Interdisciplinary Co-Development of Intelligent Building Envelopes with On-Site Power Generation

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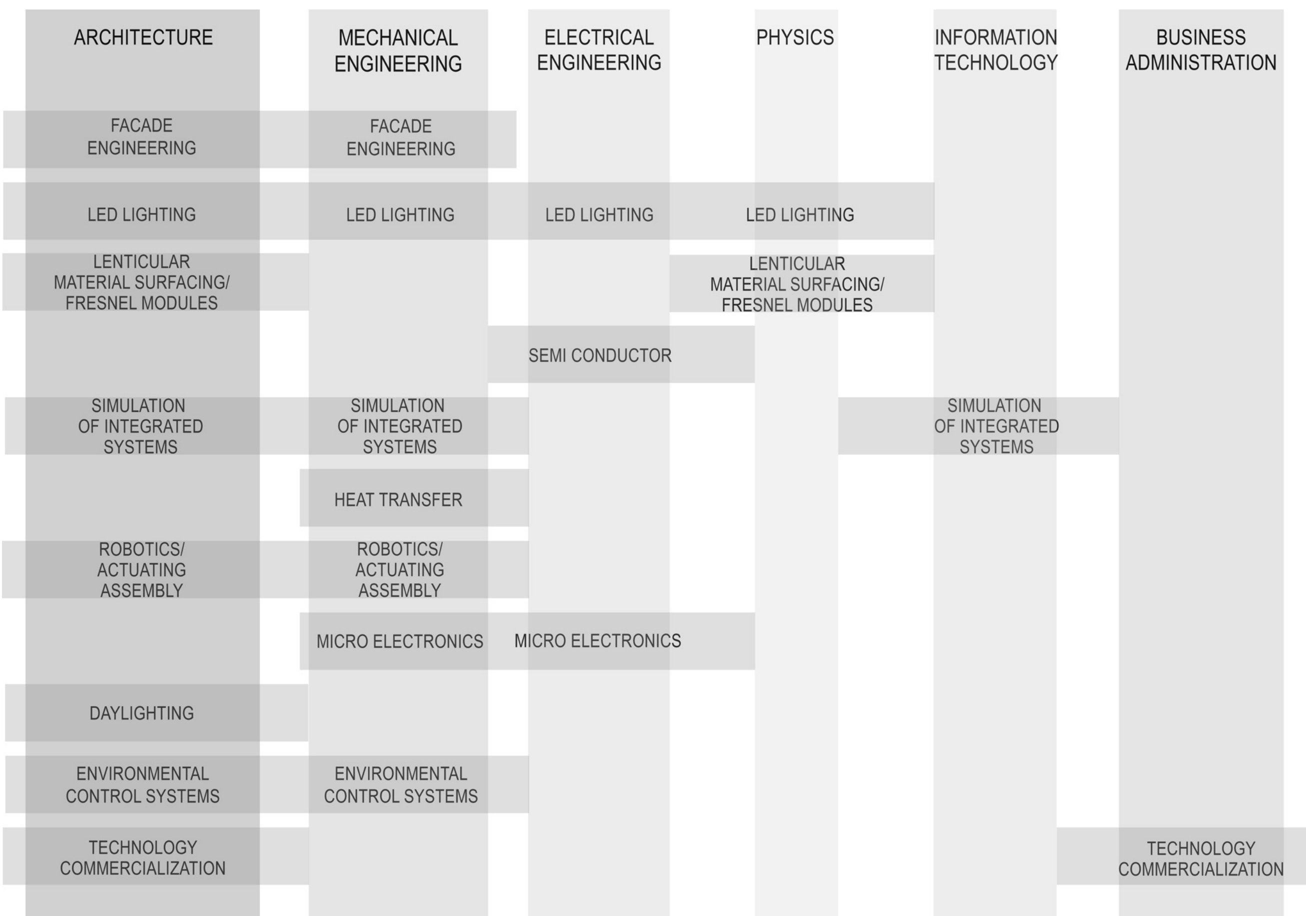

Fig. 1. Diagram showing each different specialized[1] *field of applicable knowledge required to develop the energy system.*

1. CONTEXT: MANAGING AND VISUALIZING INFORMATION INTENSIFICATION

The modern era was permeated by a proliferation of information about (and visualization of) material phenomena at vastly diverging scales, from the cosmological to the nanospheric. The contemporary technological condition is increasingly characterized by an evolving ability to *design* at these multiple scales.[2] The development of this façade system typifies the 'hybrid' phase of much emerging environmental innovation in technology: it is caught between vestigial mechanical technological paradigms, while striving to 'miniaturize' components by integrating as many so-called *functional* materials as possible. 'Functional' materials embody the radical transformation currently shifting our fundamental material technologies from mechanical models deploying *structural* materials like steel that guarantee operational 'stability', toward a *bio*-responsive models that deploy miniaturized machinic processes into functional materials that are *designed* at the molecular scale to transform themselves in response to various stimuli. Although the current iteration of the façade system has greatly miniaturized many aspects of conventional solar technology, particularly with respect to the materials themselves, the global dynamism of the system still relies on conventional mechanical technology for the actuating assembly.[3] This has been conceived as temporary; while the group members were committed to the immediate application of demonstrated technologies, however nascent or emergent, the conscious consideration of future tendencies for material innovation are impregnated into all aspects of the design process. Moreover, facilitating a diagrammatic transition into evolving future iterations is an essential criterion for all current development of the system.

2. METHODOLOGY: PARAMETRIC SIMULATION AND ANIMATION OF THE SYSTEM

Due to the performative interdependency of the different material components within the system, in order to share file information for the simultaneous development of different components, (optics, robotics, microelectronics, heat transfer, etc.), a web-based list serve was set up for regular posting by various group members. However, because the trade-offs in over-all system performance were highly reverberant with respect to each component (i.e. decisions concerning any one aspect tended to ramify throughout the system) it soon became imperative to develop a parametric simulation program that would register and process input criteria from each aspect, in order to be able to measure the effects of various decisions throughout the system(s).

The simulation program became a very important conceptual tool for the group, not just for giving constant feedback on the projected performance of the system, but also for generating an iterative systematic entity that could be customized according to user requirements. That is, the performance simulation allowed the group to think about trade-off decision making between components *(specialties)* more *flexibly* in such a way that the specificities of variable climactic context and programmatic application could allow for the *customization* of various aspects of the system. Instead of the conventional expectations for parametric simulation as a method for achieving the overall (static) 'optimization' of a system (a paradigm that tends to grip individual specialties operating in isolation) the need for a more 'situated' *versioning* of the system became apparent. In contrast to modernist mechanical paradigms of technology, there was no 'ideal' or optimum version of the system; an optimized application of the system was wholly dependent on the specificities of context and multiple programmatic criteria.

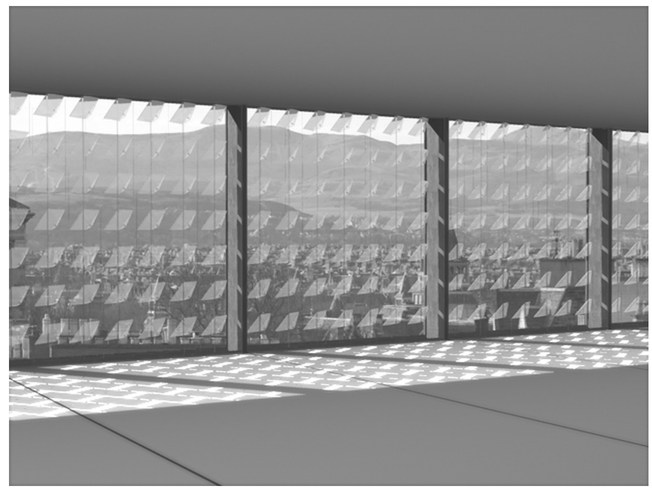

Fig. 2. Diagram showing a section through the fresnel solar module within a double skinned facade.

3. BUILDING THE SYSTEM: ITERATIVE PROTOTYPING

The project proposal was to develop and demonstrate a prototype for a prefabricated automatic 'tracking' assembly in which translucent fresnel lens 'shading' louvers are hung on a tensile actuating assembly between the two layers of glass within a 'double skinned' façade. The double axis actuating system for the shading is as simple to operate and maintain (but ostensibly more robust and precise) as any of the single-axis automatic louver shading systems currently available.[4] However, the principal innovation of the system was the integration of (newly demonstrated) concentrator cell photovoltaic (PV) material, used for the first time *within* environmental control systems for buildings. Because concentrator PV material requires only a tiny fraction of the area of silicon used for conventional flat plate PV for the same energy output, it allows for the miniaturization of what are typically large and unwieldy panels into small modules that can be incorporated into an automated louver *micro* shading system.

The fact that concentrator cells *require* two-axis tracking for efficiency was a challenge that turned into an *opportunity* for the development of a more geometrically efficient system; while conventional automatic shading systems tend to deploy horizontal slats regardless of the azimuth angle movements (east/west) of insolation, the tracking louvers of the proposed system are *always (and only)* in the plane directly perpendicular to the sun, therefore there is less shading material required and far greater connection to the exterior. In addition, while existing shading systems typically try to deflect light away from the building, with this system, tracking fresnel lens louvers capture and focus the light and heat onto PV cells towards the direction of the interior, thereby allowing for more diffused daylight on the façade and roof, but no direct glare. The continuous unimpeded views and increased usable daylight ostensibly improve the occupants' comfort level and productivity.

This prototype integrates emerging solar power generation models, while demonstrating the cost savings associated with grid load reduction by *combining* on-site generated power with energy efficient interior technologies for conservation *within the same system*. Thus far, flat plate photovoltaic (PV) systems for commercial buildings have not shown cost effectiveness, nor has feasible concentrator PV cell technology been readily transferable from aerospace to building applications. The prototype takes advantage of recent incremental advances in several different disciplines, (including concentrator cell technology, and optical engineering) to develop a product that profits from the synergistic effects of their combination.

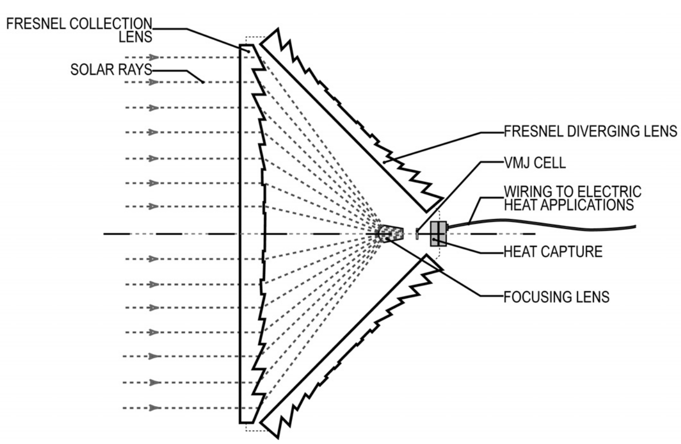

Fig. 3. Rendered ANIMATION of the façade system, a 'parametric' document which is numerically programmed for complete compatibility with the material performance simulation; that is, the animation visualizes adaptations in the system in response to desired changes in the parameters of the performance simulation.

4. CONSIDERATIONS OF THE SYSTEM

Although currently available PV panel systems for buildings are increasingly attracting attention, they are unresponsive to the functional and aesthetic criteria that are necessary for successful integration into high performance buildings. Not only are they far too inefficient to cover any serious portion of a commercial building's energy consumption, they use far too much silicon in their fabrication for cost-effectiveness. Also, in order for photovoltaic systems to appreciably reduce the energy consumption profile of commercial buildings, they must be integrated with other techniques for the reduction of cooling loads. In response, the proposed prototype is demonstrating a pilot panel for an intelligent shading system that generates and transfers electrical energy *directly* from 'concentrator' solar cells to a low energy LED lighting system, as well as to supply *high quality* heat for multiple possible applications within the building. Projected for efficiencies in the range of 40-80%, depending on the application, (compared with the best current systems at 12.5% on average), the prototype attempts to capitalize on the possible synergistic effects when multiple new technologies are integrated at the *beginning* of a design for application, something that is rarely possible with current economic and academic structures.

Because this prototype is attempting a far more economically and *architecturally* viable alternative to fixed, flat plate PV systems, the research has focused on the integration and direct current (DC) transfer between the power captured on the façade, and the low energy consumption applications on the interior. An intelligent dynamic facade system for the roof and south facing exterior envelope of buildings implements low cost concentrator PV cells coupled with tracking fresnel lens louvers that capture and focus the sunlight, thereby reducing the energy consumption of lighting systems on the interior of the building through better (diffuse) day lighting conditions and a direct current connection from the façade system to various potential DC low energy consumption applications on the interior, such as LED task and/or ambient lighting that is calibrated with (individually controlled) photosensors to adjust the light levels to the amount of daylight in the space. These systems would be far more cost-effective than the current PV systems for buildings, because they will actively generate up to five times the power output. They will also provide an entirely new way of eliminating direct solar heat gain into buildings through the use of lens systems that capture, as well as diffuse, direct solar rays.

5. ADDRESSING PRACTICAL CONSIDERATIONS THAT HAVE HAMPERED THE DEVELOPMENT OF VIABLE BUILDING INTEGRATED SOLAR POWER SYSTEMS:

Aside from the enormous gain in power production by using co-generating (electricity + heat) techniques through the VMJ cell, this façade system attempts to resolve the principal impediments that currently face the wide spread application of PV Solar systems on buildings:

a) Due to the enormous silicon content required for existing panel systems, they are currently too expensive, and the energy savings pay back period too long to attract consumer interest without large public subsidies.

b) In domestic markets, *even* with complete subsidies to consumers, the systems still have not been widely marketable because the large silicon panels are commonly perceived by users as unsightly and/or inappropriate for most building types.

c) PV systems have not been designed to be adequately integrated into the necessary components of buildings, and therefore, have been seen as 'tack-ons' that have nothing to do with the overall design of the building. (In cases where advanced daylighting has deftly integrated photovoltaic material, such as with thin films, the technology has been either prone to reliability problems, or has been associated with such poor operating conversion efficiencies, as to render the product unviable for most applications).

d) Because the PV panel industry is currently dependent on scrap from the semi-conductor industry, the large amount of silicon required for panels now on the market will make the current systems increasingly unviable as the interest and demand for building integrated PV grows rapidly, particularly for European and Japanese markets.

e) Perhaps most importantly, because PV systems have been largely considered in isolation from other building systems, valuable resources are wasted because the materials they deploy do not perform multiple functions such as reducing solar heat gain or transferring captured heat for functional use. In particular, much efficiency has been lost in the necessary transfer from DC to AC when the power from PV systems is simply thrown back into the grid, and when the excess heat captured by the cells is simply dissipated back into the atmosphere.

Substantially addressing these five points will be made possible by the integration of concentrator cell technology, because it will *require only about 1% of the silicon* that current panel systems use to achieve the same output of energy to the building. This allows for the employment of far more inexpensive and aesthetically workable materials in the production of low-cost, lightweight panel systems for manufacture. Importantly, it also allows for the prototyping of systems that employ *translucent and transparent materials*, thereby allowing more workable daylight into buildings and affecting the general energy requirements of the building (particularly with skylights and atria in office blocks with large floor plates, where day lighting conditions have been rampantly sub standard).

To increase the overall energy efficiency of concentrator systems, the viability of heat collection and transfer through micro channels is being demonstrated within the system. Concentrating solar collectors gather direct solar energy and concentrate it on the PV cells. With solar to electric efficiencies in the order of 20 to 30%, 70 to 80% of the incident energy must be removed from the PV cells in the form of heat or the cell's temperature will rise too high and its efficiency will drop. This condition presents an opportunity for further energy capture and use, as heat is gathered with an active PV cell cooling system. Thus the use of PV concentrators to eliminate solar heat gain, provide electrical power, and supply heat for cooling would demonstrate the synergistic effects achievable when technologies are integrated at the beginning of a design. However, thus far, there have been several administrative (integrative) and conceptual cultural impediments to getting these technologies into building applications. In the case of concentrator cell technology, the use of expensive photolithography techniques in their manufacture has previously made ubiquitous (outside of NASA) application to the marketplace impossible. In addition, the high heat fluxes within the system due to concentration have necessitated much development of fire safety mechanisms through the use of secondary diffusing material within the louver modules.

4. CONCENTRATOR PV CELL TECHNOLOGY: *RADICAL MINIATURIZATION OF PARTS:*

An important opportunity provided by concentrator technology is its ability to focus heat into a higher quality form that could be transferred and utilized, as opposed to conventional systems that allow the *majority* of solar energy to be dissipated in the form of heat that lingers around the envelope of the building.

The VMJ (Vertical Multi-junction) cell has unique inherent features, making it capable of more efficient operation at higher intensities than other silicon concentrator solar cell designs. Technical feasibility has been proven under the NIST/DOE Energy-Related Invention Program with near 20% efficiency at 332 suns (33.2 watts/cm^2) intensity demonstrated with unoptimized ''working model'' VMJ cells. The prototype applies VMJ cell fabrication processes with efficiencies around 25% at 500 to 1000 suns intensities (theoretical efficiencies are > 30% at 1000 suns). Furthermore the VMJ cell design is suitable for *high volume, low-cost manufacturing* since there is only a single high temperature step and no photolithography involved. VMJ cells provide the economic and technical breakthroughs needed to enable high intensity photovoltaic concentrator systems to become cost-effective for large scale applications.

5. DIRECT CURRENT (DC) TRANSFER TO INTERIOR ENVIRONMENTAL SYSTEMS

To minimize losses in the power from PV systems, the electricity must be *fed directly* (DC power) into a complementary system that is designed for energy conservation on the interior. For this, we chose the rapidly evolving technology of white light LED's, which will soon be applicable for a far greater range of application due to projected rapid advances in their luminosity. LED's are direct current low energy light sources that are ideal to be used with PV systems. Most traditional light sources are configured to use AC power, and converting the DC power generated by the PV systems to AC is inefficient. Therefore PV systems are an ideal source for powering LED task lights. When the energy savings on lighting is coupled with the efficiency of direct current transfer from within the building, the energy savings of the system start to compound. It is predicted that white LED efficacy would reach 50 lumens per watt by the year 2005, and 200 lumens per watt by 2020. With our current prototype, the effectiveness of PV powered LED task lighting for energy efficiency in commercial buildings is being demonstrated.

The second phase of this research will be the integration of technology from Phase 1 into a new prototype for 'breathable' double skinned façade systems. This second phase has much more criteria to consider that relate to the internal air handling systems and the method of inducing airflow from the external facade layer and the interior. This phase will also include assessment by Mechanical Engineering for connections to an 'expanded' energy system with heat capture used to drive *distributed* absorption refrigeration systems for cooling, a nascent concept in development. PHASE 2 in the prototyping development will focus on the difficulties associated with actual integration of diverse systems into a façade design for new construction.

6. CONCLUSION

Unlike recent high-end building practices in Europe and Japan, there has been a marked division in North America between the research and development of products for the building industry and their subsequent implementation and occupancy on site. The lack of contact between professionals in industry and professionals in building design and construction administration has led to building types in the latter half of the twentieth century that contain multiple systems designed with separate and often mutually exclusive criteria; systems that *know* nothing about each other or the complex dynamics of ambient conditions in buildings. This lack of interdependency and integration among building systems has contributed to some of the serious environmental issues of utmost concern to our society. Aside from possibly the most serious ramification, the gluttonous energy consumption of buildings where many potentially generative resources are not utilized, sick building syndrome is the related problem that results from the independence of building envelope systems. Typical methods of heating and cooling that attempt to completely seal a building from the exterior, are leading to epidemic maladies and hypersensitivities on the part of occupants of office buildings in developed countries. There is thus a projected further development in the research whereby the high quality heat generation and capture by the façade system can be coupled with emerging developments in d*istributed* absorption refrigeration cooling, whereby the wasteful centralized units, conventionally used for absorption cooling, would give way to a far more efficient distribution that could potentially be covered by the heat captured by large facades on 'low energy' (long thin) building types.

For complex conditions such as the energy equation and the ambient air quality of buildings, it is imperative to engage information technology in attempting the difficult task of bringing together multiple specialized disciplines for the cross-referencing of information and requirements. With the traditional role of the architect as generalist, along with ever evolving information management systems and performance simulation programs, there is a new opportunity for architecture to seriously participate in academic research responsive to ecological criteria. By acting as both an administrative umbrella, and as a conceptual liaison between specialists in the integration of multiple emerging technologies, Architecture is *the* discipline that is critical to the development of ecologically integrated building systems. Without resorting to technophilic or utopian rhetoric, it is clear that information technology must play a critical role in making buildings more energy efficient and environmentally/biologically responsive. The 'proof of concept' prototype presented is the first installment in an extended interdisciplinary research project that will look towards developing an overall integrated building prototype that would eventually use multiple systems to shift the diagrammatic model of buildings from sites of energy consumption towards sites of *politically unsanctioned* energy production.

NOTES

[1] It is maintained throughout this essay that architecture is inherently ***not*** a specialized discipline, as we have come to understand the narrow focus of specialization in other fields. Rather, it is because of its inherently composited social and interdisciplinary nature that architecture can actually become the conceptual and administrative link for the integration of multiple scales and data sets that is so necessary for technological innovation that addresses the complexity of ecological criteria.

[2] Although the quest for design capability at the smallest of scales remains deliberate, the ecological effects of our designed environments on the geological and 'environmental' scales remain inadvertent and controversial.

[3] this is largely due to the discrepancy between the large surface areas required for the collection of solar energy and the minimum size of the concentrating solar cell required for the capture of high quality heat — to be explained further on with the description of the system.

[4] Including one for the 'marionette' actuating assembly, there are several patents pending on the system. The VMJ Cell, developed through an Innovations grant from the DOE has already been patented. Significantly, with respect to Architecture, there is a patent pending on the 'conceptual integration' of multiple technologies being assembled for the first time into environmental building systems. The process for a 'conceptual assembly' patent is the most difficult to argue, yet it is an important opening for academic revenue for ecological design research (necessarily integrative), which can potentially include architects from the patent process, from which they have been typically excluded altogether due to our historic lack of involvement in 'fundamental' research.