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RESEARCH ARTICLE

Designing for change: The poetic potential of responsive architecture



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Received 12 October 2014; received in revised form 9 March 2015; accepted 13 March 2015

KEYWORDS

Responsive architecture;
Poetics;
Mechanical components

Abstract

The integration of responsive components in architecture offers the potential to enhance the experience of the building by giving expression to fleeting, changeable aspects of the environment. Responsive buildings enable a physical response to changes in the environment through specific building elements; in rare cases these responsive elements become an integral and poetic element of a culturally significant work of architecture. In this paper I examine two types of responsiveness, one which concerns the changing environment and another the activities and needs of the building's inhabitants. I look at two examples of buildings that illustrate a potential poetic role for architectural components responding to these two types of change, and propose that architects will need to acquire experience with designing for specific rates, scales and types of change before responsive elements will more frequently appear as a poetic and integral part of the building.

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1. Introduction

For the first visitors to the Institut du Monde Arabe in Paris, standing in the open plaza and looking up at innumerable mechanical diaphragms set in the glazed south facade, the spectacle must have been extraordinary and unprecedented (Figure 1). The sight and sound of movement in each mechanical diaphragm across the facade, combined with the realization that this movement was linked to the constantly

shifting modulation of sunlight, must have inspired the building's first visitors with wonder. It is now easily forgotten that Jean Nouvel's early implementation of responsive components was remarkable in scale, complexity, and architectural ambition at the time of its construction. What this project promised was an architecture based on change: response to change in the external environment and a corresponding modulation of conditions in the interior. Each of the building's facades, including the translucent panels of the internal courtyard, proposed a different method for daylighting and a different approach to the inevitable variability of natural light. Equipped with sensors, actuators and an array of mechanical diaphragms, the south facade of Nouvel's building

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Peer review under responsibility of Southeast University.

<http://dx.doi.org/10.1016/j.foar.2015.03.002>

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Figure 1 Institut du Monde Arabe: the south facade.
Image source: Peter Blundell Jones.

proposed a pattern that would be adjusted in response to variations in the intensity of sunlight.

Many forms of building automation are now commonplace, and in recent years sensor networks have been broadly employed in buildings to monitor and control diverse aspects of the built environment. Sensors are commonly used to track indoor and outdoor climatic variables such as humidity, temperature, and solar radiation; and to recognize patterns in the activities of people. In addition to this common instrumental role, these automated elements of buildings have occasionally played an important aesthetic and cultural role in the design of engaging architectural spaces. The automated diaphragms of the Institut du Monde Arabe offer one example of a dynamic building element which was conceived from the beginning of the design process as an integral, defining aspect of a significant work of architecture.

Responsive components are defined here as all those elements of the building that adapt to the needs of people as well as changes in the environment. These components may be high tech systems that employ sensor networks and actuators to monitor the environment and automate control of operable building elements. I am also using this term to refer to the moveable, operable, often manually controlled elements of buildings which allow the adjustment of the building envelope and interior in order to adapt the building's performance to meet everyday needs. The term is sometimes used to describe only the automated responsive components in buildings, a usage that ignores the strong connection between manual and automated mechanisms. There is also a potential for the relatively new phenomenon of automated building components to be informed by a long tradition of design excellence in manually operated mechanisms, a tradition represented in this paper by the Maison de Verre of Pierre Chareau, where mechanical adjustment achieves a remarkable level of poetic expressiveness.

In this paper I will use the Institut du Monde Arabe and the Maison de Verre to tell a story of the architectural contribution of responsive building components, and to suggest alternative ways of thinking about the elements of buildings capable of movement in response to change. The

question I will address in the paper is whether it is indeed possible for the responsive components of architecture to become a poetically expressive part of the building, and if so how why it is that this result has so rarely been achieved in contemporary and recent built work. In other words, I ask whether responsive building components have the capacity to transform, or at least to poetically inform the way that architecture is conceived and experienced. In a discipline as rapidly changing as responsive architecture, it is easy to overlook the roots of contemporary ideas in architecture's recent history, and this paper aims to redress this oversight by recognizing important pre-digital precedent for a current and future responsive architecture.

2. What is responsive architecture?

Every building is in some aspects a fixed entity, static and passive. At the same time, every building is also a changeable body whose permeability, appearance, and affordances for activity are capable of sudden and unpredictable change in response to the environment and the needs of its inhabitants.

The fixed aspects of buildings include location in the landscape and structure, things which change little if at all over the life of the building. And yet, if a building's behavior were entirely static it would hardly be capable of accommodating the range of contingencies that characterize daily life. Shifts in weather, changes in the behavior and needs of people: these require a certain degree of flexibility, a capacity for adaptation and change.

Architecture by necessity contains elements that are static and fixed: human survival depends on maintaining a constant core body temperature and our survival behavior includes the construction of shelters that maintain a stable interior environment. One of the most elemental functions of the building's responsive components is the maintenance of these stable conditions - opening or closing windows, raising or lowering blinds and sunshades, controlling fans and chillers and other air conditioning machines. Although we require stability we design our shelters to actively seek equilibrium using behaviors that involve frequent adjustment in order to accommodate variable meteorology.

Buildings are static, but most buildings also incorporate equipment which allows for a greater degree of 'fit' with variable circumstances. Le Corbusier used the term 'household equipment' to refer to furniture as well as the operable or movable elements of the building. To this list I would add the mechanical parts of a building that allow adaptation of the interior to conditions related to environment and human behavior: windows, doors, movable partitions, operable vents, louvers, sunshades, screens, etc. In other words, all the equipment that permits adaptation of the building interior and surroundings to meet the needs of everyday life. What I refer to in this paper as responsive components encompasses all the parts of the building that are able to adapt and change in response to the environment or to accommodate the contingencies of daily life.

As early as the 1970s, visionary thinkers like Nicholas Negroponte proposed that advances in artificial intelligence and the miniaturization of components would soon give rise to buildings capable of intelligently recognizing the activities of their users and responding to their needs, as well as

changes in the external and internal environment. Tristan d'Estrée Sterk writes of this early proponent of intelligent, responsive buildings, "Negroponte proposes that responsive architecture is the natural product of the integration of computing power into built spaces and structures. He also extends this belief to include the concepts of recognition, intention, contextual variation, and meaning into computed responses and their successful and ubiquitous integration into architecture."¹ Although the computer has not had as transformative an impact on the built environment as that envisioned by Negroponte, automated building components have become commonplace and are frequently integrated in facade systems as a tool for reducing energy consumption. Common examples include automated shading that reduces cooling loads due to solar radiation, and dimmable lighting fixtures that respond to photosensors, reducing the brightness of artificial lighting when daylight is available.² In this sense, the responsive component has become a commonplace of contemporary architecture.

3. Types of responsive architecture

In the broad definition proposed in this paper, responsive architecture can be understood as any building or building component designed for adaptation to change in its surroundings. In the examples investigated here responsiveness involves a primary focus on either changing patterns in usage (the activities of the building's inhabitants) or changes in the (exterior or interior) environment. The rate at which these changes take place provides another means of describing and categorizing types of responsive architecture.

One of the most influential writers in the theory of responsive buildings is Cedric Price, whose Fun Palace proposal defined *the* prototypical building capable of adapting to the needs of its users. This building, with its temporary circulation and enclosures suspended from a space frame superstructure, was intended to radically transform the experience of architecture and was a strong influence on 'High Tech' architecture such as the Centre Georges Pompidou (1977) of Renzo Piano and Richard Rogers in Paris which follows the spirit of the Fun Palace with its visible expression of independence between structure, services and skin which was intended to increase flexibility and adaptation to change over time. In reality, this approach has most often resulted only in the appearance of flexibility and despite its extraordinary influence on subsequent architecture Price's Fun Palace has proved elusive and difficult to successfully reproduce.

If the example of Cedric Price has in some way influenced most buildings responsive to the actions of users, Reyner Banham is behind much contemporary thinking about responsiveness to the weather and environment. In 1969 his essay 'A home is not a House', Banham introduced minimal environmental solutions such as the tent and the campfire as representations of a building capable of dynamically modifying its boundaries and thermal properties in response to the environment. This theoretical proposal is further developed in a vision for the future of the house as a

mobile structure reduced to its minimal environmental functions and capable of rapid reconfiguration in response to change in the exterior or interior environment. Recent art works by Philippe Rahm have explored the traces left in the configuration of interior microclimates by users and building environmental systems: in 'Interior Weather' at the Canadian Center for Architecture in Montreal, Philippe Rahm created a visualization of interior climatic variation driven by an array of fluorescent fixtures, as well as the passage of visitors through the exhibit.³

Another means of categorizing responsive architecture is in terms of rates of change, an approach promoted by Stuart Brand in his book 'How Buildings Learn'. Brand's 'Shearing layers of change' diagram, with its concentric rings of building components organized according their relative rates of change, promoted the idea that building components should be segregated according to their rate of change. 'Stuff', the furnishings and personal equipment that accumulate in buildings, has the highest level of obsolescence and a rate of change that varies from daily to monthly, while 'structure' is the most durable aspect of the building itself, the part that persists over time. Brand's diagram not only provides a convenient schema for organizing the elements of building, it also presupposes the idea that all components of the building are constantly in a state of change and was innovative in its time for suggesting rates of change as a primary organizing principle for building components. According to Brand, "Because of the different rates of change of its components, a building is always tearing itself apart" (Brand, 1995). This is a warning with particular relevance in the case of responsive buildings, which incorporate not only moving parts but also a digital infrastructure of software and hardware with a rate of obsolescence measured in months rather than years. Brand's 'Shearing layers of change' concept emphasizes the fact that new expectations for the rate at which buildings change imply specific strategies for the integration of responsive elements in the building.

4. Beyond instrumentality: the poetic functions of responsive architecture

In addition to the measurable goal of producing more energy-efficient buildings, there is also a tradition of employing responsive building components as a poetic, expressive, and potentially subversive element in architecture. The concept of interactive surfaces as an expressive element of the building has been explored in numerous installations, mostly temporary, which have explored the architectural implications of materials capable of change in response to their immediate surroundings. Rachel Wingfield's illuminated fabric installations include dynamic pieces that respond to their surroundings and offer the possibility of integration in the architectural environment. Her 'Sound reactive wallpaper' is a patterned surface that glows in response to ambient noise levels and becomes spatial in its wrapping of an interior.⁴ Jeffrey Huang and Muriel Waldvogel have described how "the tectonic and psychological effect of our surroundings can be augmented, subverted, and

¹d'Estrée Sterk (2005, p. 226).

²Sullivan (2006, p. 151).

³Rahm (2007).

⁴See Underhill (2006).

estranged by animating wallpapers and introducing an interactive, possibly darker dimension into architecture.”⁵ The interactive surfaces that they have developed in a series of interactive digital art projects introduce an unexpected, subversive quality realized through a range of innovative material interfaces such as crocheted fabric with integrated electroluminescent wires and touch sensors and pneumatic structures with integrated display screens.

In this paper I define as poetic those functions of responsive architecture whose purpose is not primarily instrumental. The meaning of poetics can be linked to that of ornament, traditionally an element of architecture without instrumental purpose or whose architectural significance had outlived an original purpose. The definition of ornament is a contested issue, and there is considerable ambiguity in contemporary uses of the term. Some theorists have insisted on the distinction between ornament and decoration: using etymology to claim a link between decoration and ‘decorum’, Bloomer associates decoration with social custom and ornament with “the timeless order and the intricate rhythms of nature.”⁶ Joseph Rykwert echoes Bloomer’s identification of decoration with decorum (“decoration implies grace and honour”), but does not insist on a strict distinction between ornament and decoration.⁷ Sir John Summerson offers a still more inclusive definition, identifying ornament with any surface treatment in architecture designed to realize specific aesthetic ends.⁸ Among these ends is the use of ornament as an articulate surface that embodies cultural meaning and informs the reading of the building as a whole. The finishing of surface materials, the color of surfaces, the built-in objects and furniture: all these are elements that can contribute to the beauty and legibility of the building. Color, texture, hardness, form, and transparency are among the qualities of surface that make up its expressive potential, its ability to inform the experience of architecture. To these qualities can be added speed, behavior, choreography: the attributes of responsive surfaces whose properties are subject to change over time.

The two buildings investigated in this paper, the Institut du Monde Arabe and the Maison de Verre, respond to change in the activities of their inhabitants and the interior and exterior environment. But, the responsive components in these buildings go beyond the needs of instrumentality in their complexity, subtlety and beauty of operation. Each building offers specific strategies for the integration of poetic responsive components in architecture, and the purpose of the following discussions is to briefly describe the approaches to designing for change represented by each building.

5. First case: mechanical adjustment at the scale of building equipment

The Maison de Verre (1928-1932) in Paris is known for its integration of multiple kinetic elements which permit the adjustment of the interior to the changing needs of its inhabitants. These elements were designed by Pierre Chareau in collaboration with Louis Dalbet, a talented metalworker who

produced full-scale models of each of the important mechanical devices in the house for evaluation by Chareau and his client, Mme Dalsace.⁹ I will first describe several of these elements and then consider their implications for the design of responsive components.

The interior is characterized by a plethora of operable devices invented by Chareau and Dalbet to serve a range of practical and poetic functions within the house. The need to control the flow of air through the facade is anticipated by providing manually adjustable louvers controlled with a system of weights and pulleys. The equipment of the interior includes retractable stairs, vertical and horizontal dumb waiters, and movable partitions operating at a variety of scales. The mechanisms of the Maison de Verre act as facilitators of frequently repeated events, and they also serve as poetic mechanical representations of these events. The mechanisms of the house trace the path of repeated movement, translating this anticipated motion into a mechanical action that constantly reminds one of the possibilities of a ritual event: the passing of the teapot, the ascent of a stair, the closing of a shade prior to taking a bath.

The mechanical inventions are part of a larger intention to graciously accommodate specific situations and events, an intention that includes the material finishes, furniture, as well as the architectonic elements of the house. So prolific are these devices and so integral to the concept of the house that some commentators have proposed considering the entire house as an elaborate work of furniture.¹⁰ The word ‘furniture’ in the Romance languages (French *meuble* and Italian *mobilia*) is derived from the Latin *mobile* - something movable, changeable, adaptable. In English, *furniture* is cognate with the act of furnishing, or *decoration*: the provision of “equipment needed for work or active service”.¹¹ This is also the word used by Le Corbusier defines in his essay ‘The Undertaking of Furniture’: “Events are unfolding, *the notion of furniture has disappeared. It is replaced by a new term: ‘household equipment’.*”¹²

Furniture is related to the state of being equipped for a particular action or set of actions. Architecture is also about anticipating and providing the necessary conditions for a particular set of actions to take place. What distinguishes furniture and architecture is in part the degree of mobility: furniture is essentially movable, architecture is (usually) fixed. This freedom of movement does not imply, however, that the configuration of furniture in a room is necessarily incidental to the overall effect and impression of the space. Which is to say that furniture itself has the capacity to take on some of the roles typically associated with architecture: the poetic expression of everyday patterns of movement

⁹Wigglesworth (1998, p. 266).

¹⁰On this topic Kenneth Frampton writes “The genre of the work itself is problematic. Are we to regard it as a building in the accepted sense or should we rather think of it as a grossly enlarged piece of furniture, interjected into an altogether larger realm? ... This precious distinction acquires greater validity once one realizes that Pierre Chareau was, by temperament and training, more concerned with interiors than with exteriors. It is further substantiated by the relative banality of Chareau’s free standing buildings.” Frampton (1969, p. 77).

¹¹Merriam Webster’s Third New International Dictionary.

¹²Le Corbusier (1991, p. 121).

⁵Huang and Waldvogel (2005, p. 172).

⁶Bloomer (2008, p. 46).

⁷Rykwert (1976).

⁸Summerson (1998, p. 215).

and events. By elevating such prosaic elements as louvers, pulleys, gears and levers to the level of poetry, the *Maison de Verre* finds a use for the mechanical in architecture that celebrates the routine events of everyday living.

This ability to accommodate daily activity and change through the design of operable building elements is different from the concept of *flexibility* as this was developed in the writings of Cedric Price or the High Tech architecture of the 1970s and 1980s. The example of the *Maison de Verre* is rooted in something older and possibly more integral to the practice of architecture: the association of a complex symbolic agenda with instrumental thinking. It is also a case in which adaptable and changeable components were made a *defining* element of the building as a whole, despite a relatively rapid rate of obsolescence due to their precise relation to a particular client and a particular moment in time.

By showing how the movable, adaptable elements of architecture can become an essential part of the building, the *Maison de Verre* provides an important precedent for responsive components in buildings. Because of their scale, materiality and relation to the human body, these movable elements are inherently *interactive*: they are designed to become an integral part of life in this house. And through their proximity to and inextricable involvement in everyday actions, these devices take on a potent role in terms of symbolic and poetic expression.

6. Second case: responsiveness at the scale of the building

The Institut du Monde Arabe (1988) is an instance of mechanical adjustment as a strategy for producing a measured response to change in the environment. One of the first buildings to include a sensor-controlled responsive facade, the Institut du Monde Arabe, is still one of the most ambitious examples of this type and an important reference in understanding the integration of responsive components in architecture.

It is the building's south facade that I will be concerned with here: light passing through its fully-glazed surface is filtered through a screen of operable diaphragms which were capable of reducing their apertures in the case of strong direct sunlight (Figure 1). The zones of the plan are distinguished more by the quality of natural light than by any other factor - each of the building's facades presents a semi-transparent veil through which light is filtered to the interior, but only the south facade incorporates automated components which respond to changes in the environment.

As a piece of machinery, the design of the south facade's 27,000 diaphragms and the mechanics of their control is not as complex as it first appears. Not all the 73 diaphragms in each panel are operable - only 57 are capable of motion. The diaphragms in each panel are controlled in two independent groups by linear actuators, each of which is associated with its own light sensor (Figure 2). In total, there are 480 light sensors controlling the same number of individually actuated groupings of diaphragms. Each panel is encased with a single pane of glass on each side, and is able to swing in toward the interior for maintenance.

The south facade was criticized at the time of the building's opening for the doubtful relevance of its rec-

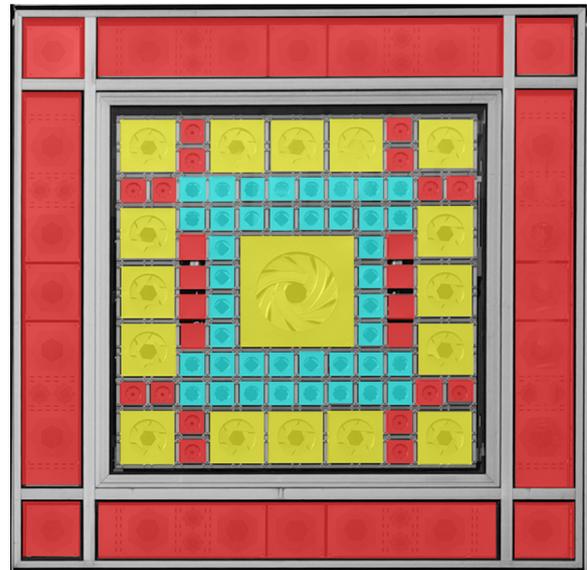


Figure 2 One of the south facade panels, indicating non-functional diaphragms (shown in red) and the separate operation of diaphragms by the two actuators (indicated as yellow and blue). Image: Author.

reation of the *moucharabieh*, a traditional form in Islamic architecture.¹³ Given the building's other facades, which are consistently precise in responding to variable qualities of light, I believe that it makes sense to assume that the primary environmental function of the south facade diaphragms was to regulate the quality of light in the library, offices and other south-facing spaces.

Unlike the *Maison de Verre*, whose mechanisms of adjustment are clearly analog, the south facade of the Institut du Monde Arabe is an example with comparable architectural ambitions that is electronically controlled and relies on sensor data and embedded computational elements. The south facade was ambitious at the time in its implementation of an electronically controlled mechanism on such a large scale. The sheer number of light sensors used to control the panels, and the fact that the surface is divided into as many individually functioning parts, indicates a desire for precise and local registration of light levels across the facade. Rather than changing all panels at once in response to a general shift in solar illumination, each panel was intended to operate with complete independence from the others, revealing a map of local variation in light levels across the facade.¹⁴ This variation in the performance of

¹³As Sakher Farzat, speaking of the relation of the facade to Arabic architecture, Boissière (1988, p. 16) "Un autre aspect de cette prétendue influence de l'architecture arabe sur l'Institut est la référence aux moucharabiehs dans les pans de fenêtres de la facade sud. Bien que le choix du motif soit satisfaisant, cette idée ne répond ni à l'esprit ni aux règles fondamentales de l'architecture arabe, ou l'usage du moucharabieh est lié aux conditions climatiques environnantes, à savoir la protection contre les rayons de soleil qui laisse cependant transparaître la lumière."

¹⁴It is apparent from Nouvel's statements that the operation of the panels in response to the sensor data was critical to his conception of the facade (Vonier, 1995).

each individual panel would have been noticeable from the interior, particularly in spaces like the library where large expanses of diaphragms were visible at once; and particularly from the exterior, where the entire facade can be seen and where the differences in the openings of each panel would have presented a pattern responsive to changes in solar illumination. This is the experience that I believe the south facade was designed to produce: the recognition that the automated mechanical motion of the south facade's myriad diaphragms was responsive in a very precise and immediate way to changes in the environment.

This kind of responsiveness is different in character from that of the Maison de Verre, most obviously in its automation: while the mechanisms of the Maison de Verre were operated by hand, those of the Institut du Monde Arabe were motorized and provided no possibility of user control. More importantly, the diaphragms of Nouvel's building presented the appearance of intelligence in their automation, an appearance which required the multiplication of sensors across the facade. This aspect of the facade's behavior was symbolic as much as it was functional. While the panels did serve an environmental function in their modulation and control of natural light, the complexity of the facade can best be explained in terms of an elaborate exploration of the poetics of responsiveness.

There is one aspect of the Institut du Monde Arabe that is fully consistent with the Maison de Verre. Just as many commentators on Chareau and Dalbet's masterwork have observed that the entire building is a kind of elaborate mechanism, so the south facade Institut du Monde Arabe was conceived as responsiveness at the scale of the building, as though the building itself had become a sentient creature capable of movement and intelligent behavior.

No discussion of the south facade is complete without acknowledging that the diaphragms failed to function as intended. It is not clear what part of this problem was due to faulty design and what resulted from a failure of the

client to properly maintain the complex mechanism. Litigation over these questions began even before the building was completed. Wherever the blame may lie, within three years of the building's opening in 1988 the diaphragms were controlled centrally, bypassing the 480 sensors embedded in the wall; and within six years the diaphragms had ceased to function entirely. Although an inadequate maintenance regime was surely part of the problem here, it is also evident that greater attention to the long-term viability of the mechanisms during the design process could have contributed to the lasting performance of this remarkable responsive facade (Figure 3).

7. Conclusion

The two buildings considered in this paper each presents an example of responsive building components conceived as an integral part of a culturally significant work of architecture. In this way, they are representative of a rare phenomenon, and suggest an alternative paradigm for understanding the relation of such responsive components to the building as a whole. Each building represents a different type of responsiveness, and (more importantly) a different approach to designing for change and integrating responsive components in the building as a whole. It is this latter aspect of the two examples that I will focus on in conclusion.

Given the reduced cost and increased effectiveness of embedded computing and dynamic building components over recent years, it seems inevitable that ever more buildings will be designed with components that respond to change in terms of use and the environment. The success of these buildings as works of architecture will depend in large part on how their designers learn from the architecture of the past to inform new challenges in the future. The two buildings considered here each contribute to this dialogue and to a growing list of examples of designing for change.

In Stuart Brand's 'Shearing layers of change' diagram, what he terms *stuff* and identifies as furniture and personal equipment is that part of the building with the highest rate of change and obsolescence - it is the equipment which supports activities and events, the things one touches and interacts with on a daily basis. This usually mobile equipment is ideally suited to interact with and shape the rituals of daily life, and the primary contribution of the Maison de Verre to the future of responsive building is in demonstrating that equipment can become an integral part of a poetic work of architecture. This re-imagining of architecture as a robotic machine is also a rethinking of the building as responsive to the patterns and flows of everyday living. And, by making a conceptual and practical distinction between the responsive elements of the building at the scale of equipment and the 'stable' elements of the building at the scale of structure, the Maison de Verre acknowledges the 'shearing layers' which in Brand's view threaten to tear the building apart if not adequately considered in design. Speaking of this building Mohsen Mostafavi writes "... it is hard to make a distinction between the rooms and their furniture; there is continuity and fluidity between its spaces and the design of elements such as staircases, bookshelves, and bathroom fittings, which are more akin to pieces of

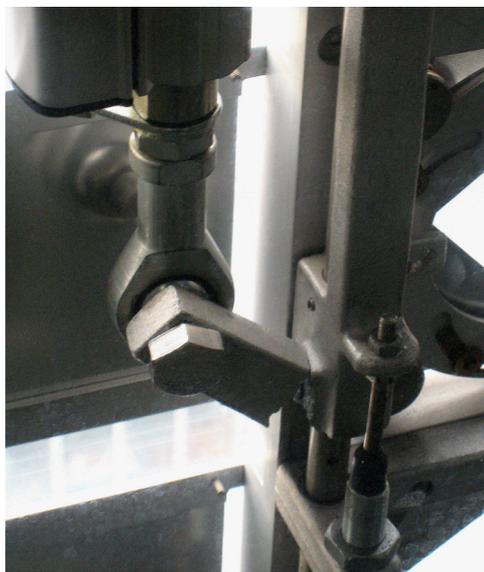


Figure 3 Mechanical diaphragms - image showing damage to the arm that transmits the force of the motor to the diaphragm actuation mechanism. Image: Author.

equipment than furniture.”¹⁵ If we take this example as a model for future responsive buildings, the work of the architect may in the future be as much about the design of equipment and devices as it is about the sculpting of space and the crafting of materials.

The fact that rates of change and obsolescence are ignored at one's peril is one of the primary lessons for future responsive buildings of the Institut du Monde Arabe. Seen from the building's courtyard, the IMA's wall of mechanical diaphragms is a monumental display of technology that, in light of their widespread failure, can easily be seen as a hugely expensive gesture doomed to failure by its own hubris. Speaking of the example of the Institut du Monde Arabe Frederic Kaplan has written that “The time-frame of electronic devices and that of architecture is not the same. Although the dream of a house that integrates ‘all modern technology’ continues to fascinate, it is perpetually surpassed in reality by the rapid and flexible innovation cycles of devices. In the long term, it seems ever more relevant to live *with* machines than to live *in* a machine.”¹⁶ There is perhaps another side to these devices: the individual panels are at a scale that relates to that of the human body, with the central oculus roughly at eye level - it appears that the diaphragms, when functioning, would have acted as a constantly changing screen or filter between inside and outside, one which related directly to the scale of the human body in its interaction with the building. Their performance as building equipment at the scale of the human body is thus more nuanced and powerful, as well as more present in the everyday experience of the building, than the exterior view usually associated with the building.

To return to the opening question of this paper, one reason why there have not been more examples of poetics in the design of responsive components is surely a dearth of examples, both positive and negative. It is becoming clear that to design for change architects must develop a deep understanding of multiple types of change in buildings, and this will surely have a positive effect in terms of identifying significant precedent for the design of buildings that intentionally change over time. The rate of change, the scale at which change happens, and the type of change (weathering, mechanical adjustment, interior reconfiguration, shifting use) are all potential factors in the design of

responsive buildings. Examples like the Maison de Verre and the Institut du Monde Arabe can be studied as lessons in the benefits and dangers of particular approaches to the design of responsive buildings, examples that will become more important as it becomes increasingly common to include robotic, responsive components in buildings of cultural and architectural significance.

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¹⁵Mostafavi (November 2008, p. 9).

¹⁶“Le temps des objets techniques et celui des architectures n'est pas les mêmes. Même si le rêve de la maison intégrant ‘toute la technologie moderne’ continue de fasciner, il est perpétuellement dépassé par les pratiques rapides et flexibles d'innovation par l'objet. Sur le long terme, il semble toujours plus pertinent d'habiter *avec* les machines, que d'habiter *dans* une machine.” (Kaplan, 2009, p. 201).