Icarus Redux, Sustaining Inventions in the Art of Building with Air, Light and Flight

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The argument put forth in this paper is situated at the crossroads of the poetic and the prosaic, responsive to both the metaphoric potential of an ancient Greek tale and the pragmatic exigencies of sustainable building technologies. Structuring this intersection of architectural myth and practice is the figure of the sun, a physical and imaginative trope naturally aligned with the elements of air, light and flight. In communicating the results of a highly interdisciplinary design development process undertaken by architecture students involved in the construction of a single family residence entirely powered by solar technology, this paper posits a highly productive venue for the integration of both narrative and construction within the teaching of design. And it does so by critically challenging a number of now commonplace fictions; be they current in the development of architectural pedagogies or in the field of sustainable design.

The Greek narrative of interest to this paper is intimately associated with the origins of architecture and with the history of technology. The ancients envisioned the very first encounter between architect and *technē* in the figure of Daedalus;[1] the builder of the labyrinth and the dance platform in Knossos who was decidedly crafty with his technological inventions. His legendary exploits were even of interest to Plato who wrote of his cunning in *Euthyphro.*[2] One of his many devices, however, seriously angered his royal patron King Minos resulting in his forced confinement on the island of Crete. Desiring his freedom, this ancient artificer set out to invent his way of out of captivity and he did so by fabricating the first apparatus of flight. By dexterously combining feathers and wax into a simulated wing and by navigating the skies with this aerial sail, Daedalus gained his liberty. Having safely arrived in Sicily, it was truly an accomplishment of immeasurable proportions. Unfortunately, he paid a rather high price for his freedom; the death of his son Icarus. The youngster had also been fitted with wings, but having ignored his father's warning, he flew too close to the sun's ray, destroying the wax's binding capacity and falling to his death.

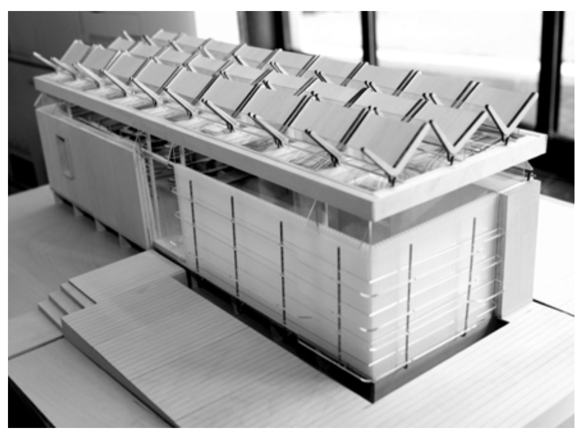

Figure 1. Solar Decathlon Building Model

The mission statement underpinning the student design project described herein is inextricably bound to this cautionary tale. It presents a modern day attempt to once again navigate the skies using Daedalus' wings, albeit this time knowingly aware of its inherent risks. In January 2006, the Georgia Institute of

Technology was selected to participate in the 2007 Solar Decathlon Competition,[3] an international sponsored research project whose highly interdisciplinary structure has enabled the design of a truly innovative residence which harnesses and celebrates the sun's power. Integrating both architectural and engineering principles, the house's design critically advances alternative approaches to the present day production and consumption of solar technology. And the research question which the project seeks to answer is one with far reaching consequences.

Is the integration of solar design principles, and their allied mechanical systems, within contemporary works of architecture environmentally and economical feasible given the increasing desire on the part of designers and consumers for spatial and architectural transparency?

Over the past three decades, countless have been the building projects conceived and built with an eye to de-materializing the very matter with which they are built. The propensity to eliminate the occupant's artificial skin has been at the center of much of the work of architects Renzo Piano, Jean Nouvel, Norman Foster and Tom Phifer. Corporate clients and national governments intent on revealing the inner workings of their respective enterprises and institutions have been equally attentive to the architectural imperatives of transparency.[4] And the very definition of modernity in the west has been predicated on the desire for clarity in thought, lightness of bearing and transparency of reason.

But in a manner analogous to Icarus' flight, our contemporary fascination with building lighter and more transparent buildings evades many dangers incumbent with unbridled attempts to attract the sun's power. The increasing global consumption of glazing technologies has resulted in an increased demand for energy to condition building interiors to the comfort levels to which we've grown accustomed. Moreover, the embodied energy of glass is many times that of plaster board, kiln dried woods, and in-situ concrete and this is a fact now well known and difficult to ignore in assessing the sustainable value of our projects.

Remarkably however, at no other time in the history of the art of building have advances in the technology of architectural materials rendered Daedalus' vision and Icarus' rapprochement to the sun more realizable. Developments in nanotechnology have expanded our understanding of the microscopic properties of building substances and accelerated the invention of new materials.[5] The ability to measure a building's performance has been enhanced by significant transformations in computational technologies and discussion of a building's thermodynamic behavior is now commonplace in evaluating its architectural merit. Most surprisingly, products and processes previously untenable and marginal within the context of sustainable practices are now touted as positive for the successful advancement of ecological principles. And nowhere has this proven to be more the case than in the design of architectural skins intent on increasingly levels of transparency.

The following project narrative investigates this apparent contradiction by focusing on a specific example; the design of a zero-energy home whose material choices and fabrication details openly challenge accepted notions of "good practices" in solar design. In the delicate, yet dangerous, integration of varying veils of transparency, distinct aspects of the house's design have been devised to attract that which could well destroy them; the sun.

The Competition

The project which lies at the center of this paper is motivated by the competitive drive to win. No differently than the first foot races run in 8th century Greece, the Solar Decathlon is predicated on the active measure of excellence in matters of performance. During Fall 2007, twenty custom designed homes will be delivered to the National Mall in Washington DC, each built by a group of university students competing in a week long series of activities testing the house's efficiencies in collecting, storing and consuming solar energy. Amongst the twenty international schools participating are Massachusetts Institute of Technology, Cornell University, University of Colorado, Universidad Politécnica de Madrid, and Texas A&M University. The rules and regulations have been carefully scripted by highly committed organizers of the Solar Decathlon at the US Department of Energy's Office of Energy Efficiency and Renewable Energy. This third in a series of bi-annual competitions is surely to garner the greatest public attention given the topical and timely interest in alternative sources of energy.[6]

All aspects of the house's design will be put to the test. The architectural and engineering scope of the competition is all inclusive; objectively measuring the optimization of appliances, hot water usage, and temperature and humidity levels; subjectively judging the merit of construction details, spatial layouts, and material choices. The following list of ten competition categories identifies the versatility which students must master and deploy; Architecture, Engineering, Market Viability, Communications, Comfort Zone, Appliances, Hot Water, Lighting, Energy Balance, and Getting Around.

The success of such a venture necessitates collecting expert team members. And notwithstanding the origins of the research proposal within the Architecture Program, alongside co-investigators Ruchi Choudhary and Chris Jarrett, essential to the team are its collaborators in engineering, biology and marketing. A vast interdisciplinary team has been organized at both the faculty and student level. Experts in the College of Engineering in Photovoltaic Design, Lighting Design, and Mechanical Systems have been incorporated into the analysis and design aspects of the project. The Center for Biologically Inspired Design has been instrumental in offering an analogical structure within which to organize the house's organic behavior. The Institute for Sustainable Technology and Development is active in securing the project's transmission amongst larger segments of the sustainability community. And expert members from practice and industry have been welcomed into the project as consultants, be they architects, subcontractors, truckers, photo voltaic installers or material suppliers.

The Pedagogy

The project is itself an experiment in architectural pedagogy, critically challenging current fictions about the education of the architect. Upon completion, the house will have been conceived, developed, built and tested across 15 months and four consecutive academic sessions; the result of which will be the involvement of nearly one hundred different students.

From its inception, an important pedagogical goal has been the integration of an interdisciplinary model enabling students from varying departments to participate in a fully collaborative design environment. To this end, students from biology, architecture, mechanical engineering, electrical engineering and management have all worked together on various aspects of the project's development, both in studio and seminar formats. Intra-departmental integration was also fostered by instituting the first vertical design studio in the Architecture Program, permitting undergraduate students to work alongside graduate and PhD students.

Figure 2. Charette Design Review

The house's initial design was devised over a five week intensive summer design *charette* which witnessed twenty-eight architecture and engineering students collaborating on the articulation of one project for advancement to the design development round; by no means a simple task given the present normative pedagogical framework within which much of architectural education is delivered. The idea that one and only one architectural proposal would result from the design initiatives of many was in itself a journey of discovery for many students who had never worked in a team prior to this experience.

On the other hand, the idea that one's architectural designs should be constrained by engineering requirements communicated during coordination meetings was equally novel for many architecture students who had never been limited by the size of supply and return ducts, the spatial accommodation of ventilation equipment, and the exigencies of visually integrating one's power source in the design of the building itself.

Additionally, the recognition that each and every drawing line has an associated physical reality was equally transformative in the pedagogical sense. The immediacy of construction drawings as a design language is rarely engaged whilst a student and it remains far from the vocabulary of a young architect. In the context of this studio, however, the material limits of building assemblies and their details acquired a palpable dimension when students were asked to produce the full roster of construction drawings needed for the erection of an 800 sq. ft. house. The drawing set produced after the first *charette* included architectural plans and sections, large scaled wall sections, plan details, window details, roof details, landscape plans, as well as mechanical, electrical and plumbing drawings.

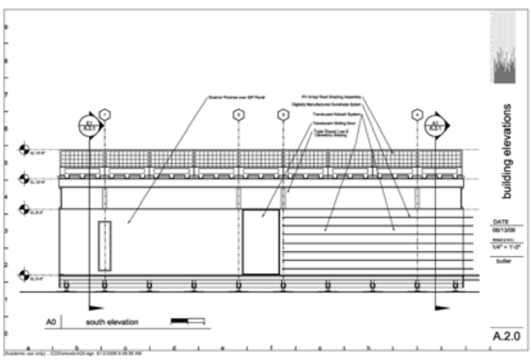

Figure 3. Typical Working Drawing

Moreover, securing access to design-build activities has offered a segment of the student population an alternate model of the design studio; one predicated on the physical constraints of construction and on the responsibility of accounting for the execution of one's design decisions. In this regard, the initial construction of various building segments prior to the actual full scale construction of the entire house is proving essential to the design process. The making of prototypes, an art onto itself and one rarely entertained in the context of traditional architecture studios, greatly facilitates the invention of new modes of fabrication.

And finally, students were asked to integrate established manufacturing processes alongside custom solutions for the house's construction. This necessitated collaboration with industry representatives in order to test the limits of one's designs. Intended construction techniques as originally proposed by students are analyzed and challenged by direct interface with assembly and material producers. And in the best of circumstances negotiating new details and precipitating transformations in standard building procedures is a possible outcome of such exchanges.

This five part transformation in the methodology and daily operations of the typical architectural design studio was precipitated by the structure of the Solar Decathlon Competition and the remainder of this paper communicates the inventive results made possible by this re-design of the normative studio.

Sustainable Inventions in the Spirit of Daedalus: Courting the Sun

Transparency is a utopian vision; a state much desired but hardly attainable. The very premise that we can safely live and thrive under the unprotected splendour of solar rays is an impossibility in the material world. The best we can do is to invent mechanisms to both enjoy its benefits and guard against its dangerous effects. To this end, this project is predicated on finding the most amenable design conditions which celebrate the sun's architectural potential all the while being attentive to the possible ramifications of such actions.

The drive to achieve clear and uninterrupted vision is at best a search for greater values of light transmission. With increasing and decreasing degrees of luminance, the house's architectural concept is physically and metaphorically situated upon the building's skin. And in the context of this particular solar house design, struggling to establish an operative median between attracting and repelling the sun's rays necessitated the design of a system of architectural light veils; one of air and one of flight.

Air

Indispensable to the house's narrative was the decision to integrate into its design a somewhat paradoxical building assembly. Self consciously, and flying in the face of accepted solar practices, student designers proposed a radical re-thinking of how the house's roof may be built. Discounting the necessity for complete opacity at the interface between the sun and a building's upper most skin, the use of an innovative material was proposed. Incorporating the building material referred to commercially by the abbreviation, ETFE (Ethylene Tetrafluoroethylene), the inventive roof assembly has been designed to channel greater amounts of light within the interior of the building; ironically, there where the building is most vulnerable.

Built of a series of plastic foils inflated into air cushions, the product is primarily an assembly of semi-transparent layers held together by a series of metal extrusions. The ETFE foils are reminiscent of polyethylene sheets, fairly resistant to tears and typically 200 microns thick (0.2 millimeters). The weight of foils is negligible in comparison to an equal surface area of glass; a property which has rendered ETFE competitive in a series of building types requiring large amounts of glass. The foil cushions maintain their shape by way of a small quantity of pumped air. The aluminum metal extrusions clamping the foils are at times the main structural members for the entire assembly.[7]

Over the past decade, ETFE has become a much celebrated material. Used by architects Michael Hopkins, Nicholas Grimshaw and most recently by Herzog and de Meuron, it has proven its versatility and resistance to many environmental constraints. Early on in 2000, the engineering firm of Buro Happold in collaboration with Hopkins completed the multi-use cultural building called Wildscreen @Bristol using ETFE cushions.[8] More recently, the Allianz Arena, Munich's new 60,000 capacity soccer stadium, stands as the largest project to have used this still experimental material. Skinning both its vertical and horizontal surfaces it was incorporated into a continuous surface eliminating the boundary between wall and roof.[7] The highly custom nature of the design components resulted in nearly three thousand different cushion components, all of which were skinned with ETFE foil. Lighter and more thermally resistant than glass, this material is perfectly suited to botanical enclosures such 'The Eden Project' built by Nicholas Grimshaw in collaboration with engineers ARUP in Cornwall England. Eight quasi-geodesic domes termed 'biomes' were organized in structural hexagonal frames resulting in a landscape of pneumatic figures, with cushions measuring 30 feet in diameter and six feet in depth.[9] Most topical at the moment is the intended use of ETFE for the construction of China's 2008 Olympic pool. The Australian architectural firm of Peddle Thorp and Walker in collaboration with Arup Engineers has been commissioned to engineer this truly innovative building using thousands of inflated cushions. The entire assembly is structured about a crystalline-like geometry whose metaphorical allusions to water are surely not coincidental. All await the completion of this most innovative of ETFE integrated buildings.[10]

The house to be built by the team of architecture and engineering students at the Georgia Institute of Technology is a great deal smaller in scale and scope than the projects discussed here above. With only 800 sq. ft of livable space, the introduction of ETFE within the design and construction of this solar house is an attempt to reinvent the role of technology within residential construction.

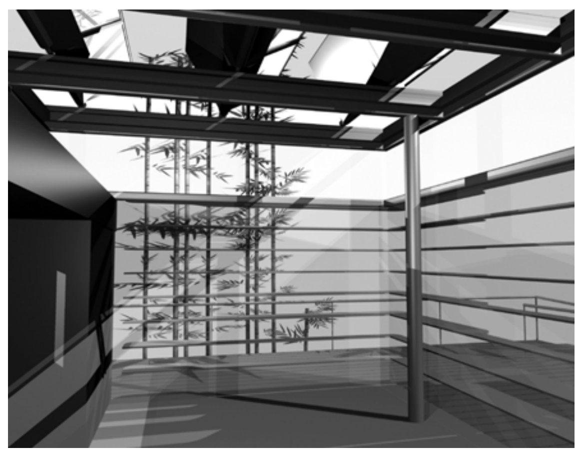

Figure 4. Interior view of light filled space

The house, whose dimensions are a modest fifteen feet by fifty feet is segmented structurally into nine structural bays with ETFE carefully integrated within its organizing geometry. Conceived as nine separate pillows, rectangular in proportion and twelve inches deep when inflated, the roof is a landscape of light transmission. Design considerations as pedestrian as thermal bridges and water drainage were highly instrumental in the roof's design development. And at this moment all further modifications to the assembly are predicated on the engineering possibilities which reside in the foil. The introduction of various films may be used to halt the transmission of harmful rays and the introduction of insulation between the various layers of foil may be used to increase the assemblies' thermal performance.

Air is the main building block in the construction of the ETFE pillow. It is also the main ingredient in the insulation type chosen by students for key areas of the building's skin. 'Aerogel', a by-product of the aero-space industry, is a highly insulating material which paradoxically transmits large amounts of light.[11] Its composition is ninety nine percent air and one percent silica. First used experimentally decades ago in an architectural assembly by Thomas Herzog who designed and built an exterior facade for a private residence using this material, its highly porous structure exists at the scale of nanometers and its insulates at a rate 40 times that of fiberglass. Herzog adapted the material's thermal capacities in the design of a 16 mm silicate infill sandwiched between two layers of glass achieving thermal comfort without a correspondent loss in transmitted light. [12]

At present, this material is commercially available in the building industry and increasingly integrated within standard construction details. To further the project's goal, it will be proposed as a form of insulation for the ETFE roof under consideration. It will also be fully integrated into the design and construction of the house's "light walls"; its eastern and south eastern edges. Experimenting with a range of polycarbonate panel types and sizes, the students have undertaken to devise a new wall sandwich assembly incorporating the Aerogel within polycarbonate panels. Other commercially available light walls, such as *Kalwall,* have already successfully integrated this super-insulative material into fiberglass panels and are also being investigated for possible integration into the design. In either case the students are asked to measure the design trade offs of three distinct variables; the weight and structure of each assembly, its thermal performance and its light transmission. Difficult decisions will be taken at the end of the design development stage in order to assess the best possible solution.

Flight

The integration of air as a material in the construction of building assemblies posits a particular means of satisfying the architectural desire for "lightness". Another manner of achieving the like is by returning even more pointedly to the narrative referenced at opening of this paper. Flight, with its accompanying forms of artifice enables the cunning architect to defy the very ground upon which he or she walks. In a manner analogous to Daedalus' calculated, yet perilous design, embedded in the logic of this Solar Decathlon house is an attempt to recapture the dimension of flight.

At the very center of the house's signifying matrix is the presence of its solar array; the main energy collector which ensures the building's performance and offers life and sustenance to its inhabitants. Its importance is easily identified by the intensity of effort and design interest which was brought to its support and integration within the overall profile of the roof. So vital had it become to the narrative underpinning the house's identity that students invented an entirely new method of conceiving of Building Integrated Photovoltaics.

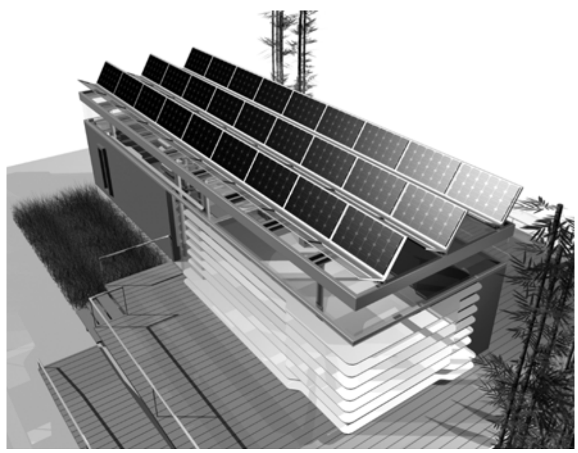

Figure 5. Exterior view of house's solar panel assembly and ETFE roof

Designed to perch over the ETFE roof pillow is a matrix of twenty seven solar panels individually supported using custom made wing-like figures. The entire assembly is comprised of both a Photovoltaic panel support and a shading device to ensure one hundred percent shading of the ETFE skin. To this end, the wing like figure will move, operate or rotate allowing the shade to be adjusted in length and/or angle. This imaginative wing-shaped support was designed to carry the photovoltaic panels in a highly efficient manner by permitting the building occupant to set the panel at its optimized solar angle. In its capacity to pivot to any desired configuration, the array and its support are capable of attaining maximum energy draws regardless of the time of year.

Conclusions

The project here described has enabled both students and faculty to engage in a form of design development rich with possibilities. Integrating architectural questions within engineering and performance imperatives is a constant source of innovation. And given the necessity to continue developing imaginative means for rethinking the relationship between building and its sustainable ecologies, the lessons of this project are worthy of consideration. Icarus may have failed to attain flight in his youthful and careless attraction for the sun. We, as architects, students, builders and teachers in the 21st century, surely cannot afford to do so. In cultivating a seemingly paradoxical relationship with both technology and light we are bound to learn this lesson. And I trust this project has shown a possible venue to this end.

Endnotes

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