within a free flowing network of information. Our Virginia Tech team was composed of graduate and undergraduate students from seven disciplines - architecture, industrial design, interior design, landscape architecture, electrical, mechanical, and structural engineering. It also included faculty and practicing architects, engineers and manufacturers who served as advisors. It is rare for such a group to work together in the university setting. Yet when the participating students enter practice, collaborative skills will be an essential part of their day-to-day activities.

Design Concept and Philosophy

The design process was driven by a

multidisciplinary approach that challenges research through application. It harnesses the tension created by the dualities of calculation and intuition; technological innovation and architectural expression; optimized performance and sensible materials; and between physical fact and psychic effect. Simultaneous consideration of technology and architectural content has guided the identity of the house. Every decision involving quantitative criteria was measured in terms of its contribution to spatial quality. New forms have been derived from technical considerations, and enriched patterns of daily life find expression in a celebration of energy awareness and resource conservation.

With the growing need for effective utilization of resources, there is a desire to develop architectural forms derived from harnessing the sun while addressing local climatic conditions. Developing such forms requires going beyond adding environmental control systems to standard building types. Rather, these new forms must evolve from an approach of



3. North Core Wall exterior houses inverters, batteries and electrical equipment for the solar panels. The same degree of care and order is given to technical equipment as to the layout and detail of interior spaces.

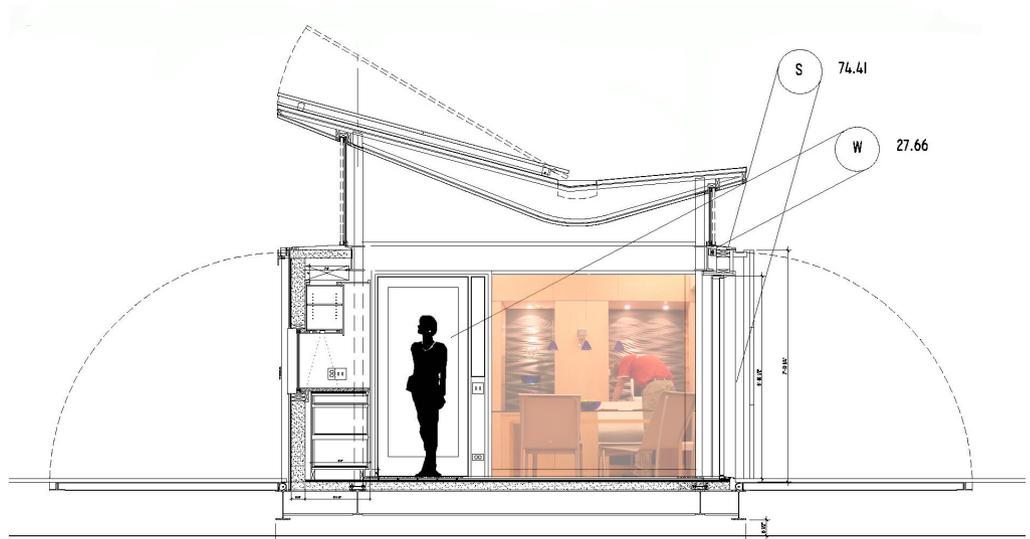
4. North Core Wall interior contains electrical closet, LCD screen, pull out coat closet, pull out pantries, storage above and below kitchen window, refrigerator, mechanical closet for water tanks and heat pumps, washer/dryer, fold-out ironing board, and pull out closets. The dark line running the length of the wall contains the registers for air conditioning.

systems integration that maximizes the benefits from heat, light and airflow. Currently, new and emerging technologies such as photovoltaic and insulation systems allow existing architectural design paradigms to be modified while improving performance. Materials that are renewable, recyclable and reflect low embodied energy can be used in combination to decrease the level of adverse environmental impact. This project pushes existing paradigms by proposing an architectural form that celebrates solar energy while obtaining a high level of systems integration.

Design Process

To promote interest and awareness across a wide range of students, a research course was conducted to assemble a design brief for an energy efficient, sustainable solar house. The product of that course was used as a program for a university wide competition. Fifty teams comprised of architecture, industrial and interior design, and mechanical and electrical engineering students submitted projects. Criteria for evaluation was based on technical awareness, design innovation, architectural identity, and viability of construction by unskilled student workers. Faculty advisors identified seven teams to advance their designs over a two week period. From this group a single scheme was identified to serve as a basis for what was to become an intensive design/build process. Around the core group of individuals a comprehensive team was established and divided into specific task areas. A special research class was conducted involving 80 individuals who examined all aspects of the project, collaborating on issues such as material selection, energy collection systems, conservation strategies, and transportation - this last issue proved to be of distinctive complexity. Design development, prototyping, and construction documents proceeded through a network of remote and face-to-face meetings of teams.

The 24-month process involved individuals



5. Section through kitchen showing fold-down trusses. The roof, a folded plate, stressed skin structure sits on five pairs of columns and floats over the clerestory.

with varying degrees of skill, expertise, and background. Teamwork in conjunction with strong student leadership was required. Problem solving, information flow and integration, alternative generation, ideation, innovative troubleshooting and testing are all part of an experience where the consequences of decisions are real and verifiable. This thinking and constructing learning experience not only requires innovative design strategies; it necessitates a program of funding through corporate and industry contacts. As part of this effort, students in collaboration with architects and engineers, surveyed manufacturers and suppliers to procure materials that were sustainable, energy conscious and a qualitative improvement for the residential environment.

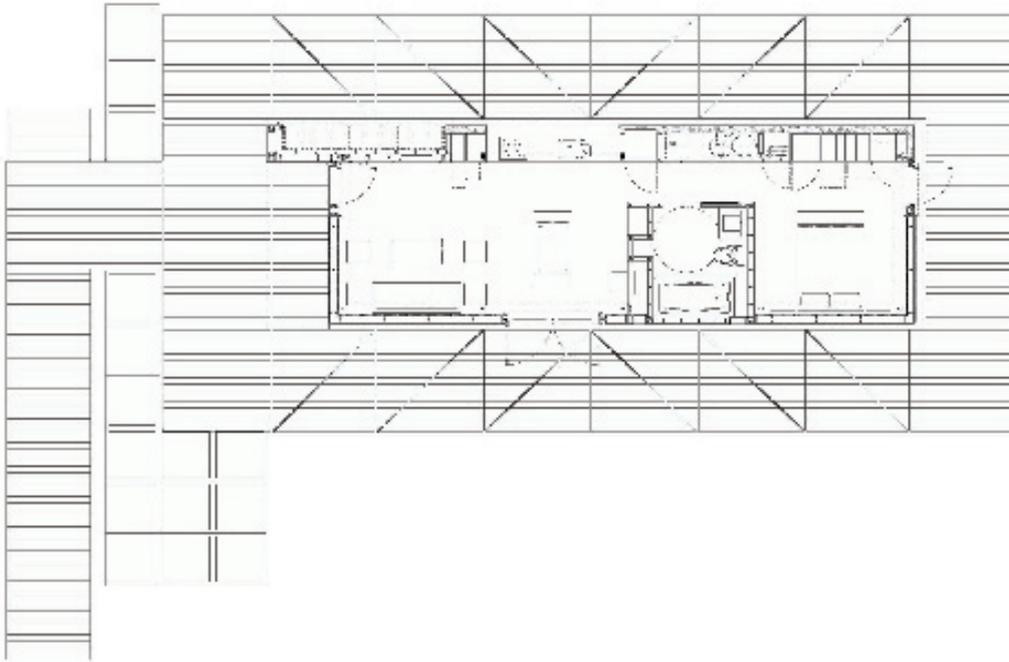
Design research included the college's 2002 entry for the first Solar Decathlon Competition. This project was analyzed, noting and scrutinizing its strengths and deficiencies. Though this pioneering team graduated, the knowledge derived from the initial endeavor

has been transferred to and transformed by the 2005 team. The new project has achieved a higher level of complexity expressed in an elegant simplicity. As the 2002 project was a ribald confederation of pristine parts, the new work has been reconsidered as a systemic whole. The initial theme of the art of integration has been realized through a process of design that strives to avoid problems and discover new forms. Though there were many technical components to master, months of work was dedicated to the distillation of a rigorously ordered plan and the simultaneity of a section offering spatial richness.

A House Larger than Itself

The house is comprised of a rectangular plan wrapped on three sides with a translucent skin and covered with a hovering curved roof inflected toward the sun. A thick linear core defines a massive north wall and houses technical equipment (batteries, electrical, mechanical) and service functions (kitchen, laundry, storage, closets). This establishes a sense of stability and permanence that is

6. The house is approached from the west up a gentle ramp along cascading trays of water plants. A roof cantilever provides an initial change of scale and protection from the weather. Circulation is along the north core wall and projects directly out to the east door in the bedroom. The activity spaces of the living, dining, and bedroom borrow from the circulation, maintaining a positive ambiguity of use with the strong entry axis. The bedroom is the most closed, sharing part of the core that contains closets and the laundry. The dining room is defined by the axis of the table that links the horizontal window in the kitchen and the large patio doors opening to the deck. It shares space with the living room whose domain is nestled into the adjoining column bay and the corner of the translucent panels.



reinforced by contrast with the delicacy of the translucent wall. A second core (bathroom) divides the space lengthwise into the public and private sectors and provides another reading between the heavy, cave-like slate interior and the ephemeral walls of the outer rooms. These differentials psychologically expand the volume and create a sense of generosity. The space breathes as experienced in changing natural light and from alternative points of view. One can walk directly through the house on the circulation path that runs along the north wall and overlooks each activity area (tens of thousands of visitors were directed along this passageway while on the Mall). Or, one can take various routes – a detour to the patio off the dining area, or promenade on the deck circumnavigating the house.

The unorthodox appearance of the roof (one inquisitive Montessori student asked us why the roof was on upside down) belies a rationale that presents a form based on

meaningful and efficacious criteria. The Steep slope expresses the capture of the sun's energy at the proper angle. Riding on columns, an actual reading of the roof suspends it in air. Seen through the clerestory, the ceiling's reflected light (both sunlight and electric light) make the roof appear as if it is floating. The section is not uniform – the roof thickens in the center. Part structural (it is a folded plate and a stressed skin), the form is also an intuitive statement of reaching for the sky. Rain is celebrated by directing the water to a fall line on the short sides of the house into storage tanks for filtration and grey water use. The corresponding ceiling creates a space that releases toward the clerestory, providing intimacy at the low center and making it seem much larger than its modest 590 square feet.

Putting Light Where It has not Been

An innovative wall assembly contains light literally and phenomenally. The east south and west facades are constructed of two layers of polycarbonate panels filled with Nanogel,

a translucent aerogel. This wall section gives an R-24 insulation value while transmitting a beautiful translucent light. This highly insulated wall acts as a dematerialized surface, holding light similar to that of a Japanese pagoda. Mornings, the walls of the east bedroom come alive with a radiance shifted toward yellow; evenings in the western oriented living room are immersed in a reddish cast atmosphere. Increasing natural daylight in building has long been a goal in architectural design. Studies have shown that people thrive in natural lighting: they are healthier, happier and more productive. In this house, there is no need for electric light from sunrise to sunset and the energy collected during the day is symbolically radiated back out at night through the lantern glow of the house.

Between the inner and outer polycarbonate panels is a six-inch airspace containing three systems that enhance energy performance and spatial quality (see Tunable Wall below). The most important of these are banks of LED (light emitting diode) fixtures. These lights are controlled by the user to produce an unlimited set of colors and lighting effects. The walls can be turned any color desired, thus changing the atmosphere of the space. More needs to be understood regarding how color effects our reaction to space, but studies have confirmed its efficacy on biorhythms of the body. Color plays a role in one's sensitivity to temperature (blue might be employed to cool the hottest summer nights) and color through light will become a normative architectural element within the next decade. The degree to which color forms a determinant of our psychological composition is subject to study, but its transformative role in this house is manifest in user enjoyment and a distinctive nighttime identity.

Research

Architectural research does not necessarily fit the scientific model and thus has not been given due credit in the university. To

the outsider, the iterative nature of design tends to make the process appear redundant and without focus. The Academy is often criticized for generating knowledge that does not always have a direct correspondence to application, while the conventional method of practice is often viewed as too insular and predictable. To break through the stereotypes, our interdisciplinary team sought to develop alternatives to the normative methods of architecture through the application of new materials and manufacturing techniques. Early interaction between the architect, industrial designer, engineer, supplier and manufacturer encouraged the development of more efficient and elegant building components. Materials were examined through various qualitative and quantitative criteria. Characteristics of low embodied energy, durability, minimal off gassing and recycling potential were contrasted with their contribution to spatial quality. A synopsis of innovative components include:

- Translucent wall assembly - Polycarbonate panels filled with nanogel, a translucent



7. Living room

aerogel, provide a R-24 insulation value while delivering a soft glowing light that animates the entire space. From sunrise to sunset no electric light is required. Increasing natural daylight in building has long been a goal in architectural design. Studies have shown that people thrive in natural lighting: they are healthier, happier and more productive.

- Tunable walls - Motorized shades between the polycarbonate panels allow for darkening of walls and reduce direct solar gain when necessary; automated dampers ventilate the cavity and give additional thermal and moisture control; LED lights allow for any desired wall color, no paint required.
- Expanded polystyrene structural insulated panels (SIPS) that are lightweight, easily assembled, and yield a high insulation value comprise the north wall and the sub floor.
- Cabinet enclosures are made of an annually renewable wheat straw. The material exhibits reduced volatile organic compound emissions, including a reduction of formaldehyde emissions by 97%.
- Appliances were selected based on maximum energy efficiency (energy star rated) and visual elegance that creates a coherent wall module. The kitchen was designed as an effective service area that occupies a small volume yet offers full service.
- Paint products use sustainable raw materials such as soy and sunflower oil and emit no volatile organic compounds (VOC's).
- Eucalyptus flooring was used throughout the house. It is highly durable requiring little maintenance and is harvested from renewable,



8. Sunlit translucent wall panels with motorized shades partially deployed in the bedroom walls.

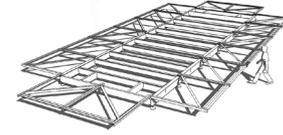
managed forests. Underneath this engineered floating floor lies a radiant heating system – the most efficient and best quality of heat. There is little air noise or movement and the ambient temperature can be kept lower saving energy.

- The roof is a lightweight folded-plate structure filled with icynene foam insulation. Its form sets the solar panels at an optimum angle for energy collection and modulates the interior space. The top of the roof responds to the demands of harvesting sunlight and rainwater while the corresponding underside creates rooms that provide intimacy yet makes the space seem much larger than its modest size.
- The landscape is built to demonstrate water conservation techniques through developing a system that integrates the exterior and interior environments inclusive of a rain water harvesting system, constructed wetlands, and planting schemes. The water system is developed as a three-part system of rainwater harvesting for recycling as potable water, wastewater treatment system that filters gray water for reuse, and a potential heat sink for the HVAC system.



9. Landscape serves as an entrance threshold and a gray water filtration system. Scuppers harvesting rainwater create an acoustical waterfall.

As a result of this work three major manufacturers are considering a joint project to develop a product from the translucent/tunable wall assembly that can be adjusted to any color. An international supplier has



11. Transport arrives on site and the rear bogey and gooseneck are removed. Truss structure is rotated vertically to provide for wrap around cedar deck.

requested the development of an AIA continuing education course base on this solar house technology. In addition, a national manufacturer of cabinetry (using the renewable wheat board for the first time in this project) is considering wider use of sustainable materials.

Prototyping and Industry Ties

The unique nature of the materials and assemblies made prototyping essential to the successful development and integration of the building systems. At times full-scale mockups were constructed to determine points of potential conflict and best assembly techniques. This was an iterative process



10. Roof structure being filled with icynene foam insulation

often dependent upon the learning curve of an unskilled student task force. Another area in which prototypes were used related to the engineered systems. Prefabricated modules were developed by architecture and engineering students to be tested and evaluated prior to their installation in the building module. Construction was interwoven with prototyping, testing and re-design. Since many of the materials and components were new to this type of application, techniques of fastening and assembly had to be explored. In many cases jigs and special fixtures were designed to meet particular needs.

Material and system selection evolved hand-in-hand with industry. As much as

possible, regional businesses were selected that supplied materials and systems that had the desired characteristics identified in the design phase. The students worked closely with these industries to understand the specific requirements of installation. At times, industry representatives conducted workshops on the correct way of using their products. There were several instances in which students suggested new and innovative approaches to the use of the products to the manufacturers. There were 75 participating industries supplying material and services to the project. The original contacts made with these companies are evolving into long-term research relationships.

Transportation

Shipping something this big presents its own set of problems – a unique solution was derived from special collaboration between the architects and structural engineers. In the Virginia Tech 2002 Solar Decathlon



12. Prototyping of polycarbonate wall assembly alternatives.

Competition entry, the house was transported to Washington, D.C. in two separate modules. This rendered weight and size a simple issue,

but caused considerable difficulty setting up on the Mall. The alignment of systems across the two sections with tolerances of one sixteenth of an inch proved problematic. The task became a ballet of student operated forklifts and crib carrying grips working 24/7 over four consecutive days. It was determined to make the operation both simple and more graceful for the 2005 project.

Students and faculty met with trucking industry designers and discovered the low-boy double-drop trailer. In this equipment the wheels lie outboard of the heavy load in order to keep the cargo as low as possible on the highway. A special chassis serving as the house floor and foundation structure was designed to receive a detachable gooseneck and rear axles for transport. A truss on each side of the 48' span resists deflection while in transit. Upon site arrival, the trusses rotate down 90 degrees to create a deck surround for the house. Though there was some doubt among the structural engineers, our student's calculations proved true and the system worked flawlessly; the project arrived on the Mall at 2am and the



13. Strange cargo

house was ready for operation soon after daybreak. This transforming technique now facilitates moving the house as an exhibition/education piece, but more importantly, serves as a model for the potential shipment of units with the roof in place.



14-18. Light, color and space.

PHOTOVOLTAIC PANELS

The roof integrates 36 solar panels for collection of energy without the negative connotations of technical equipment. Peak generating power is 8.5 kilowatts.

FABRIC CEILING

A fabric ceiling reflects natural and electric light for efficient and effective interior illumination.

FLOATING ROOF

An intuitive form oriented towards the sky provides the primary identity of the dwelling. Uplifting from the center, a simultaneous sense of intimacy and spatial openness is established.

CLERESTORY

Transparent glass makes the roof appear as if it is floating; connects interior to landscape; and admits selected sunlight.



NORTH CORE WALL

A monolithic block anchors the volume of the house; contains electrical and mechanical equipment, kitchen, laundry, and generous storage.

TUNABLE WALLS

Motorized shades allow for darkening of walls; linear actuators ventilate cavity and give additional thermal and moisture control; LED lights allow for any desired wall color, no paint required.

WALL MOUNTED SOLAR PANELS

Six solar panels provide additional energy in the coldest months and are made accessible for viewing to the public.

TRANSFORMING DECK

A surrounding cedar deck spatially expands the house and links inside and outside activities; the deck structure rotates 90 degrees to reduce deflection of the main beam while transit.

TRANSLUCENT WALL ASSEMBLY

Polycarbonate panels filled with aerogel deliver high insulation and sound absorption values while transmitting beautiful translucent light.

POTENTIAL ENERGY

Exuberant Energy from the student team was transformed from erratic performance to refined precision during the course of the project.

Aerial view of house undergoing final assembly and initial testing before transport to Washington D. C.



20. Fourth day of the competition during a break in the rain with heavy overcast skies.

Aftermath

Students and practitioners from architecture, industrial design, interior design, landscape architecture, mechanical, electrical, and structural engineering developed new and efficient components comprising a house that derives all of its energy from the sun. The goal is to develop sustainable ways of building - and thinking about building - through collaborative design and construction. Designed and built in the spirit of no compromise, this solar house offers energy efficient living in a sensuous and rich environment.

Their efforts were validated in winning the critical awards judged by panels of experts. The Virginia Tech house was ranked first in the architecture, dwelling, daylight and electric light portions of the competition. It was also recognized with the AIA President's Award for best house. For the first four days of the competition it was leading overall, finishing eventually fourth of 18 competitors. It rained most of the competition (if there were sun during any of the five days of competitive measurements, the house would have finished first, but this is a story about energy strategy within the story of the house).

This project was made possible through the efforts of the entire solar decathlon team. They include among others:

Primary Student Team: Brian Atwood, Brett Moss, Chip Clark, Mike Christopher, Nancy Hodges, Tom Shockey, Brandon Ligenfeler, Dan Gussman, Alan Todd, Matt Wagner, David Rairden, Ben Mohr, Phil Hassell, Kyle Longbrake

Other Contributors: Chuck Hoover, Adam Tomey, Nathan Gabriele, Nick Monday, Nathan King, Alec Clardy, Seanene White

Primary Faculty: Joe Wheeler, Robert Dunay, Robert Schubert, Michael Ellis

Other Contributing Faculty: Ben Johnson, Greg Tew, Michael Ermann, Ben Gauslin, Ed Dorsa, Mehdi Setareh, Jay Stoeckel, Michael O'Brien



21. House on the Mall with selected light of the evening.