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INFORMATION STORM

An assessment of Responsive Facades and their potential to introduce new relations between building users and the weather

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Abstract. Today buildings are increasingly responsive to the weather. In such responsive buildings an "Open System" is emerging which consists of a coupling between buildings and their temporal environments. This paper assesses whether these new technologies, in addition to potentially reducing energy consumption, can also lead to a new experiential relation between building users and the weather. The paper qualitatively assesses current examples of Responsive Facades and their effect on the user's experience of the weather. The information structures of the facade systems are then examined. From this analysis identify potential future avenues of research – or strategies – which may be most effective in making the weather apparent. Finally some design proposals which explore the possibilities of these strategies are presented. The paper is intended to complement the current, primarily technical, emphasis of research in this area by exploring the innovative architectural potential of Responsive Facades to create new user experiences and relations to the weather.

Keywords. Responsive facades; weather effects; experience.

1. Weather Information and Responsive Buildings

From the beginnings of its systematic study in the 17th Century Meteorology has always been about the collection and effective use of information (Jankovic, 2001). What this has meant for weather-forecasting is that increasingly vast blocs of information need to be processed and for this reason the fastest computers used today (the so-called supercomputers) are used for this purpose. From this it can be seen that every weather-system contains a huge amount of *non-compressible* information. The relationship between this information and our perception of the weather, through the medium of the responsive facade, is the subject of this paper.

Today buildings need to be able to adapt to changing conditions outside in order to maintain the effective running of heating and/or cooling systems inside (Perino, 2008). It could be said that in such responsive buildings an “Open System” is emerging which consists of a coupling between buildings and their temporal environments. The result is a continuous free-flow of constantly-changing information from the weather to buildings and back again (see for example Knaack et al. (2008) and Ritter (2007)).

Historically the design of energy-efficient buildings has sidestepped the potentially insuperable complexity of this relationship by being solely based on *climatic* information. The rich and varied information of the weather has been compressed into long-term statistical averages removing the unpredictable variability of actual temporal change and replacing it with seasonal means. But today, the limits of this approach are being reached. While buildings can become more energy-efficient this also means that they are more sensitive to deviations from the predicted climate (van der Aa et al., 2010, pp. 112–113).

On the other hand, while energy is becoming more and more expensive -both monetarily and environmentally —and this is likely to continue into the future (DGEE-IEA, 2012 p. 3)— we also have the imminent arrival of the so-called “Internet of Things” (Guo et al., 2011). These two developments together mean that the costs of installing, running and maintaining responsive buildings will decrease and, increasingly, be offset by the savings in energy consumed. This leads us to believe that, even though there have been some issues with the spread of responsive buildings (Perino, 2008, pp. 24–25), they are likely to become more common and inevitably more sophisticated in the future.

2. Responsive Facades

In this paper we are discussing what have been variously called Advanced Integrated Facades (AIF) (Perino, 2008) or Climate Adaptive Building Shells (CABS) (de Boer et al., 2011). Here we use the term Responsive Facades (not to introduce yet another term but because we feel this is more inclusive of all the examples we look at-not all examples can be described as “Advanced”, it omits the overt reference to Climate in CABS and also it is less cumbersome).

Our definition of a Responsive Facade is: A facade that responds automatically to variations in external and/or internal environmental conditions, in order to reduce the energy consumption of a building.

It is clear that the complexities of the responsive building envelope require much technical research. While acknowledging the importance of this work, this paper takes a more qualitative approach. We also take a different track to previous qualitative analyses such as Wyckmans (2005) and Loonen (2010) by assessing how the *user’s experience* of these envelope systems can create new relations between users and the weather by taking in the information generated by the weather and not just displaying it but making its dynamic apparent through the performance of the envelope.

3. Analysis

Methodology: Thirty new and existing Responsive Façade Technologies were selected and analysed against a series of criteria outlined below (see Table 1). Each technology was assessed empirically for its ability to produce effects which would make the dynamic of the weather apparent. This assessment took a phenomenological approach based on empirical evidence: personal experience, video documentation and extrapolation from written descriptions, following the model of phenomenological research in environmental design proposed by Seamon (2000).

Weather in the environment is sensed through vision (clouds, sunlight, snow etc.), thermoception (the sense of heat), sound (the wind blowing, thunder etc.), touch (wind or rain against the body) and even smell (the smell following rain is

Table 1. Matrix of Responsive Façade Technologies against selected criteria.

	CABS Name	**Conventional technologies**	1. Le Corbusier's mur neutralisant	2. Modern Double Façade Systems	**New Materials:**	3. Electrochromic glazing	4. Photo-chromic glazing	5. Photoelectrochromic glazing	6. Gasochromic glazing	7. Fluidized Glass Façade	8. GlassX crystal -(wax PCM)	**New Components**	9. Adaptive Fritting	10. Integrated Venetian blinds	11. Printed ETFE foil cushions	12. Glazed louvres	13. The esplanade -Singapore	14. Aegis Hyposurface	15. Aldar Central Market	16. Institute du Monde Arabe	17. City of justice, Madrid	18. Flare façade	19. SmartScreen (shape memory)	20. Hotel habitat Ruiz-Geli	21. Kinetic light	22. GSW Berlin	23. Bremtex, VOX Architects	24. Solar shutters (TU Graz)	25. PV shutters (Colt International)	26. Deployable External Insulation	27. Heliostat	28. iHomeLab	29. Sagami bay house -Foster	30. Showroom Kiefer technic
	Visible ?					■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Type of Visible Response	A. Position												■	■	■	■	■	■	■	■	■					■	■	■	■	■	■	■	■	■
	B. Shape																					■	■											
	C. Colour					■	■	■	■	■	■																							
	D. Data																							■	■									
Speed	A. Instant					■	■	■										■								■								■
	B. Delayed								■	■			■		■		■		■	■	■	■	■	■	■		■	■	■			■	■	
	C. Deferred										■																			■				
Scale	Microscopic					■	■	■	■	■	■																							
	Component												■	■	■	■	■	■	■	■	■	■	■	■	■	■								
	Object																									■	■	■	■	■	■	■	■	■
Inform. Structure	Open		■				■	■			■			■		■							■					■	■	■				
	Closed			■		■		■	■	■			■	■	■		■	■	■	■	■	■		■	■	■	■				■	■	■	■

quite different to before). Vision, however, is clearly the way in which architecture is most commonly described (drawings, models, simulations etc.) and, inevitably, experienced. We do live in a visual culture after all (Jay, 1994, pp. 21-82) and, for this reason, we will focus in this paper on the potential for Responsive Facades to create a *visual* link to the usually invisible dynamics of the weather.

In addition, to be perceptible, a change in the weather must be visible at a *speed* we can perceive -fast-approaching rain clouds can be seen moving towards us but the clouds of a slow-moving pressure-system cannot. And it must be at a *scale* where we can perceive difference between different areas -a large mass of cloud that fills the sky from horizon to horizon may be moving or changing but this will not be immediately visible while the drift of small, moving clouds is much more easily perceivable. Based on this analysis of how the weather is perceptible in nature, we identify 3 criteria which are required for a facade system to make the dynamics of the weather perceivable: Visibility, Speed, and Scale. Under each criteria we identify varieties of performance. We then assess the potential effectiveness of the different varieties of performance to give a perceptual link to the weather.

3.1. VISIBILITY

First it must be determined if the performance of the responsive building envelope visible, and if so, is it visible at the macro scale to human observers? This criteria separates the many responsive building technologies that have no visible effect, such as conventional double facades, concealed ventilation etc., from those which do. We identify several ways in which changes in the weather are made perceptually visible:

- **A. Changing Position:** Through the adjustment of shading in response to the changing position and intensity of the sun (Responsive Shading). This can take the form of mechanical devices such as shutters, louvres etc. Examples include the “Solar Shutters” as used on the Biokatalyse building at TU Graz (Wyckmans, 2005, p. 165) or the Glazed Louvres used on the LVA Schwaben Building, Augsburg (Wyckmans, 2005, p. 170).
- **B. Changing Shape:** Through the visible effects of changing shape as a result of an environmental change or stimulus. For instance flexible materials which move in the wind; laminates with different expansion rates bending in response to heat. One example would be the prototype Homeostatic Facade System developed by Decker Yeadon (deckeryeadon.com).
- **C. Changing Colour or Opacity:** Through a change in the visible appearance of a material as a result of an environmental change or stimulus (Responsive Materials). Examples include Electrochromic, Photochromic and Gasochromic materials; Phase-Change Materials (PCMs) etc.

- **D. Data Visualization:** the translation of invisible data (temperature, wind speed, humidity) into visible stimulus -digital readouts, colour gradients etc. Examples include Hotel Habitat by Ruiz-Geli (Ritter, 2007, p. 128) or Kinetic Light (Loonen, 2010, p. 51). These are generally “displays” of invisible information streams and, while potentially making the weather visible, they do not contribute to energy saving -in fact quite the opposite.

All four of the visible transformations described above could potentially be configured in such a way as to produce a dynamic effect which reflects the weather if combined effectively with the criteria outlined below.

3.2. SPEED

Selecting those systems that do have a visible effect is that effect at a speed that is immediately perceptible to the human eye? Applying this question to the examples it becomes apparent that the visible effects can be separated into 3 speeds of performance:

- **A. Instant** – visible change (within seconds) in the appearance of the facade as a result of changes in input. For instance the change in colour of electrochromic glass as a result of changing input voltage.
- **B. Delayed** – a change in appearance that is directly attributable to a change in weather conditions but which happens some time later (usually in the range of 10 seconds to several minutes). A typical example would be the change in colour of photochromic glass, as a result of changing light levels which can take from several seconds up to 1 or 2 minutes.
- **C. Deferred** – a change in the appearance of the facade which takes place several hours after a change in ambient conditions. A typical example of this would be the day-to-night transformation in a phase change material facade. Example: GlassX Crystal PCM (Ritter, 2007, p. 164).

We suggest that in order to register most clearly with people’s experience of the weather a transformation in the facade should be as fast as possible.

3.3. SCALE

If the effect is immediately perceptible at what Scale does the visible change take place? Here again we have 3 categories:

- **A. Microscopic:** Some transformations take place at the microscopic scale and therefore appear uniform to the human eye. For example electrochromic glass that changes colour all at the same time.
- **B. Component-scale:** This is the transformation of visible components which are small enough not to be discernible as individual objects combining instead into a distributed field effect.

- **C. Object-scale:** At this scale responsive building elements are large enough to be comprehended as individual objects-eg. shutters, louvres etc.

The distinction between B and C is not absolute and is related to the overall scale of the building. For instance storey-high shutters on a small building of 2-3 storeys will appear as distinct objects (Example Biokatalyse building at TU Graz (Wyckmans, 2005, p. 165) while on a large building of many storeys they will appear like a distributed field as seen in the GSW Building by Sauerbruch Hutton (Sauerbruch et al., 2000, and the author's personal experience). In addition detail, colour etc. can concentrate or dilute this effect.

In terms of implementation the Component Scale is, in most cases, probably the most complex/expensive. However it is the most sensitive to local variation and so can potentially provide the most finely adjusted energy savings and so these systems are likely to become more common. In addition simplifying the complexity of the individual component and especially its mechanics can reduce the overall complexity and cost.

3.4. INFORMATION STRUCTURE (OPEN OR CLOSED)

As mentioned at the beginning of the paper information intensity and non-compressibility is one of the distinctive characteristics of the weather thus we also look at the way in which information is processed. Loonen (2010) provides a useful distinction in this regard between "Closed Loop Control" and "Open Loop Control". To summarize his categories:

An Open Loop Control System (OLCS) is one where there is a direct transformation of the system or component as a result of changing conditions. Examples of this would be photochromic or thermochromic glass and phase change materials (PCMs) where material change happens without the need for any remote data processing. The disadvantages are that it's performance is hard to predict and if not anticipated correctly at the design stage it can be problematic as its performance cannot be changed.

In a Closed Loop Control System (CLCS) on the other hand information is taken in (via sensors) processed (digitally) and instructions are output (to materials or actuators). CLCS is more complex but has advantages: the use of feedback; potentially the ability to "learn" over time; and the possibility of human intervention to adjust the parameters, used to control response.

The question we are interested in here is: Does the type of control system influence the potential relations between the weather and the building?

In this regard OLCS has the advantages that, because of its relative simplicity, it can be fast and it can be the cheapest way to get the immediate effect required.

The advantages of CLCS are that the software can be adjusted after installation-either through human input or the system, if programmed to do so, can "learn" and optimize its responses. This suggests that both systems have potential but in different contexts-for instance OLCS can provide some environmental control and a direct link to the weather cheaply but cannot be very tightly calibrated to a specific energy performance. The building must have other systems which can make up for energy short-comings. CLCS can potentially provide much more precise responses but can only be installed in buildings where there is a budget and personnel capacity to install and maintain a complex system.

3.5. CONCLUSIONS FROM THE ANALYSIS

Based on this empirical analysis we conclude that for the dynamic effect of the weather to become apparent change must be visible, but this visibility could be a change of position, shape, colour or opacity; It should be instant or delayed only slightly; It should be at a scale where multiple pieces combine into an overall dynamic pattern. In addition, both open and closed control systems have potential if combined with an appropriate material system.

4. Experiments

Based on this analysis, in the experiments presented here, we pursue 2 different strategies:

- Strategy 1: Omit information processing completely and develop a mechanically simple material Open Loop Control System; Compensate for the lower energy efficiency of this kind of system by producing energy.
- Strategy 2: Omit all moving parts but still produce an effect of drift through a Closed Loop System combined with a large (but not too large) number of individual pieces.

4.1. EXPERIMENT 1: "SOLAR GRASS FIELD"

This experiment follows Strategy 1 outlined above, using the wind as the motor driving the dynamic. The experiment began by taking a field of grass billowing in the wind as its model. This performance produces a dynamic effect but it is difficult to align it with any requirement for sun-shading in order to reduce energy consumption (though based on our dynamic simulations it could provide a, statistically, fairly constant level of shading). We address this lack of shading-efficacy by proposing a concept prototype called the "solar blade" which consists of a flexible photovoltaic (PV) material (e.g. Nanosolar (nanosolar.com) mounted on thin

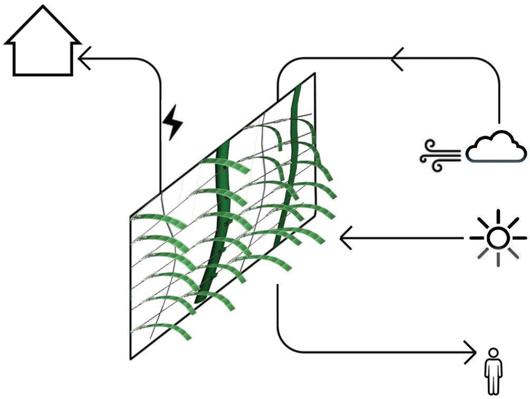

Figure 1. Open Loop System with 2 inputs (wind and sun) and 2 outputs (visual and electric).

metal strips. A relatively recent development, the flexible PV is a fully functional photovoltaic cell mounted on a very thin, flexible sheet of steel or aluminium that allows it to bend while retaining its power-generation capabilities.

The design takes the form of hundreds of these flexible solar blades which are each mounted on a spring which is then attached to a network of lightweight support cables allowing them to bend and flex in the wind. The intention is that the effect would make the weather more apparent by making the local turbulence of the wind visible. The overall performance would emerge from the local interaction of uncompressed climatic information with the specific materiality of the blades (Figure 1).

Outcome: This low-tech Open Loop System has the potential to provide instant manifestation of weather performance in the building fabric however its potential to produce enough energy to offset costs would need to be assessed through prototyping and testing as simulation involving so many parameters (wind dynamics, material flexibility, solar position, overshadowing) is difficult.

4.2. EXPERIMENT 2: "PIXELLATED GLASS FACADE"

Following Strategy 2 this experiment proposes a Closed Loop System that achieves a distributed, responsive field effect with no moving parts. Electrochromic Glass has the advantages that it can respond to changing conditions without the use of moving parts and is, as a result, in comparison to mechanical devices, relatively cheap. But it has the disadvantage, in the context of what we are discussing here, that it gives a uniform instant change from one state to the other. The question this experiment asks is how can we use this material to produce a less uniform, more dynamic effect?

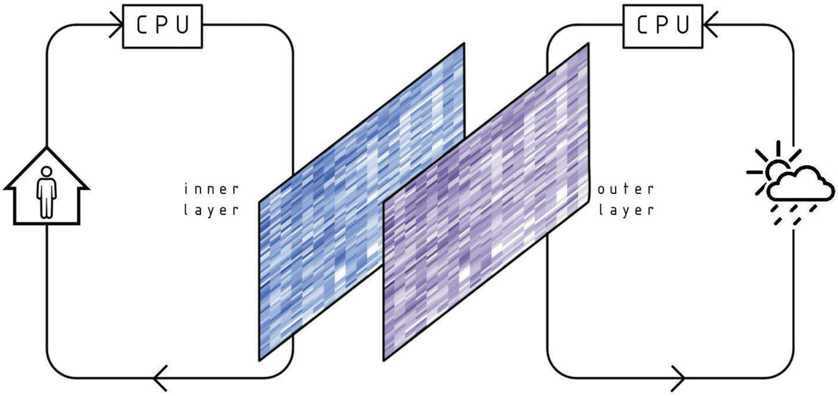

Figure 2. Closed Loop Controls for inner and outer layers of pixelated glass.

To answer this, the concept of pixelization from digital displays is used as a model. Specifically, this experiment proposes the low-resolution monochrome display as a model to translate the changing weather onto the facade while at the same time providing a responsiveness to changing light levels. The pixelated facade would be a curtain wall made up 2 layers of laminated glass each with an electrochromic interlayer, which would be divided into 2,752 pixels (Figure 2). Each pixel would be about the size of the exposed face of a traditional brick and could be individually activated, made transparent or opaque, through the application of an input voltage. Input to the outer layer would be a field of individual sensors or a low-resolution video capture of clouds in the sky, filtered to reflect the overall light level and then pixelated. The inner layer of pixels would be controlled by user.

As clouds roll overhead the facade would adjust its transparency in real time to maintain a constant light level inside while providing an ever-changing display on the outside. The unpredictability of the Weather would introduce an unpredictable element into the facade and its real-time information would be converted directly into a real-time performance.

Outcome: This Closed-Loop pixelated electrochromic system can generate an interesting interaction between the dynamics of the weather on the outside and the of user needs on the inside. Again cost may outweigh energy savings though this would need to be tested through prototyping.

5. Conclusion

In this paper we have described a qualitative analysis of Responsive Facade Technologies to determine their potential to incorporate the perceptual effects of the weather within the fabric of buildings and hence to make a new perceptual link between users and the weather through the medium of buildings. Our finding is that in order to best reveal the performance of the weather the system's transformations must be visible, instant or only slightly delayed and small-scale relative to the overall scale of the building to produce the dynamic effect of drift. However these requirements would make existing systems quite expensive.

To address this we present two experimental proposals which try to build on the potentials that we have identified by using either materially simple or informationally simple solutions. While, these are only proposals and would need more extensive research and testing to become realizable we hope that they suggest future directions for research exploring the "Open System" which is emerging between buildings, their temporal environments and their users.

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