Comparing Three Emerging Facade Technologies and Their Capabilities

An Honors Thesis (ARCH 402)

by

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Abstract

With carbon neutrality becoming an ever-increasing goal of architecture professionals and consumers, smart glazing designs can become a key factor in reducing a building’s carbon footprint. Many new glazing technologies are emerging to fulfill this demand and it is timely and important to assess the value of these products in order to best apply them. This paper is an attempt to evaluate the strengths and weaknesses of three such products through a literature review supplemented by interviews with experts in the field. The three types of glazing discussed herein are chromatic, thin film, and robotic systems. They are described and then evaluated based upon categories of user satisfaction as well as energy consumption. The current state of the industry is discussed, as well as speculation about the future.

Acknowledgements

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Introduction

What are the capabilities of thin film, robotic, and chromatic glazing technologies to impact a building’s carbon footprint and its users’ satisfaction? A building’s exterior skin is the main interface between the built and natural world, between construct and context. In the midst of an energy crisis, it is essential to maximize the efficiency of these “windows to the world”. Technologies have emerged to make windows more than mere static sheets of glass. These technologies range in the spectrum of “smart,” from responsive to switchable to automated. In the following pages their abilities and drawbacks in relation to occupant satisfaction and energy consumption will be explored and possible impacts on façade design will be discussed.

The technologies discussed herein are part of a wave of “smart” design. In order to evaluate them and maximize the intelligence of their application, it is important to initially define the term “smart”. In an etymological sense, “smart” comes from roots meaning quick and prompt and also brings to mind the concepts of cleverness and intelligence. Colloquially, it has come to mean anything equipped with electronics or microprocessors. For the purposes of this thesis, “smart” goes beyond that. A piece of smart architecture is anything that responds and adapts to its environment, anticipating conditions and adjusting accordingly.

Corollary terms include “active” and “passive”, which become trickier to define in the world of architecture. “Active” implies something that is in a state of motion and causes activity or change, as opposed to “passive”, meaning inert or not reacting visibly. This is not to be confused with the conception of “active” in mechanical systems, which can be wasteful of energy and is regarded as secondary to passive systems in terms of sustainability. Activity level can be further broken down into the categories of switches and sensors. A switch, such as those often used to control overhead lights, responds to human interaction. A light controlled by a switch is therefore more active than a light that is constantly on. Sensors take this one step
further, by eliminating the need for human involvement. An everyday example of a sensor is a
thermostat, which automatically gathers information and adjusts the environmental conditions in
a room. While varying on the spectrum of activity, the three technologies that are about to be
examined comprise some of the most intriguing products being researched and developed in the
field of smart glazing.

Glazing Types

Three current leaders in glazing technology are important to compare. The first type is
chromatic glazing. Chromatic glazing is a product of liquid crystal technology, similar to LCD
lights. The arrangement of these liquid
crystals can be manipulated by certain
stimuli, causing the material that contains
them to become alternately transparent or
opaque. In fact, there are three types of
chromatic glazing: thermochromatic,
responsive to temperature; photochromatic,
responsive to light; and electrochromatic,
responsive to electrical currents. The latter
type is therefore controllable by a switch
(Elvin). Cutting edge architect Werner Sobek
used this idea in his pre-fabricated “R129”
residential project, allowing the envelope’s
opacity to be altered at the flip of a switch.
thereby eliminating the need for curtains and reinforcing his sleek, modern design. (Zaki)

Chromatic glazing offers solutions regarding privacy and glare, as well as radiation absorption. Because of its ability to regulate privacy levels, it has many applications for interiors as well as exteriors.

The second type of glazing is thin-film technology. Thin-films allow for the integration of photovoltaic cells, henceforth “photovoltaics”, into a number of materials. Some noteworthy examples are being researched by architectural firms. Kieran and Timberlake’s Smart Wrap, for instance, proposes to integrate an entire composite wall system, including photovoltaics, into a micro scale (“Smart Wrap…”).

Sheila Kennedy’s Soft House utilizes thin film to incorporate photovoltaics into household curtains. Thin films may eventually allow photovoltaics coatings to be painted onto any façade treatment (James 1058).

Thin films have the potential to reduce the cost of expensive photovoltaics due to a reduction in material. They also allow for printed electronics and information display, as seen in Smart Wrap (Kieran and Timberlake). Thin films were named one of Time Magazine’s “50 Best Inventions” of 2008 (Caplan 61).

The third and final classification is robotic systems. These are the most active, with moving, mechanical parts. Robotic systems include blinds, louvers, or other sun-shading devices. Extending beyond kitschy robotic window washers of the science-fiction realm, these
systems can have a real impact on user comfort and energy consumption. A prominent example of modern day robotic window systems is the “living skin” of Morphosis’s Federal Building in San Francisco, California. The building, completed in March 2007, utilizes automatically adjusting windows above the fifth floor to cool and ventilate the building. In this case, automated systems can allow for passive heat gain, by opening windows in the day and closing them at night (Elvin). These window, vent, and sunshade systems are controlled by a computer that responds to interior and exterior conditions (Kiser). The main strength of robotic systems is in their ability to operate without human involvement whenever or wherever a person could not.

**Evaluation and Comparative Advantages**

Products in all three of these categories have the potential to improve user satisfaction as well as reduce a building’s carbon footprint. Satisfaction, here, includes eliminating glare and maintaining a comfortable temperature range. Architectural areas that could be most affected include interior lighting conditions, privacy, heat gain, transportation costs, and façade design (See Appendix, Table 1). How does each type of glazing measure up in these categories?

Interior light conditions may be the most visible effect of any window system. Chromatics take advantage of this visual appeal by allowing light through while reducing glare, similar to frosted glass. They also make possible rapid alterations in privacy level, allowing for many applications requiring alterable visual separation such as conference rooms and hospitals.
Robotic sunshade and louver systems also alter light transmittance, although this is more limited to the amount of light than to the quality.

The main purpose of thin film systems is to capture energy and allow for information display. This often draws more attention to the window itself than to how the window transforms the surrounding space. Still, they have enormous potential to affect an interior space. With the developing capability of thin films to be implemented onto any surface, lighting fixtures could be virtually eliminated. Materials themselves would become emissive. Transparency and opacity would be rendered virtually irrelevant as far as light transmittance is concerned. Electricity and materiality would be forever intertwined (Reeser 89).

Transportation costs are another area that could be vastly affected by more efficient glazing systems. In this case, “efficient” refers to efficiency of space. Emerging systems like Smart Wrap can integrate and compress many of a wall system’s functions into a considerably more compact product. This makes for easier shipping which is good for both the environment and the consumer. Any time functions can be integrated, waste is reduced. Environmentally, a reduction in shipping utilizes fewer petroleum-based resources, minimizing a project’s carbon footprint. Commercially, it reduces costs for the consumer.

According to the Architecture 2030 Challenge website, building operations engulf 78% of the energy consumed in the United States. Much of this is due to heating and cooling loads. Therefore, a glazing system’s ability to manage heat gain is a primary characteristic. Chromatic systems, because of the ease with which they become opaque, filter out much of the sun’s rays. However, because electrochromatic glazing requires an electrical source, it wastes energy in order to save energy. Therefore, photochromatic and thermochromatic glazings are more efficient in energy consumption. Thin films have a lesser ability to filter light waves, but they go a step further and absorb the excess light as energy which can then be stored and used later.
Robotic systems also have traits which allow them to reduce heat gain. Returning to the example of the San Francisco Federal Building, the robotic system opens vents at night, allowing for natural ventilation of 50% of office tower. Even with the expensive façade, it was possible to eliminate enough mechanical units to save $11 million in construction, and doubtless more in operating costs (Reeser 71).

Innovative window systems also have the power to transform façade design. Just as the invention of steel allowed for heavy, masonry walls to open up and allow light and interaction, so too could new technologies revolutionize building façades. Thin film products with information display technologies allow for advertisements or exhibitions to take place on any surface, engaging passersby and enriching façades. Chromatic glazings transform exterior walls through their variable opacity. Blurring the distinction between window and wall, these technologies create more flexible scale and fluid rhythms.

Large glass atriums can certainly be benefited by these technologies. Robot systems and electrochromatic glazing permit an operator to easily control windows that could not be reached, saving on maintenance and operating costs. This ease of alteration is also useful in smaller, residential scales, for those who are unable to reach high blinds or pull curtains shut on their own. The easier a system is to implement, the more likely it will be used instead of ignored, and therefore greater actual savings can be realized.

**Drawbacks**

While all of these products have the capability to transform the way we look at glass, each has their own set of problems too. Many of these challenges are characteristic of any
emerging technology, but will nonetheless need to be resolved before these products reach widespread application. Overarching dilemmas include unproven lifetimes and high upfront costs (James 1060). Others are specific to the genre of glazing. All of these combine to make early adopters wary of cutting edge technology.

For instance, though chromatic types of glass offer many solutions, they have their drawbacks too. Developing full transparency has been a problematic issue, leaving many prototypes with a frosted look or bluish tint. Even to achieve this level of transparency, full switching can sometimes take up to fifteen minutes (Selkowitz 6). Photo- and thermo- chromatic glass can raise the risk of user discomfort, especially in relation to temperature, because they respond to environmental factors and do not adapt to human interaction (James 1). This sensitivity to outside sources can also be problematic in climates with rapidly changing weather and dynamic light levels. Sites such as London or San Francisco would be vulnerable to this effect, as switching is not instantaneous and could create an inappropriate lag. Electrochromatic glazing is more responsive in this respect, but it must be hard wired into an electrical source, which reduces flexibility of design and increases energy consumption. (Hart 150)

Thin film photovoltaics share a similar transparency issue with chromatic glass in that neither is yet able to be truly transparent. A second unfortunate problem is that the organic photovoltaics used in thin films, based on carbon rather than silicon, aren’t as efficient as their inorganic counterparts (Wright). The organic versions are more flexible and adaptable, but it comes at the cost of energy loss.

Robotic systems are inherently more complicated than a system that is integrated into the glass itself. More parts and more moving pieces create more possible problems. Cleaning and maintenance become greater issues with robotic systems. The automated louvers previously mentioned in the Federal Building, for example, have encountered problems with torque,
rendering many of them dysfunctional. Upkeep in situations like these could negate any possible savings in energy costs, making such a system undesirable.

**Industry Restraints**

Each type of glazing has strengths and weaknesses. Only once these have been considered is it possible to wisely and effectively utilize any system in its most appropriate application. Current challenges within the industry as a whole suggest trends that lead to speculation about the future of glazing design. In order to examine where the market is headed, experts were consulted and their opinions gathered. These interviews supplement an overall exploration of the literature in the field.

There are certain problems to which any new technology can fall prey. These hindrances span across all three glazing types. The first of these problems is risk aversion in the construction industry (Elvin). Owners, architects, and contractors want products that are durable and easily specifiable. Building owners need to know what to expect but with new products this is not always possible. Without extended warranties or proven product life, it is risky to use a new material. There is always a fear of unexpected expenses, embarrassing mishaps, or even dangerous shortcomings. In short, pragmatic consumers avoid being the “guinea pig” when it comes to their project. New technologies, while exciting, may have trouble being widely accepted in the building industry.

The second factor that gets in the way of rapid adoption and development of new glazing technologies is the relatively high first costs for both the consumer and the producer. In their early stages, unproven products typically cost more than ones that have been in production and development for years. Risk-averse consumers avoid spending large amounts of money on neophyte companies and ambiguous products. Likewise, product development is also risky for
the producer. Because of a habitually wary industry or a lack of name recognition, there is seldom enough market demand to offset investment costs. As Chris Macneal, senior associate at the firm of Kieran and Timberlake, describes their own setbacks with *Smart Wrap*, many products are "not currently mature enough, robust enough, or inexpensive enough," for a commercial market (Macneal). These issues combine to make it very difficult for ambitious new products to emerge from a research lab into an actual catalogue.

**Future**

These industry challenges are not insurmountable. Each product has much to offer in the building sector if it can survive the curve of adoption. As Dr. Robert Gilman, publisher of *In Context* magazine, suggests, for any innovation to be widely adopted, the perceived cost of the change must be greater than the difference in value of the new way over the value of the old way (Gilman 10). The cost of implementing many of these glazing technologies will undoubtedly prove minor in comparison to their lifetime value. The experimentation phase is already in process, and will continue as the technologies are improved and perfected. Pilot projects, such as *Smart Wrap*, and Sheila Kennedy’s *Soft House* are also underway. At this time, the key is in the building of support by early adopters who will help accelerate awareness of these projects. As part of the green building trend being championed by many in office, smart glazing systems will even become part of electoral politics. Inferring from

![Diagram of the curve of adoption for innovations](Source: In Context)
Gilman’s ideas on the adoption of change, eventually the products may become widely popular and may even be mandated by government or industry regulations, such as LEED certifications.

While there are many impediments to the success and proliferation of new technologies, these will in time be overpowered by potential benefits. Now that the likely future of these systems has been laid out, some side-effects can be predicted. Several developments are likely to occur because of, and surrounding, the propagation of new glazing systems. First, expect to see a continuing decrease in operating energy consumption versus total energy consumption of a new building. Currently construction is minor to operating energy, but with greater efficiency in glazing systems and otherwise, the latter will be lessened. Total lifecycle costs, in resource and energy consumption as well as monetary expenditure, will be reduced (Elvin).

LED lighting will be a likely step toward more active and sustainable glazing systems. LEDs can be integrated into a window itself because of the small size and high efficiency of these bulbs, providing luminescence day and night with very little energy expenditure. LED-incorporated glazing will vastly change a pane of glass’ ability to transform and environment and engage an occupant.

Another requisite direction will be an improvement in insulation properties for glazing. Vast amounts of heat are gratuitously gained and lost through uninsulated windows. Strides have been made in insulating walls, but the same trend for windows has been much slower. This inability to regulate heat transmission overworks heating and cooling systems and wastes resources. According to George Elvin, associate professor of architecture at Ball State University, “reducing energy is the number one way to reduce carbon emissions and insulation is the most cost effective way.”
Visually, a next step in glazing development will be to develop full transparency. Once thin films become fully transparent they will be more viable, more flexible, and more appealing to a wider audience. Fully transparent photovoltaics, now rapidly under development, have great possibility for numerous applications. Imagine a world where every surface is able to collect energy without having its visual properties compromised.

As we begin to see a revolution in glazing products in the future, there will also be drastic changes in the development process. The pace of development will increase exponentially to allow for accelerated progress. Rapid prototyping, a process wherein virtual designs are inputted to a 3D printer which produces a solid physical model, will be essential in accelerating development trends. This technique, assisted by sophisticated software, will allow designs to be refined quickly through physical and digital visualizations. (Macneal). These techniques also facilitate performance based design, wherein material properties, such as ductility or transparency, are specified and those parameters are chemically fulfilled by a 3D copier.

Just as, in the realm of computers, solid state hardware is faster and more reliable than mechanical counter parts, so it is in the world of glazing. To further the design of forward-looking glazing systems, responsive materials must develop without moving parts. At present, there is too much room for error, too much maintenance involved, and too much energy required to move those parts. Unless corrected, this trend bodes poorly for robotic window systems, which may soon be a thing of the past. Smaller, simpler, glazing-integrated systems like chromatics and thin films are more likely to have a fruitful future in the long run.

Conclusion

Chromatic systems, thin films, and robotics are three forerunners in the realm of emerging glazing systems. All three have significant capability to advance the position of glazing
in architecture. User comfort has always been instrumental and, in today’s world, energy conservation is imperative. Each system has strengths which adapt to different applications. Robotic systems can control glazing mechanisms when human operators are unable, but their moving parts make them prey to malfunction and inefficiency. Chromatic glazings boast enormous flexibility in their control of privacy and light transmission, though further development is necessary to achieve faster switching and full opacity. The strengths of thin films lie in their ability to make surfaces more active and engaging through energy collection and information display. Their weakness is a loss of efficiency compared with more traditional photovoltaic cells. Often new technologies have trouble taking off due to hesitant consumers and expensive start-up costs. Nonetheless, many of these systems will pay for themselves in time when used effectively. Today’s emerging glazing technologies will revolutionize the way we look at, and into, buildings.
### Table 1: Matrix of Strengths

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Chromatics</th>
<th>Thin Film</th>
<th>Robotic Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interior Light Quality</strong></td>
<td>- Frosted look - Rapid privacy transition</td>
<td>- Draw more attention to themselves - Can create indoor light without fixtures</td>
<td>- Adjusts quantity more than quality of light</td>
</tr>
<tr>
<td><strong>Transportation Costs</strong></td>
<td>- Shading properties are integrated into the window, minimizing transportation and waste</td>
<td>- Allows the integration of all functions of a wall system in a compact product</td>
<td>- Additional parts increase these costs</td>
</tr>
<tr>
<td><strong>Energy Consumption/Heat Gain</strong></td>
<td>- Minimizes heat gain when opaque, but electrochromatics require an energy source</td>
<td>- Stores energy</td>
<td>- Allows for natural ventilation and sun shading, but utilizes energy to operate moving parts</td>
</tr>
<tr>
<td><strong>Façade Design</strong></td>
<td>- Blurs distinction between window and wall - Increases flexibility</td>
<td>- Creates opportunities for information display and lighting - Engaging</td>
<td>- Could clutter façade</td>
</tr>
<tr>
<td><strong>Universal Design</strong></td>
<td>- Can be controlled at the flip of a switch</td>
<td>- Not applicable</td>
<td>- Allow for control without direct human interaction</td>
</tr>
</tbody>
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Works Cited

Elvin, Dr. George. Director of Green Technology Forum and Associate Professor at Ball State University. Daisy Winkler. 16 February 2009.


