Adaptive Fritting as Case Exploration for Adaptivity in Architecture

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ABSTRACT
This paper explores the incentive, design process, and realization of an adaptable building system. Hoberman Associates' installation at the Graduate School of Design at Harvard University, Adaptive Fritting, is used as a case study for the more general thesis of mechanism design in architecture. Traditionally seen as expensive and impractical, 'movement' in buildings can be accessible if done with high economy and simple elegance. The goal of this example is to illustrate the design process, challenges, constraints and parameters required to realize an adaptable architectural system.

1 PREMISE FOR ADAPTIVITY
The notion of a building that can move or reconfigure itself is not a novel concept. The premise of modularity and dynamic control in combination with unique mechanisms has permeated architectural practice at many points and through a diverse range of projects. Often, the large scale and custom nature of these systems with consideration given to structure, mechanism and control results in a cost that can only be justified by a projects high profile (Milwaukee Art Museum, Santiago Calatrava) or commercial benefit (Cardinals stadium roof and field example, by Peter Eisenman and HOK Sport).

The built environment is inevitably adaptive. Environmental forces beyond gravity and pressure are constantly causing building materials to deflect, expand, contract, rupture, and deform all around us. Standard design guides us to limit movement in favor of stability. However, if stability can be maintained while incorporating movement new design opportunities are suddenly possible.

New material systems in architecture have always produced new design opportunities. For example, reinforced concrete was born through combining a metal lattice with liquid concrete. This new material system supported many of the amazing structures we see today. Adaptive Fritting is a first embodiment of a newfound "material system" that allows the designer micro-control of the user experience.

2 DEVELOPMENT OF ADAPTIVE FRITTING PROTOTYPE
Inherent to the development of Adaptive Fritting was the desire to take an established architectural treatment and imbue it with expanded functionality. The benefit of such development would be twofold: providing architects with a new design element that is already a familiar part of their vocabulary and a performance increase that expands upon the current appeal of using fritted glass (namely, as a means of easily customizing shading while preserving transparency where desired).

2.1 INITIAL ASSUMPTIONS AND BEHAVIORAL INTENT
The benefits of a fritted surface in reducing incident sunlight come from a combination of the surface treatment and the density of that treatment. In setting out to achieve a purely mechanical transformation, focus was limited to the modulation of density for initial investigations.

In order to preserve the current aesthetic of fritting it was important to create an object that was relatively thin. The primary challenge then was in determining what type of motion could be applied to a standard fritted pane in order to achieve the desired density modulation without drifting too far a field of current fritting implementations. Once a desired motion was chosen, material and construction choices could be made to complement that motion in development of a proof-of-concept prototype.

Further, the desire to create an adaptive element requires a means of autonomous control. The assumption here was that an electromagnetic motor would be used as an actuator in conjunction with programmable motor controller.

2.2 TRANSLATIONAL MOTION BY PARALLELOGRAM LINKAGE

Mechanical modulation of density requires the movement of material. Often, as with typical louvered systems, this is achieved by rotation of an element out of plane. Though the movement is economical, it establishes a direct relationship between density and depth. To achieve full coverage, the width of a louver dictates both the minimal spacing between louvers in-plane and the minimal required depth through which the louver rotates.

By approaching modulation of density through an in-plane motion, the movement of material would require no change in depth but instead a change in height and/or width. This method of motion was deemed as preferable for a fritted application as the relationship between the frit size and the sheet size would allow for small translations of a large sheet. The desired underlying motion to evolve from this thinking was a series of stacked sheets containing identical frit patterns. When aligned, the stack would reveal a single frit pattern with multiple layers of depth representing a state of least density. When shifted in plane relative to one another, the sheet stack would create patterns of various density correlated to the distance of the shift.

To achieve this translational shift it was desired to utilize a parallelogram linkage system. The motivation for this decision was driven by the mechanisms ability to simply convert a rotational motion into a translational motion. To further minimize the addition of components, a scheme was devised by which the translational panels themselves could be used as the linkages.

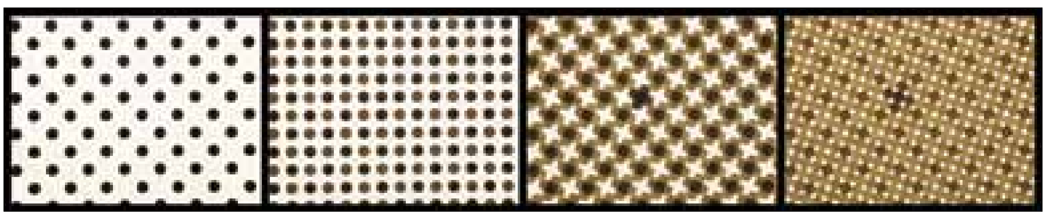

Figure 1 Adjustment of Fritting Density by In-Plane Translation of Stacked Panels.

2.3 ACTUATION & CONTROL

By utilizing a parallelogram linkage the resultant motion is not a pure linear translation, but a significant advantage is gained in economy of actuation. The rotational motion allows for the configuration of the linkages in symmetric locations around the axis of rotation. Since the linkages are also the panels themselves, the weight of the panels is fully supported at these pivot locations. The symmetrical weight distribution sets up a force-balanced mechanism that establishes two advantages. The first advantage is that extremely low torque is required to move the panels. The major considerations for motion then become friction and inertia, allowing the actuator sizing for control of the panels to be minimal yet scaleable for enhanced performance. The second advantage is that panel position need not be maintained by the actuator. As such, power would only be expended while the panel density is modulated and could be minimized whenever the panel is at rest, regardless of position.

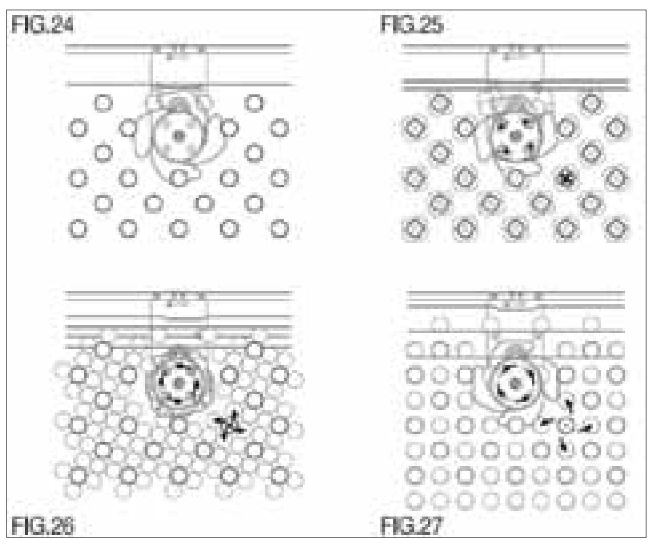

Figure 2 Preliminary Patent Diagrams Illustrating Panel Linkage Actuation Scheme.

As an adaptive element, responsiveness is a key factor in enabling a reaction to some impulse. The proposed mechanism handles this aspect well as only a small amount of rotation is required to achieve the maximum density shift. Thus, dependent upon gearing requirements and desired speed, very few actuator rotations will enable the full range of motion, and speed is limited only by actuator size in relation to the inertial requirements of the load.

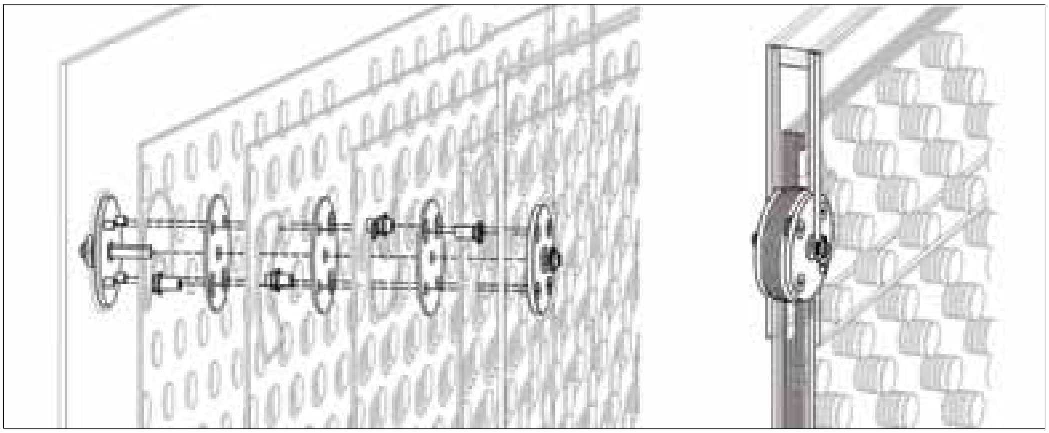

Figure 3 Panel Stack-Up and Rotational Pivot Mechanism.

2.4 MATERIAL CONSIDERATIONS

The fundamental material requirement to be considered was panel material choice. Traditional fritting is typically created as part of the glazing manufacturing process. Fritting can also be applied as a secondary application, and various vinyl transfer technologies exist that emulate the "frosted" look of traditional fritting. For our purposes, utilizing glass was impractical due to weight, fragility and manufacturing complexity. Additionally, our primary area of exploration was concerned with density and not the properties of the frit itself.

The prototype was ultimately manufactured as laser cut cast acrylic panels. Clear acrylic was chosen to maximize transparency and achieve the effect of glazing. To emulate a frit, an orthogonal array of circles was etched onto the panels so as to penetrate the protective laminate but not cut through the acrylic. When the protective laminate was removed, an array of laminate dots remained affixed to the panels, serving as the fritting pattern.

3 PROTOTYPE FINDINGS

The prototype was manufactured first as a representative mechanical test unit, and then as a small run of seven panels, six of which were installed as part of the exhibition Ecological Urbanism in Gund Hall at Harvard's Graduate School of Design. Functional expectations for the prototype were all met, and it served to validate the concept as constructed.

The issue of note uncovered in constructing the mechanical test unit was the necessity to maintain adequate spacing between the translating layers to prevent rubbing and abrasion of the surfaces. To achieve this separation, polyester pads were introduced at regular intervals between the layers, concentric with the frit pattern. Though successful at maintaining an air gap between the moving sheets, the pads rubbing on the plastic induce a static charge which is highly attractive to dust. Care was taken to keep the panels as clean as possible because cleaning requires disassembly, but this emphasized the need to reconsider construction from a maintenance standpoint.

Panel performance and responsiveness was verified at a level greater than anticipated for this construction. The short motor stroke allowed for quick movement, thus validating the ability of the system to respond to events in real time. Extracting large variability through relatively small movement was one of the primary successes of this case study.

4 AREAS FOR FURTHER DEVELOPMENT

The development of the fritting stood up as a proof of concept as both a functional architectural element and an aesthetically interesting mechanical phenomenon. Interest has already been expressed across multiple industries for developing the core mechanism further. As this development relates to bringing the object into the built environment, the following key areas would need to be addressed.

4.1 MATERIALS AND PROPERTIES

As built, the Adaptive Fritting prototype requires more advanced thinking from a material standpoint. Acrylic served well as a convenient means of realizing the vision, but would only be applicable as for specific applications.

The critical area for improvement would be in re-conceiving the moving panel linkage system. Ideally the principles would remain the same, but a more minimal construction of the panels utilizing less material would be beneficial. Moving the mechanism away from stiff sheets and toward membrane-based construction seems the most likely development path.

The fixed panel encasement layers would also need to be reconsidered to allow for usage as a proper glazing panel. Weather tightness, insulative properties, acoustic properties, and maintenance would all need to be thoroughly considered depending upon the application. In order to effectively reduce solar gain, fritting is typically placed on the outer-most surface. The multi-layer approach of Adaptive Fritting will require the outer-most layers have the maximum amount of fritting.

Figure 4 Installation at Harvard University for the Ecological Urbanism exhibition.

4.2 ACTUATION

The current implementation of motor control was based on available componentry and greatly exceeds requirements. Depending on changes to the mechanism and construction methods, actuation loads would be reassessed. Steps taken toward tighter integration of an actuator within the panel would be necessary. Likely areas of near-term investigation would be in flat-motor technologies and embedded control strategies.

4.3 PATTERNING

Efforts to date have looked at patterning only in relation to the number of stacked layers and spacing of an orthogonal grid of similar elements. There is a great potential for patterning exploration to enhance the design potential of Adaptive Fritting. Efforts will continue along these lines independent of more physical considerations.

5 APPLICATION OF ADAPTIVE FRITTING

"Smart windows could reduce peak electric loads by 20–30% in many commercial buildings and increase day lighting benefits throughout the U.S., as well as improve comfort and potentially enhance productivity in our homes and offices."
– Lawrence Berkeley National Laboratory

Solar control in building envelope design is full of conflicting requirements. For example, maximizing view often increases solar gain. While all-glass facades give occupants a connection to the outside environment, even high performance glazing cannot insulate as well as solid mass construction. Furthermore, un-shaded glass allows profuse amounts of direct daylight into a space, creating areas of high contrast between light and dark. This high contrast effect, called glare, often forces occupants to close the blinds completely. Counter-productively, the darkness requires additional lighting which consumes electricity and generates heat.

An effective shading system allows view, blocks solar radiation, and scatters diffuse daylight deep into the space. More specifically, a shading system's effectiveness is based on the percentage of opaque material, thickness, opacity, reflectance, and position within the façade. Adjustable blinds and exterior louvers can be effective at reducing solar exposure of glazing but add complexity and expense through additional hardware installation. Spectrally selective solar coatings are the most cost effective methods of blocking solar radiation. The best coatings available today can allow more than twice as much visible light as solar heat gain through a window pane. However, as better performing coatings selectively block more of the visible spectrum, the color distribution does not always remain neutral. Therefore, many designers have chosen fritting as an additional shading component allowing a lesser performing solar coating and a more neutral color glass.

Another reason the solar coating is effective is because the shading technology is concentrated in a very thin layer within the façade. This consolidation of hardware and complexity makes Adaptive Fritting simpler to install than external blinds and louvers. Architecturally, the façade can become thinner and higher performing. There are many "between the panes" technologies currently on the market that focus on consolidating complexity. Okasolar louvers are embedded within a double glazed cavity that reflect solar rays and also redirect sun light into the space through rotational adjustments. Holographic optical elements utilize the principle of diffraction to redirect sunlight. Electrochromic coatings have great promise; however, they are still very expensive and do not diffuse light and do not maintain a bright view. Because the Adaptive Fritting technology is limited within the glazing unit, simple motion has a large performance and experiential impact.

Figure 5 illustrates a contemporary façade design using variable static fritting to customize view and solar protection. Generally, the greatest transparency for view is located on a wall between three and seven feet high. Façade areas below three feet and above seven feet are often opaque spandrel panels that primarily insulate and block solar gain. Adaptive Fritting provides opportunities for questioning these general rules of thumb. When no one is physically looking out the window, is view still important? Adaptive Fritting can control "on-demand" view by increasing transparency either when occupants approach the window or set the window to "viewing mode". When viewing is not required, Adaptive

Figure 5 AC Building, New York–Frank Gehry.

Fritting will block solar gain while letting in diffuse light. Automated versus user-based controls are vital considerations in designing active systems. The design must be robust enough to allow both modes.

The building envelope designer is actually designing porosity and energy flow through a series of material surfaces. As an abstraction, Adaptive Fritting is concerned with modulating the parameters of pattern, porosity, and movement at a micro scale. In contrast, special solar and electrochromic coatings are applied to glass homogenously. Thus, their effectiveness is not optimized as to where the sun is located in the sky. Adaptive Fritting's multi-layer solution could potentially block solar radiation based on hemispherical angles of incidence tracking the sun's movements above while allowing view for the occupants.

CONCLUSION

This paper described the process of mechanism design in architecture. Because complexity increases exponentially with moving parts, finding economies is vital to an effective design. The maximum benefit must be extracted from every inch of motion. This case study, Adaptive Fritting, is purely an example and infinite variants can be explored through altering any parameter—motion, usage, material, or configuration. What if adaptive fritting utilized rotational motion instead of translational motion? What if the acrylic sheet was punctured with holes instead of fritted with dots? This modulated porosity could control air flow instead of sunlight.

Adaptive techniques in building design will ultimately be adopted in a multitude of ways. From a behavioral standpoint, designers will be able to create more dynamic buildings that they can tune and will integrate this thinking early on in the design process. At the building management level, adaptive components will be able to interface with current Building Management Systems and become an active part of a central control system to achieve regulatory benefits. Ultimately, adaptive architectural design will free people from having to make choices based on a buildings location and will allow a building to tune itself to work within its surroundings.

REFERENCE

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