MAKING SMARTWRAP: FROM PARTS TO PIXELS

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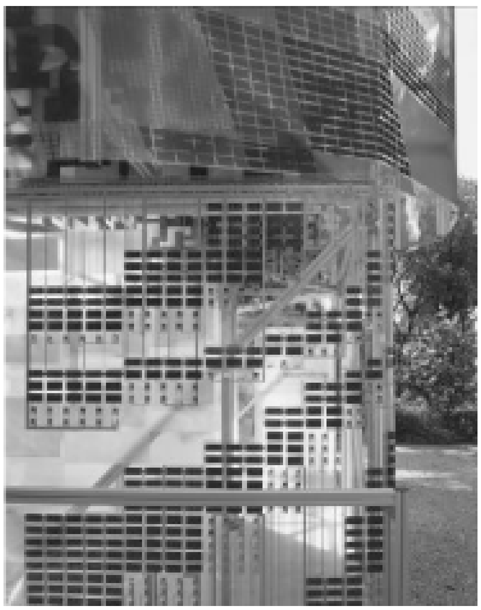
SmartWrap. Photograph by Elliott Kaufman



> "To tell the story of the white wall is to dwell on nuances, to dwell on and in the very thinness of the surface. Indeed, it is to follow those architects who have argued that the surface is the only place to dwell."
> *Mark Wigley, White Walls, Designer Dresses, Cambridge: The MIT Press, 1995.*

INTRODUCTION: CONSTRUCTION VS. FABRICATION

The present state of building construction is mired between hope and stubbornness. Forms unthinkable without computer assistance are constructed using centuries old methods of part-by-part construction. Research at KieranTimberlake Associates[1] responded to these considerations by looking to extra-architectural industries and methods of mass-customization. While buildings are still put together nail by nail on site, manufacturers of everything from toothbrushes to 747s explore new materials and methods of making. The prospect of mass customization, transfer technologies, and off-site fabrication should be givens for questions in architecture, just as issues of structure, enclosure, and use have been givens for a thousand years.

Architects should be building faster and smarter given the resources at our disposal. With infrastructural systems growing in scope, complexity, and cost in every project; architects are ceding control of the interstitial space for these systems to specialists. Wanting to challenge traditional methods, we sought a design and fabrication process which would allow more direct architectural oversight into the matter of infrastructure. The process would be one where the design of systems is as much an artistic element as the proportioning of windows. From this critique, we defined the central tenet for SmartWrap: reduce the struggle for infrastructure space by prefabricating as many of the systems as possible and generate an aesthetic from these constituent parts and their method of fabrication.

Today's abundance of cheap, mass-produced electronic devices drew our attention to deposition printing and roll to roll printing processes. With the increasing sophistication and size of available printing methods and new flexible technologies, the task of reducing infrastructural or interstitial space to a single printed plane by means of a mass-customizable wall system seemed possible. An entire wall system could be designed to contain multiple infrastructural systems, printed at a factory, easily and compactly transported, and then unrolled onto a structure. We wanted a wall to be installed in as few pieces as possible by a single crew of workers instead of the typical multitude of trades.

DESIGN: PROGRAM AND PARTS

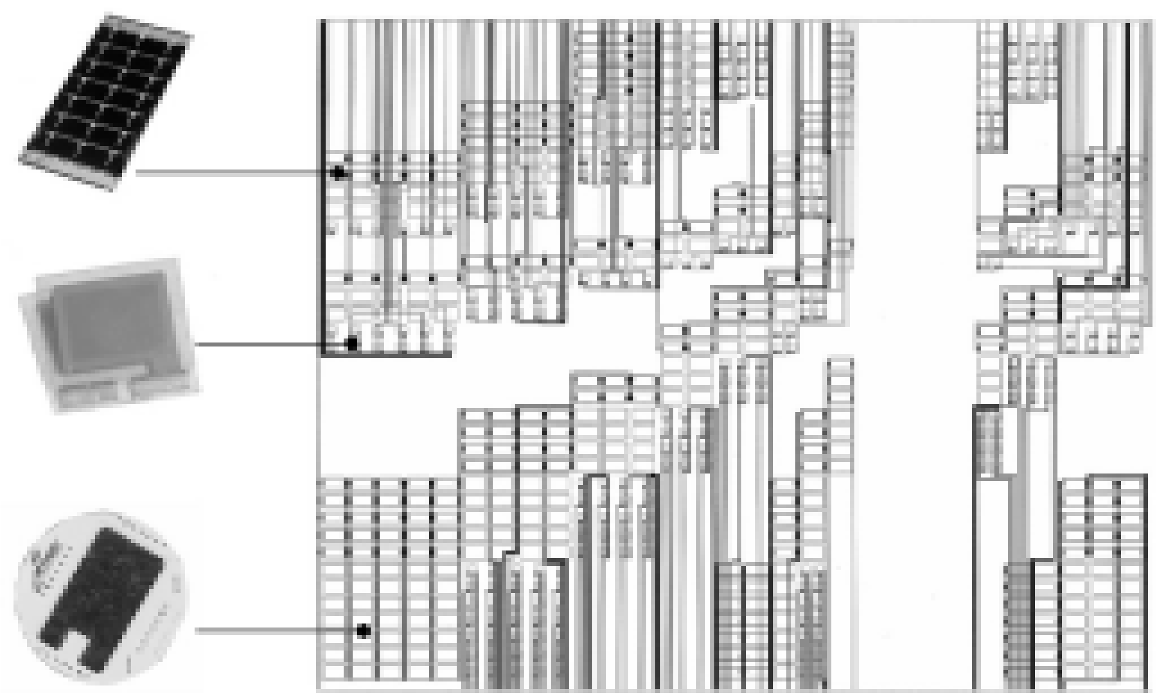
An analysis of existing wall properties defined the program for SmartWrap: some degree of shelter, weather resistance, view out or in, natural and artificial illumination, information display, generation of power, transparent or translucent, and insulation comparable to existing wall construction. Obviously there are numerous other enclosure properties which we excluded from consideration. Qualities addressing security, structure, moisture, and time are worthy of attention but removed from our scope for purposes of expediency. We were impatient to fabricate a building component, not to invent a panacea for all of architecture.

To address these functions, SmartWrap would be comprised of a Polyethlene Teraphathalate (PET) substrate printed (although laminated in the prototype) with organic light emitting diodes (OLEDs), organic photovoltaics (OPVs), phase change materials (PCMs), thin film batteries, and printed circuitry.

Since we ultimately wanted to print, roll, and see through our wall; the substrate selection occupied a good deal of our time. Finding a clear material that would hold print was paramount for our ultimate goal and PET met that criteria. This polymer is more commonly seen as a thermoset in 2 liter soda bottles. Its mildew resistance, low moisture absorption, economy, UV resistance, and colorless transparency made it an ideal candidate for the substrate. It comes in 300 meter rolls and is flexible enough to be compatible with ink-jet and roll to roll printing techniques. Its downside is that it can only be tensioned in one direction. However, we felt that its potential for printing over-ruled this limitation.

The interactive component is provided by organic light-emitting diodes (OLEDs). We envisioned display of data, images, and illumination in an ever-changing patchwork of color. In the exhibit, the OLEDs face both in and out. We needed whatever was printed on the substrate to be flexible. Although, currently OLEDs are assembled on glass carriers for consumer use, they have the potential to be flexible and translucent when printed on plastic. There are already existing research programs in pursuit of this goal. Organic molecules in the OLED emit light upon the application of an electric current. Eventually we would have them printed directly onto the PET substrate; however, for the exhibit, DuPont supplied PDA-sized OLEDs manufactured on glass slides.

SmartWrap elevation showing thin-film photovoltaics, organic light-emitting diodes, and thin-film batteries. Image by KieranTimberlake Associates



The need for power generation is satisfied by thin-film photovoltaics. These would be roll-to-roll printed onto the substrate as well. Assuming proper site and weather conditions, there is a 1 to 1 relationship between the number of PVs needed to power the OLEDs. While initially discouraging, the great likelihood of improving efficiencies encouraged us to optimistically include thin-film batteries in order to store energy for cloudy days. The matrix for moving all this electricity around is silver conducting ink printed directly onto the PET substrate. The ink while the simplest component in some ways is the part most satisfying. Its application and purpose could be immediately beneficial in an incremental development of a wall with embedded systems. Imagine being able to print a building's electrical wiring rather than punching it through structure or conduits. A universal network of electricity could be available anywhere on a wall.

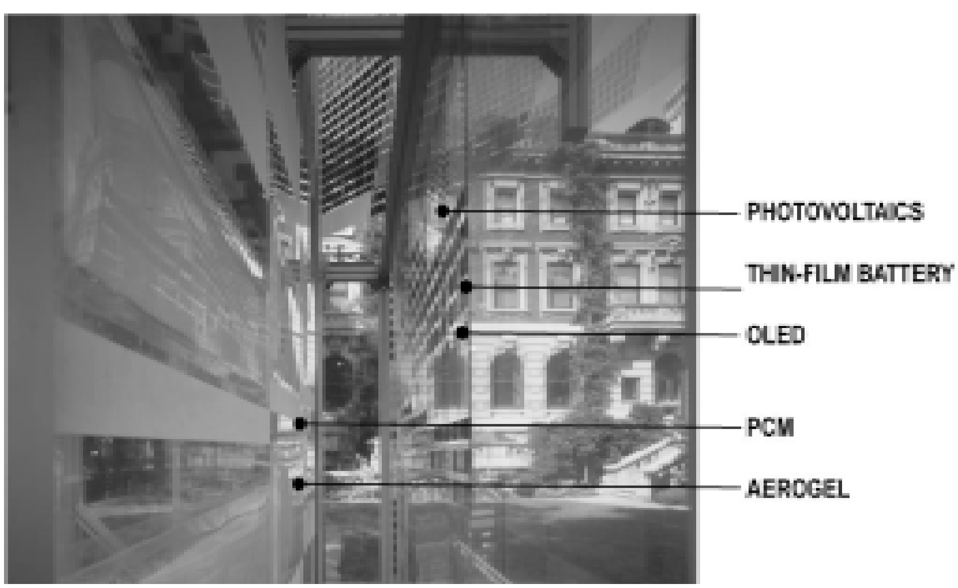
Ideally, there would be only a single layer of SmartWrap. However, to address issues of thermal comfort, this layer is adjacent to a second insulating layer of PET containing an array of aerogel and PCM pockets. The two layers are separated by a four inch airspace. The PCMs used in SmartWrap come in the form of a powder. ILC Dover mixed this powder with a small amount of resin in order to provide a means for the PCMs to adhere to the PET. The PCMs work as a type of latent heat storage and were used to thermally moderate the interior surface. Aerogel is an insulating material which can be either transparent or translucent. In order to address issues of durability and flexibility, a translucent blanket form of aerogel was utilized. The thickness and fragility of aerogel limit its participation in any form of printing process. While only two inches of aerogel are needed to achieve a realistic R-value, the fact that it cannot be a coating and its need for encapsulation were factors that we have been unable to address yet. Because of this limitation, we decided to make a supplemental layer for SmartWrap that an architect could select depending on climate and application. As dissatisfying as it was to muddy the concept of a single printed surface, we felt that it would be irresponsible to exhibit SmartWrap as a prototypical building part without addressing the issue of insulation.

DESIGN: PROCESS

Like weaving a tapestry from infrastructure, the designer sits at a virtual loom selecting the proportion of PVs to OLEDs, how much clear view there should be, all the while experimenting with an array of predetermined or custom pattern filters much as one might manipulate an image in Photoshop. Except rather than pixels of color, the architect's palette consists of pixels of infrastructure.

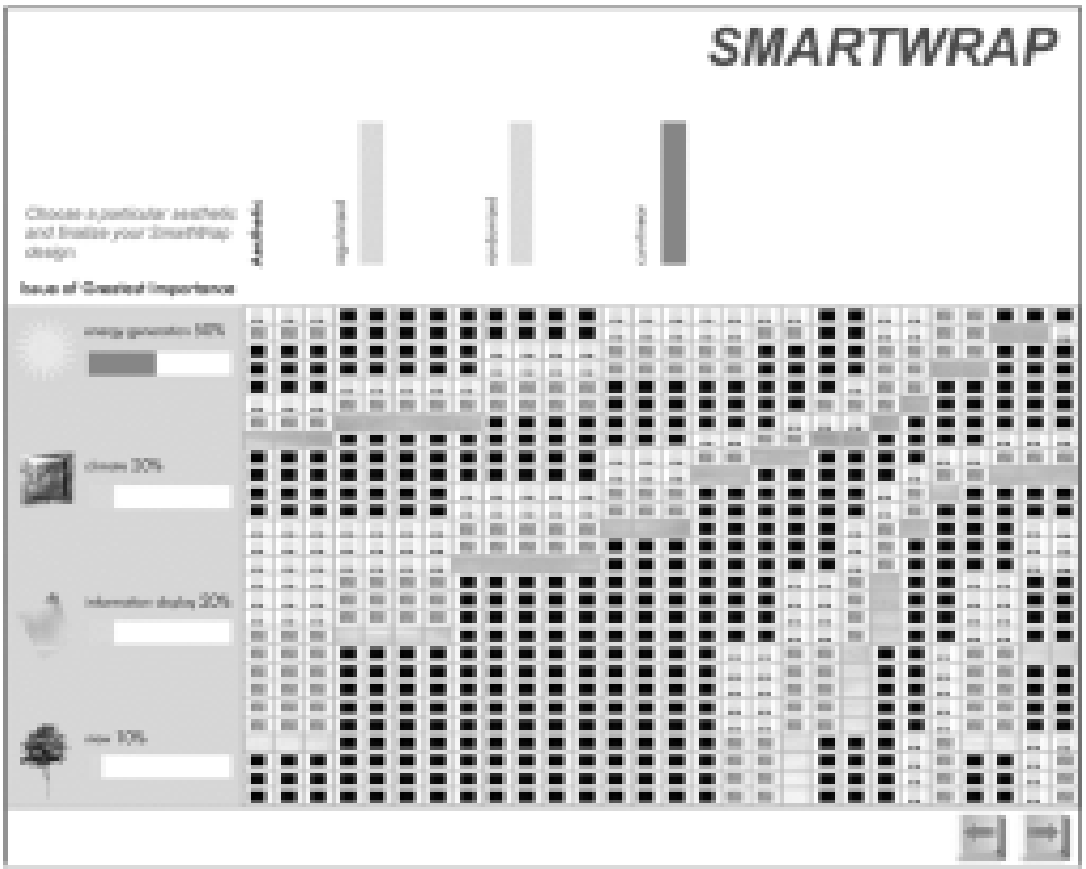
An essential and inherent characteristic of SmartWrap is that future applications would not all have the same type or proportion of compo-

View of wraps within the interstitial air space. Photograph byElliott Kaufman



nents. The list of program parts is intended to be a menu to be considered in the design of individual wraps. Variability depends on the architect's criteria: site, orientation, climate, program and use, aesthetics, privacy & publicity, etc.

The designer's virtual loom. Image by KieranTimberlake Associates



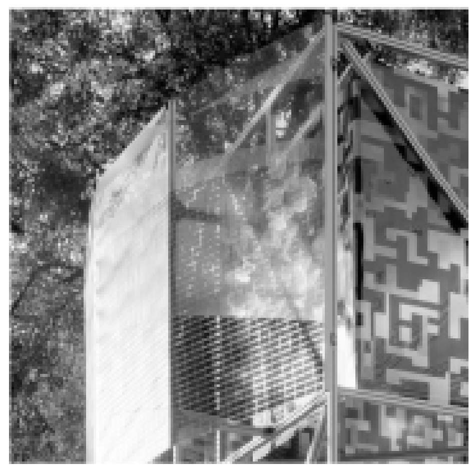
The production process is irretrievably intertwined with the process of design. Multiple building contractors would be traded for a single printer. By compressing the volume of a wall to a single plane we could utilize concepts behind existing ink-jet technology which could integrate the engineer's efforts directly into the design process. The typical circuit diagrams produced by an electrical engineer would become part of the new wall substrate upon which a variety of devices could be deposited. The circuit drawing with its array of devices would go directly to a printer for production. In addition to the variability and customization afforded by printing processes, another benefit would be elimination of the interpretive burden placed on contractors. The technique would be exactly like an ink-jet printer except instead of depositing droplets of ink, we would deposit droplets of PVs or conductive circuits. Similar technology is already being put to use in 3-dimensional printers used by industrial designers, prototypers, and in the production of microelectronics. Later, we were to find out that the seemingly small issue of scale was an enormous obstacle.

FABRICATION: COLLABORATION

Having outlined a proposition, the real goal was to fabricate a prototype in order to test the theory of reforming architecture and construction processes. Only by immersing ourselves in collaborations with engineers and material scientists could we begin to understand the nature of producing a composite. In addition to this intellectual concern was the more practical one of cost. Product development depends on resources and as a fifty person architectural firm, KieranTimberlake was already stretching its funds through the employment of four full-time researchers. If we wanted to make something, we couldn't go it alone. However, as unestablished prototypers, we were in need of a vehicle to help confer legitimacy, attract sponsorship, and to promote our prototypical wall. Interest was found at the Cooper-Hewitt National Design Museum in New York City which was trying to establish annual installations in their garden on Fifth Avenue. They liked the concept of SmartWrap and pushed us to expand the scope of the exhibit beyond the production of a prototypical material to one which also demonstrated our material's spatial potentials. Rather than displaying a single composite plane, we were now committed to the construction of an outdoor pavilion. The concept blossomed from being an experimental idea about a material and fabrication process into a full-blown architectural provocation.

Luftgroove detail. Image by author

Wrap attachment to frame. Image by Barry Halkin



FABRICATION: NINE MONTHS TO GO

With the Cooper-Hewitt committed to the project and a date, we were able to attract the type of collaborators[2] necessary to implement the project. The supportive responses received from potential collaborators assured us that we weren't the only ones interested in reform within the building construction industry. One relationship begat another and a favorite consultant KTA had worked with for years were the first on board. CVM engineers were concerned primarily with the pavilion's ground anchorage and the forces of SmartWrap (a big sail) on its supporting armature. They recommended we consult with Buro Happold in regards to the issue of SmartWrap's attachment to its structure. Buro Happold came up with the idea of using a luftgroove to attach the wrap back to the frame. A rod would be fastened to SmartWrap and then inserted into a slotted frame for the purpose of spreading the tensile forces over as large an area as possible. While there are drawbacks to this method, namely that four-sided framing of the skin and thereby full sealant or closure is not possible, it was the detail most compatible with the aluminum structure donated by Bosch-Rexroth. The benefits in terms of a simple and speedy installation due to the low number of connections became evident soon enough.

Products were lined up for all the components in the wrap, but there was no way we could print the prototype. The large-scale and unrealized infrastructure needed to support large-scale printing of PVs and OLEDs was still in the labs and minds of scientists. Lamination of the components to the PET was the realizable short-term solution which permitted us to meet our exhibit obligations. As for a fabricator, Buro Happold recommended ILC Dover[3] as a company with experience integrating textiles and technology. As it happened, ILC Dover already had a tremendous amount of experience with PET, printed circuitry, thin-film photovoltaics, PCMs, and aerogel. However, OLEDs were newer to them and they were interested in gaining experience in that area and with the general concept of intelligent fabrics. The OLEDs were critical to the exhibit's representation as a dynamic infrastructural system and so a partnership was formed. We had been discussing the project this whole time with

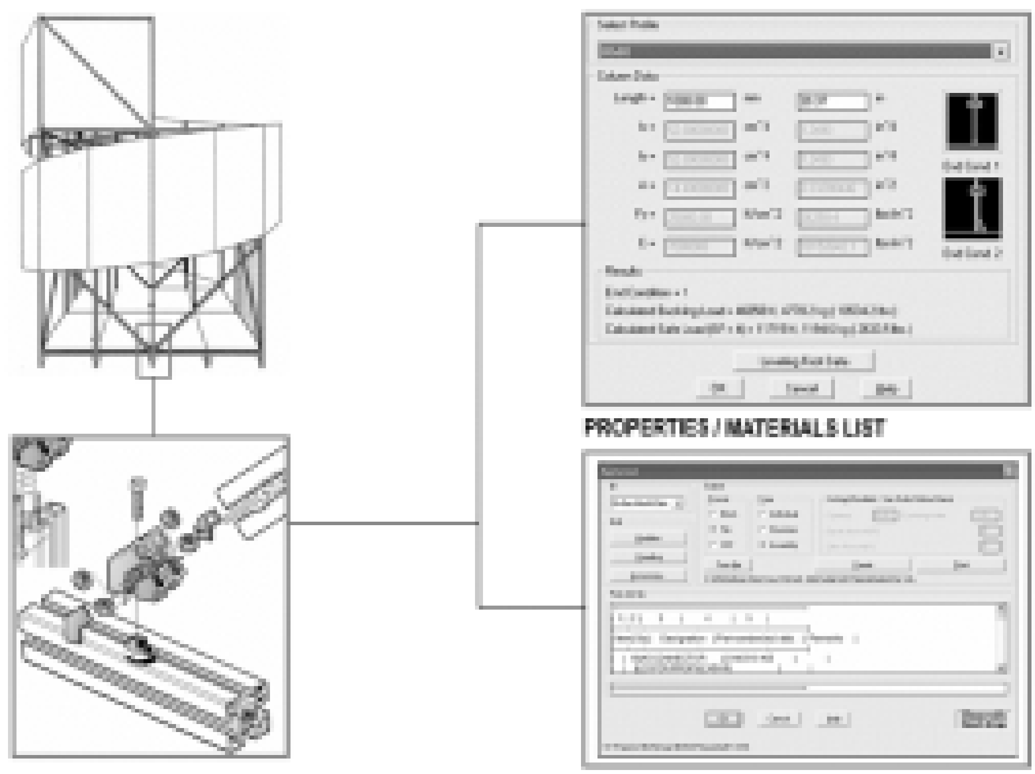
DuPont and finally an audience was granted with the right person. OLEDs are a burgeoning industry and DuPont was trying to position itself as a leader in the technology. They turned out to be a prodigious collaborator. Besides donating the most expensive component of SmartWrap (the OLEDs), they also were producers of PET and the silver conducting ink we needed for the printed circuitry. With these major collaborators working with us, it became much easier to attract help for the remainder of the pavilion design.

FABRICATION: OFF-SITE

The aluminum frame for supporting the wraps was donated by Bosch-Rexroth. This relationship turned out to be more than a material one, but gave us our first taste of digital design to fabrication enabling software. Bosch's website has plug-ins for Autocad which in addition to being a 3-dimensional library of all their stock shapes and hardware, also generates a parts list. All of the framing was delivered to the site pre-cut, pre-drilled, and bar-coded for identification.

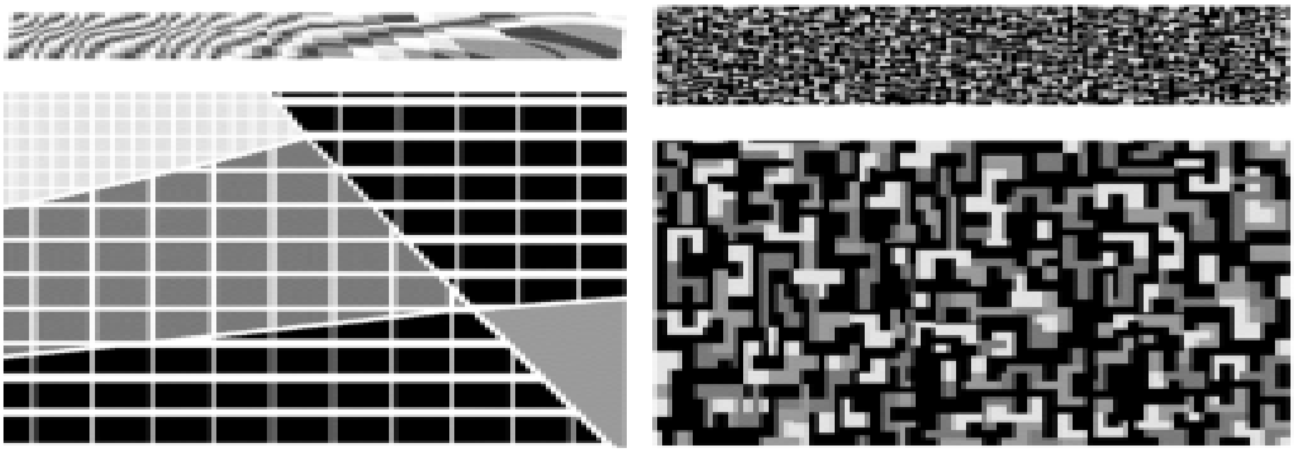
As the exhibit opening loomed nearer, the issues of creating a context for displaying SmartWrap and explaining it to the public competed against the prototype for our attention. Fabricating an operating prototype at the dimensions of 11' wide by 7' high was daunting enough. Obstacles such as the quantity of OLEDs available, overloading circuits, waterproofing the silver ink, techniques of lamination and silk-screening such a large panel; all were hindered by the issue of scale. The idea of making enough functional wrap to enclose our small 16'x16'x24' high garden pavilion was out of the question for our collaborators. So to convey our spatial aspirations for SmartWrap we would design and print over 200' of simulated wraps to enclose the pavilion. Finding a local printer who could handle 8' wide rolls of PET and was willing to experiment was challenge enough, but it turned out that the cardboard core supporting the roll obtained from DuPont would not fit on the printer's spindle. Fortunately, there is an entire industry which deals with just such problems: material expeditors re-cored the 1000' roll supplied by DuPont onto five

3d modeling with resultant detail drawings, properties matrix, and list of materials. Image by KieranTimberlake Associates



smaller cores. Finally, our pointillist array of function came together and the simulated wraps were printed in the manner that we envisioned the actual prototype would be printed: in one pass on a single roll. the most visually dynamic component of the wrap so close to our deadline. Once again, scale was our nemesis: everything which we wanted to do was already in existence, but at the much smaller size of microelectronics.

Pattern variation in the simulated wraps. Image by KieranTimberlake Associates



With all of the supporting elements for the exhibit mimicking the processes of fabrication we admired in other industries, it was somewhat disappointing that the active panel construction was fairly old-world. Most of the scientists we talked to at DuPont were surprisingly optimistic about the efficacy of our vision for a printable wall. However, we knew from the outset that this ultimate goal of printing a wall was a future eventuality dependent on years of research. As such, the infrastructural components of SmartWrap were hand laminated by ILC Dover. They worked tirelessly to help us resolve the array of electronics into a functional and poetic assembly. Most circuit boards are fairly small; the largest circuit boards we could find were electronic white boards, but none were interested in collaborating with us. So our only printed component was the conductive network of silver ink…and it was silk-screened like a giant T-shirt. Two more setbacks occurred with the production of the functioning wrap: batteries and electronic sensititvity. While the Thin-Film PVs were readily available and inexpensive, the Thin-Film battery manufacturer was unable to provide us with the quantity of working batteries needed. We kept the duds in the panel to fill out the design and to keep the intention represented. The problem of OLED sensitivity came up the week prior to the exhibit opening. It seems the PVs we had purchased created the potential of frying the OLEDs. No one was willing to risk damaging

Silkscreening the substrate. Image by ILC Dover, Inc.

Laminating the components. Image by ILC Dover, Inc.

CONSTRUCTION: ON-SITE

Despite our attention to technology and the potential benefits of seamless computer to fabrication production processes, the exhibit would have many of the messy construction aspects which were in direct opposition to the concept of prefabrication. Anchoring your building to the earth is an unavoidable and inherently messy enterprise. CVM had calculated the amount of mass needed to keep the pavilion from sailing down 5th Avenue and it translated into five yards of dirt. Unfortunately, we could only fit a small Bobcat and a wheelbarrow brigade through the garden gate. As if we hadn't made things difficult enough on ourselves, we wanted the pavilion to glow at night. An array of sixteen fluorescent lights below a translucent polypropylene floor, while the perfect design compliment to the ethereal vision of SmartWrap, required the excavation of an additional seven yards of dirt, all of which had to be stored on site and replaced at the end of the exhibit.

Many calluses later, the dirt was in place, the foundation cured, and we were ready to erect the frame. This portion of the exhibit assembly more closely paralleled our aspirations for construction reform. Following the IKEA ideal of assembling everything with a single hex-key, the Bosch system required only a single socket size for all the connections. Finding the correct piece for the frame was only a matter of knowing the last three numbers on the bar-code. The frame was erected in a day.

The simulated wraps were installed next and the need for on-site improvisation arose. The tension bars used to restrain the orthogonal wraps needed a custom fastener not supplied by Bosch-Rexroth. We fashioned our own by customizing one of their standard parts with a 5" bolt, nut and washer, a strip of cardboard, and duct-tape. The thought of such a homely assemblage acting as a key detail was absorbed into an evolving poetry of contrasts concealed within the building envelope of the future.

Our next task was the 100' simulated wrap which enclosed the entire pavilion in a helix. There had been a number of proposals calling for tools such as a scissor lift, cherry-picker lift, a 24' long pole and ball bearing assembly and an army of pulleys. In the end, the scissor lift won out. Using a board and clamp, a spindle was fashioned to hold the 8' tall roll of material to the lift. Over a 2-hour period, we drove the wrap around the pavilion and secured it to the frame.

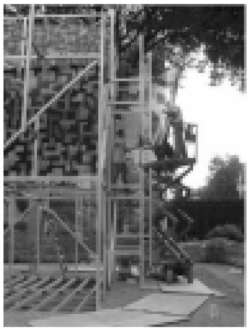
Field adjustments. Image by author

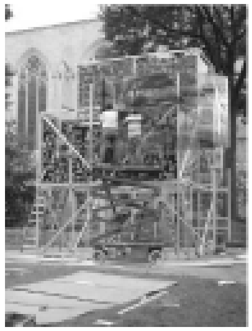
Single tool construction. Image by author

Initially we used screw-clamps to hold the wrap to the outriggers to account for the slack needed for installation. After unwinding the full length of the helical wrap, we gradually added tension by winding up slack at the bottom of the pavilion and shimming the bottom of each outrigger about an inch out of the vertical plane. In the end, the tension generated was sufficient that we removed the majority of the clamps and were left supporting the entire 100 foot length from two attachment points. Over the course of the exhibit, the PET would relax and we would return to the site a couple of times to wind up the slack.

The active wrap was fully assembled and mounted to a small frame at ILC Dover's Delaware facility. After unloading in New York, the plan was to hand

Unrolling the wrap onto the pavilion. Image by author





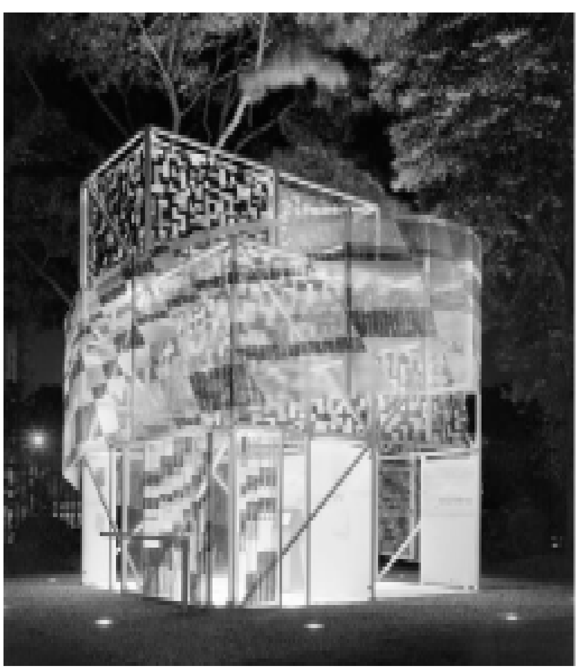
carry it through the museum and out to the garden. However, a last minute change in the routing and mounting of wires had added an extra two inches to the panel's height. This difference was significant enough that we had to unfold the panel to move it through the building. It worked out fine but was the source of last minute sweating and improvisation. Once at the site, mounting the active panel to the pavilion proceeded smoothly, the control board was hooked up and our first prototype was turned on.

CRITIQUE: ADJUSTMENTS

> *"How can design utilize the opportunities of current industrial production so that the practice of architectural representation is neither independent of nor subjugated to the domination of technology?"* Leatherbarrow & Mostafavi, Surface Architecture, Cambridge: The MIT Press, 2002, p.6.

Even with the exhibit's conclusion, it is probably more accurate to say that we are still in SmartWrap's programming phase. This realization as an architectural folly is the first step in our research into an open-ended product development spectrum. The promise that wrapping might hold for construction processes seems supported by our on-site experience. Ironically, the greater installation difficulty came from the elements that as ar-

View at night. Photograph by Barry Halkin



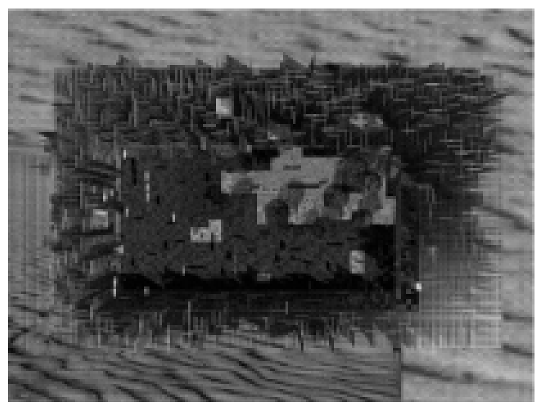
View with Cooper-Hewitt in background. Photograph by Elliott Kaufman

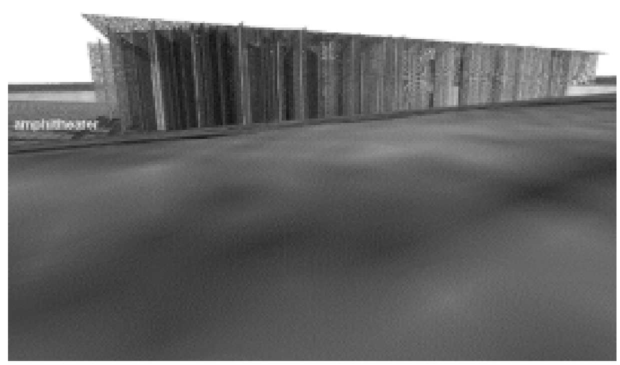
chitects, we are more accustomed to. The issues of excavation, existing conditions, structural shimming, scaffolding, modifying and improvising details represent embedded technical and cultural hurdles equal to the difficulties in SmartWrap's future evolution. While it is extreme in its cultural and performative expectations, it was the provocation necessary to attract corporate collaboration. Currently KieranTimberlake Associates is engaged in incremental product development research with DuPont and while the program guidelines for component parts and production aspects have been re-aligned to currently available industrial capabilities, the ultimate goal is still to achieve a printable, mass-customizable wall system. As a first prototype, there are many places to criticize SmartWrap, but the initial goal of promoting provocation and speculation through physical investigation was achieved. We had challenged ourselves to look at architecture through the lens of product development and seen a new world of potential processes and outcomes worthy of further exploration.

As a viable building product, SmartWrap has many issues which need resolution: attachment details, weatherproofing and sealing, energy consumption, adjustability, let alone the technical hurdles of large-scale printing. While we pushed the technical attributes of walls by prefabricating electrical components right into an enclosure system, the need for large displays and patterns of color on buildings may be limited to Times Square and Las Vegas. Illumination is another matter; by locating the OLEDs to the interior, the PVs in concert with thin-film batteries present a viable and complementary night/day marriage. There is even further potential for OLEDs to operate in dual capacity. They may one day be built with a switch enabling them to oscillate between consuming energy to generate light and collecting light to generate energy[4].

The idea of a film enclosing a building is asking a lot in terms of durability, weather, and cultural expectations. Such a thin skin may not satisfy our personal sense of architectural enclosure. SmartWrap confronts our traditional notions of edge, line and its relationship to structure when considered for its spatial potential. While it is important to pursue the resolution of attachment issues as it pertains to our common understanding of building envelopes, the question for architects should be: how is interstitial space collapsed, expanded, or re-oriented when we consider deployment. What if there were multiple planes of enclosure: a rainscreen rather than a hermetic enclosure? Perhaps the line of enclosure is sometimes perpendicular to edge conditions rather than parallel. The demarcation (lines) of shelter can be many and oblique, some parallel, some perpendicular. A line can have depth. The interstitial can be occupied. Layers of mediating material mark an agitation of the membrane with thin skins that oscillate between representing mass and plane. The wall is dematerialized through multiplicity rather than minimalism. Instead of reducing presence through planarity, the edge between inside and outside is rendered indistinct through an amplification of surfaces. Rather than wondering how SmartWrap becomes re-oriented to our accustomed notions of enclosure, it might also be productive to consider how enclosure is re-oriented to SmartWrap.

Re-orienting the skin. Images by author





The balance between craft and technology is similar to the tension between art and commodity[5]. This has been a constant struggle for us in the pursuit of not just the design of a building product, but more importantly the reform hoped for in the processes at the core of architecture and construction that led to the development of this research project in the first place. With SmartWrap, we have attempted to embrace and elevate that tension. Is the hope of utilizing printing processes a too literal reframing of the maker's hand? First the architect draws the design and then prints the object. This architecture is not in conflict with representation, it is representation. We had an idea and the construction is the drawing: a virtual and physical tattoo.

Inside the pavilion – The building as interstitial space.. Photograph by Elliott Kaufman

NOTES

[1]KieranTimberlake Associates' research for SmartWrap ran parallel to three years of graduate studios at the University of Pennsylvania. Starting in 2000 the question was put to students: how can we build projects with more features and better quality for less time and money? The projects and dialogue generated by Courtney Druz, Tim McCarthy, and Richard Seltenrich were of particularly importance in exploring these issues. The Principal researchers at KieranTimberlake Associates were: Stephen Kieran, James Timberlake, Christopher Macneal, Christopher Johnstone, and Richard Seltenrich.

[2] Our collaborators included: DuPont, Skanska USA, ILC Dover, Inc, Bosch Rexroth Corporation, ERCO Lighting, CVM Engineers, Sean O'Connor Associates, Buro Happold, Gabor M. Szakal Consulting Engineers, P.C., Celestial Lighting, and Lutron Electronics

[3] Recent projects by ILC Dover include air bags for the Mars Rover, and more famously, the astronaut suits for NASA. Their contribution in realizing SmartWrap cannot be overstated. They helped us through a myriad of technological hurdles in the drive to integrate the many components into a functioning prototype.

[4] Speculation based on remarks by Dr. Alan Heeger, one of the creators of OLED technology, at the Innovation Conference in New York City, October 2003.

[5] Steve Kieran and James Timberlake, Refabricating Architecture, NY: McGraw-Hill, 2004.