OVERVIEW OF INTELLIGENT ARCHITECTURE

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Abstract: The concept of intelligent architecture started as an interest in the latest integrated building systems operating a single building or facility, so that systems can communicate and exchange information. The communication among these systems allows the right responses and decisions to operate buildings in a productive, economical and convenient way. Communication and information sharing prevents decisions from interfering with other systems' responses or operation. Systems' decisions and responses form the responsive architecture that is represented by systems outputs.

If intelligent buildings need to receive, analyze, and react according to such processes, responsive ones are required only to receive and react to only one input parameter. Technology and communication systems make it possible to combine several parameters by using system integration and computerization. Technology and computerized systems have enhanced and changed the manner of responses and provided a variety of decisions according to different sources of information.

Receiving, analyzing, and reacting are the key criteria of intelligent building that this paper will explore. The input (reception) category covers information detection devices such as temperature sensors. The second category will be the category of analysing devices. The third category, decisions and outputs, will cover both output of sensory devices and forms of reaction and response that emanate from these systems. As a result of the third category, this paper will survey the forms of responses to determine whether or not the kinetic response is a viable choice. The paper will discuss if these three criteria are the only criteria creating intelligent building or if there are others.

The paper will give an overview on intelligent architecture and explore in the main criteria determining intelligent building. The paper will then discuss when "responsive" and "kinetic" architecture becomes "intelligent". The paper will also redefine the intelligent architecture in the light of available technology.

1. Introduction

Since the 1970s, computer and telecommunication technology have been changing human life. These changes have outpaced the theories guiding such technologies. In the1990s, social and personal life has been affected by computers and telecommunication by making distance irrelevant. Physical spaces and their definitions, as human aspects, have also been affected; meeting rooms, for example, have become virtual as their physical elements have been computerized. This is simply integration between the computer's abilities and the physical world. Through this integration, physical objects and spaces considered as intelligent. Integrating computer to the physical world gives the physical world computer thinking ability. Computers have the abilities to receive information (input), communicate with other machines, transfer information, process information, calculate, and produce results (output); in short, computers can "think."

Buildings are technology, they accommodate technology, and they use technology. Buildings as objects become intelligent in the moment of gaining computer ability. The first intelligent building used technology to provide a comfortable, secure, and energy-conscious environment. The intelligent building concept offers the connection and integration of HVAC, access, lighting, security, monitoring, management, and telecommunication. Integration gives these systems the ability to communicate and transfer information. Communication among these systems allows output decisions to happen without conflict. Outputs or systems' decisions, on the other hand, are systems responses for input information coming from different sources. Outputs or systems' decisions are the basic needs in architecture to be considered as "Responsive Architecture".

This paper gives an overview on intelligent architecture, in general, and discusses when "responsive" and "kinetic" architecture becomes "intelligent". The paper will also redefine the intelligent architecture in the light of available technology.

2. Definitions of Intelligent and Smart buildings

The concept of intelligent building presents the strongest level of communication among a building's systems. The term "building systems" refers to all systems that operate a building like HVAC, mechanical, structural, access control, safety and security, building management, lighting, maintenance, local networking, and energy management. The intelligent building concept presents control and management by a building's systems and users using computer abilities to achieve users' needs, which may include productivity, efficiency, energy savings, entertainment, delight, and comfort, return investment, and low life cost.

So, defining intelligent building should not be related to specific achievement because required achievement can be changed from party to party. The intelligent building should have the same operation concept that has the ability to be adjusted according the different needs.

Scholars have defined “intelligent building” in terms of a building having the latest technology, so they consider a building to be intelligent when it has the latest building systems. Although innovation is very important in intelligent building; it doesn’t mean that there is the necessary communication and integration among systems that can render a building intelligent. For example, the International Symposium, 1985, in Toronto, states that “intelligent building combines innovations, technological or not, with skilful management, to maximize return on investment.” This definition contains, in addition to innovations and technology, needed achievement that is "maximize return on investment". It is an achievement that may be needed by commercial and office buildings, but it may not be needed by houses, unless we consider people’s delight and comfort as an investment. In addition, other achievements that are important for commercial/office buildings, like users’ productivity and comfort, are not mentioned in the definition. Defining by stating the needed achievements is clear in EIBG (European Intelligent Building Group) definition that says "the intelligent building is the one that maximizes the efficiency of its occupants and allows effective management of resource with minimum life costs.” Efficiency and productivity are intangible; they can be determined by comparison of other or previous records, and minimizing costs is an achievement that can be reached by operation systems.

Bob, 1996, on the other hand, defined a smart building as “a building which can include the technology to allow for devices and systems to be controlled automatically.” This definition shows basic process in operating intelligent building that is transferring information between controller and controlled devices. operation process is clear also in (DEGW), (1998) (the architecture of Duffy, Eley, Giffone and Worthington) definition that says “intelligent building is more responsive to user needs and has the ability to adapt to new technology or changes in the organizational structures.” The definition mentions very important criteria and operation process. "Responsive" in the definition represent systems' outputs; "to user needs" in definition presents the ability to know "the needs" by inputs sources "user". "Adapt to" shows the ability to adapt either by itself or by others.

Atkin (1988) defines intelligent building as a “building that knows what is happening inside it and outside it and can decide the most effective way to create the right environment for users on time.” Atkin in this definition is adding to the ability to know (input) and the ability to respond (output), the time factor. Responding on time is essential in an intelligent environment; most outputs or responses needed in certain time and it will be invaluable in any other time. “Knows” in Atkin definition covers the received information (input) and the media by which this information (input) is received and collected. “Decide” covers all types of responses, like adjusting temperature and adapting building form that represents the system’s “output”.

The evolution of telecommunications and electronics has expanded the capabilities of intelligent building systems. Integrating learning ability that includes the adaptability mentioned by DEGW definition, (1998) of intelligent systems should make systems able to learn from their experiences with similar cases reaching to optimum solution. In addition to the learning ability, information transferred between systems should be processed and analysed in Building Control System (BCS) that woks as building brain. The goal should be reaching to an optimum solution.

Accordingly, the basic criteria by which the building needs to have to be considered as intelligent are:

- Input system that receives information by means of information receiver.
- Processing and information analysis
- Output system that reacts to the input in form of a response.
- Time consideration that makes the response happen within the needed time.
- Learning ability

The definition of intelligent architecture should therefore include all of these criteria and systems. These criteria will be discussed in order to clarify their contribution to intelligent architecture.

3. Inputs

Each system in the intelligent building should have a means of collecting input information. Systems can obtain information in four different ways: sensors (real time), internal backup and restored information, manually entered information (programming and reprogramming) by users, and by being connected online (Internet).

3.1 SENSORS

Whenever we discuss intelligent architecture, we should start with sensors. They are the means of getting all type of data and information to systems. Sensors are simply detection devices that collect information and data internally and externally. Internally where they allow system to perceive even its condition and externally where they detect and receive information from out of system environment in real time.

Sensors are divided into three groups that cover both interior and exterior environment. Detection solar radiation, security and surveillance, noise pollution, and façade optics and colour change, for example, are some of exterior sensors controlled systems. Systems like energy, air control, lighting system, and air-condition controlling use interior sensors to reach intelligent architecture goals. The three groups are:

3.1.1 Security and Safety Sensors

Security, safety and surveillance sensors serve interior and exterior environment.

a. Fire and smoke detection
b. Photo optics
c. Access
d. Acceleration, shock, and vibration
e. Motion and human presence

3.1.2 Weather and Space Quality Sensors

f. Temperature
g. Humidity
h. Solar Radiation
i. Pressure
j. Light
k. Flow (Liquid and Gas)
l. Air Contents
m. Moisture
n. Chemical measurement

3.1.3 System Monitoring Sensors

o. Structural system monitoring
p. Mechanical system monitoring like (HVAC system)
q. All other systems that require monitoring

Sensors work as a nerve system for a building so it can feel and determine the reaction to internal and external conditions.

3.2 INTERNAL BACKUP AND RESTORING

Any system within intelligent package should have the ability to back up and restore cases and information. Restore covers, for example, scheduling scenarios in meeting room where the room needs to be connected online and air-conditioning needs to be set at 75 degrees Fahrenheit at a specific time, so the system should be able to able to recall previous settings and reset them. Internal backup system should work as memory in the intelligent system.

3.3 MANUAL PROGRAMMING

Systems are supposed to accept manual programming by users. At any time, a user (authority/administrator) should have the ability to reprogram the main system according to new circumstances.

3.4 INTERNET

Connecting all systems to internet gives them the ability to be updated and get online information from different companies. Most computer systems and drives have updates and companies provide these updates online, so for system to be updated and perform well, it should be able to communicate with different companies to update their drives. All data collected will be delivered to the data processing application.

4. Information Processing Application and Analysis

Information processing is performed in the building control system (BCS). BCS controls all systems as one unit and controls each system individually. It is the place where all systems integrate; it is called building system integrator (BSI). For systems to be integrated, they should have addresses that other systems recognize.

5. Outputs (Responses)

Outputs of BCS come as orders to the systems according to the decision. These decisions form systems’ responses and can take at least two different classes: internal and external response. Internal and external responses are related to system. The internal is the class of response that covers all internal reactions and responses. Calculation and internal programmatic responses within the system are examples. Another example of internal response is an intelligent structure that can react to wind load by internally changing its tension. External response is the result of internal responses formed according to processed information.

An external response can take two forms: static and kinetic. A static external response can be in form of temperature, visual, audio, or/and light change. A kinetic response, on the other hand, comes in the form of movement; when a system decides to open or close a door, for example, it is considered as a kinetic response; “responsive architecture” responds to its users. In the following paragraphs I will discuss the kinetic and responsive architecture concepts.

5.1 RESPONSIVE ARCHITECTURE

Responsive Architecture is any architecture that has the ability to respond to users needs. It does not have to be intelligent unless the responses are result of an intelligent process. An adobe wall, for example, responds to outdoor temperature where it keeps cold air in the house when it is hot outside. It is a material property; it is not out of an intelligent process. The result should be according to information and data received and processed to be considered intelligent.

Some of the definitions of responsive architecture show that the term presents a specific form of response that is (kinetic respond). Fox (2003) says that “the core in responsive system is that the mechanical structures and how to implant them with interactive and intelligent behaviors.” But what if the responsive system response statically like in temperature or color change. Sterk (2003) also defines responsive architecture as “a class of architecture that demonstrates an ability to alter its form, to continually reflect the environmental conditions that surround it.” While altering the form is just a response type, the responsive architecture term is missing the term “intelligent” to represent this type of response (kinetic) and it should cover all types of responses in architecture.

So, intelligent responsive architecture is all spaces/architectural elements that have the ability to respond intelligently to the exterior and interior environment and to users’ needs.

The type of response that is represented in Fox and Sterk definitions for responsive architecture (kinetic response) is taking intelligent architecture a step further. The next paragraph discusses this type of response.

5.2 KINETIC ARCHITECTURE

The kinetic concept originated in art. Artists at the beginning of the nineteenth century started to make their sculptures that reflected movement. The “wooden merrier” by Daniel Rozin in 1999 is an example of kinetic art that uses electronic technology. The kinetic art has been also introduced in architecture as art pieces in building and sometimes within the building; Ralfonso (2004) (Figure 1) gaves examples of kinetic art that merge in architecture; a sculpture like ExoCentric Spirits that is suspended in indoor space (http://www.ralfonso.com/exocentric_spirits.htm).

Figure 1. ExoCentric.

In architecture, kinetics has been used by nomadic tent-dwellers. The tent is a kinetic structure since people can fold it up and carry it. The kinetic structure as a folding and portable system is still seen in kinetic architecture. Fox (2000) for example, defines kinetic architecture as “a building with variable location or mobility and/or variable geometry or movement.” He was describing various types of kinetic systems; one of which was the folding system. So the kinetic concept is not originally an intelligent one, but it represents the ability of controlling the structure by moving part or all of it.

The new direction is to introduce the kinetic concept to the intelligent as one of the responses that may alter the form of the building. Calatrava gave some examples to apply movement to building. Regardless of the function of Calatrava’s kinetic applications, his contribution shows the possibility to have moving form; the roof of the Milwaukee Museum, for example, can be moved and changed (www.calatrava.com).

The next step starts with the definition by Oosterhuis (2003), which states that kinetic architecture “refer[s] to a building that [is] controlled by sensors-actuators system to be able to respond according to the data received in form of movement.”

5.2.1 Control Mechanism in Kinetic Architecture

To understand intelligent kinetic architecture, I will explore different types of controls and how manual/traditional control can become intelligent. There are three main control mechanisms for kinetic architecture: inner, outer, and composite. The system, in inner control, is divided into small parts that give it the ability to alter its parts; a folding system is an example. The outer control is the ability of the system to be moved either by itself or by the power of other source. It can be seen in partition walls that can be installed and removed. Composite control merges the inner and outer ones to have a system that is able to alter its form internally and to move its mass as whole. The inner, outer, and composite controls are mechanisms that give any structure the ability to alter its form; they are supposed to be controlled manually. Manual control can be intelligent. The following are

1. Direct Control:

   Movement and control come as a result of direct source; the source includes all energy outputs like electrical motors and human energy. Moving a skylight by direct on/off source and portable partition are examples of this type.

2. Input Control:

   Input device is needed in this type of control. The movement comes as a result of this device feedback; sensors and programmed system are examples of these means of devices. The sensor, for example, should affect the system directly in a singular self-controlled response.

3. Multi Input Control:

   The control and the movement in this category should come as a result of multiple input devices; multiple sensors can be these devices that receive data from different sources to get the optimum decision.

4. Ubiquitous Multi Input Control

   Many autonomous sensors/actuators acting together are required in this type of control. The movement will be a decision of analyzed input out of sensors (input device) reflected on actuator (output device) to respond (output). The whole surface can be dynamic in such control; the surface can be building envelop.

5. Intelligent (Multi-input) Control

   The system in this category integrates learning ability in its control mechanism. The system will learn from experiences in trying to reach the best solution.

Time consideration is one essential factor that should be available starting from direct control. Depending on advanced computer control technology and the ability of manufacturing high quality kinetic part, intelligent kinetic architectural solutions can be both effective and feasible.

5.2.2 Sensors in Kinetic Architecture

Kinetics in architecture can be as simple as opening a door or window and it can be as big as moving a structure. Kinetic response is one of the possible decisions in BCS responses. To refresh room air quality, for example, the system may decide to start filtering or turn ON an air-conditioner, but it should be available as option to open window and get some fresh air if it is appropriate. Building envelop can use sensors and actuators to respond by movement. The Hyposurface by dECOi is an excellent example for kinetic envelope and inner controlled architecture element where a faceted metallic surface (wall) deforms physically by responding to the surrounding environment. It responds to movement, sound, and light as a result of real-time calculations (Figure 2) (Oosterhuis, 2003).

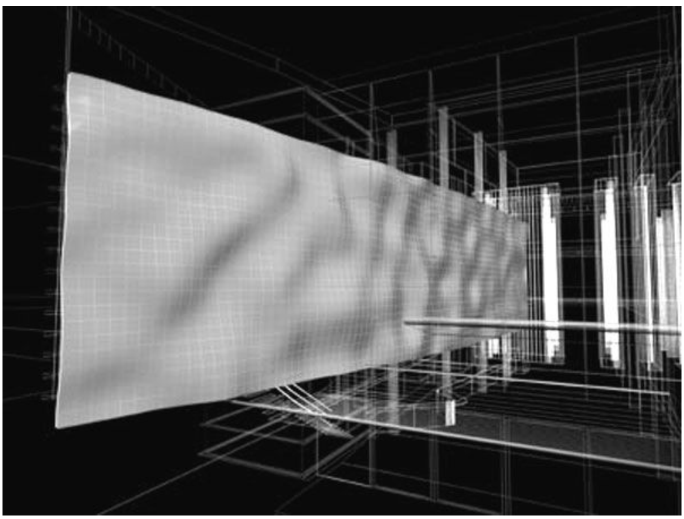

Figure 2. Hypersurface, 1999.

A structure can also use sensors to report its conditions and maintain problems like standing against wind load by increasing its internal tension using actuators. For example, chemical and physical data in concrete can be collected now by micro-electro-mechanical systems (MEMS) sensors. This sensor can be embedded in concrete to measure pH, moisture, temperature, and concentrations of chloride, sodium, and potassium ions (Snoonian, 2003). Some electronic companies like SIMENS use micro-electro-mechanical system (MEMS) to control systems.

6. Time Consideration

As intelligent criteria, time is critical for an intelligent system, where all responses and decisions must happen at or within the required time. For example, fire alarms should start on time, maintenance systems should report problems on time, and buildings should rotate to avoid sunlight on time. Sometime the system underestimates, during the analysis stage, some received information that may delay the response. Smoke from a fire, for example, may analyzed as cigarette smoke at first, but the system recognizes it is fire smoke after a while; at this point, the system must be able to adjust its sensitivity and analyzing process to respond to fire smoke next time. This can be called learning ability.

7. Heuristics (Learning Ability)

Heuristics can be defined as a set of rules that increases probabilities of solving a problem. Conceptually, it is about the ability to learn from experience. Adjusting decision time is an example of reprogramming and adjusting the system sitting on the basis of new information; information can come from people or sensors. In a meeting room, a system can feel the increasing number of people, so it reduces the temperature from 75 to 65 degrees Fahrenheit to overcome the heat of 20 persons and then the authorized person reduces it to 58; the system should realize that its calculation was not very accurate. With 30 persons, the system should calculate the heat of each person according to the last experience. The ability to learn is very critical in case of fire and maintenance.

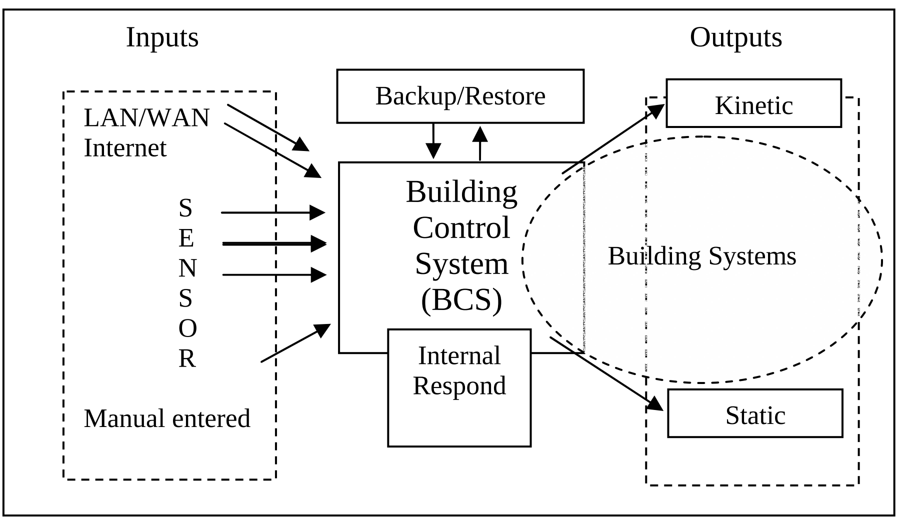

Figure 3. Intelligent System Anatomy.

Learning ability is the fifth criterion of an intelligent system and gives the opportunities to discuss some architectural examples of the new generation of intelligent architecture. Figure 3 shows intelligent architecture anatomy that combines most intelligent criteria.

8. Kinetic Architectural Examples

It is very interesting to discuss available buildings using the kinetic concept.

8.1. ROTATING HOME

The first one is called “Rotating Home”; it is exploring kinetic envelop as outer control. The building can take any shape in design; using a motor, the building rotates 360 degrees. It works in direct control concept where rotation starts and stops using an on/off switch. Conceptually, all walls in this house can change their location. The reason for rotation is to change the view. It rotates 100 times in one direction and 1000 in the other direction with all utilities fully functioning (Figure 4) (Johnstone, 2002).

Are there sensors in the building?

There are sensors in this house to detect leaks, thus notifying the home owner prior to any fluids or gases mixing (Johnstone, 2002).

Figure 4. Rotating home.

Whenever the owner needs any exterior view, s/he can get it; the problem will be direct control that can be enhanced to be fully intelligent by planting sensors to get the input information to respond to users’ needs. Sensors rotate and change bedroom location to avoid sun, heat or light; noise on the other hand can be avoided and view at certain time can be seen from specific spaces in the house. Such a house needs 24/7 follow up and check for control systems; mechanical, plumbing, and electric system, in addition, to other systems should be fully integrated to report any shortage on time.

8.2. REVOLUTIONARY (SUNSPACE) DOMES

Patrick Marsilli started the idea of the revolving dome in 1986, and developed the first dome as a basic idea for others like Albert Warson to develop.

The dome (Figure 5) can be built out of wood, lightweight concrete, or steel, so it rotates 300 degree. A one-horsepower (745-watt) motor drives the turntable. All mechanical systems rotating the dome are grouped in the central area. The rotation can be controlled by direct control that may be reflected by on/off switch. It can be controlled by programming the systems to avoid sunlight (Warson, 2002).

Figure 5. Revolutionary Dome.

The example promises to have kinetic architecture. By input control, the building change orientation; this building is more solid in its idea in terms of reason. The reason of rotation for the builder is sun radiation and heat avoiding. The shortcoming in this project comes out of rotation range and mechanism. The range is only 300 degrees that may reflect the reason of rotation. The rotation mechanism is programmed into the system; having a device to detect the sun's movement and heat will make the movements of the building more accurate. Devices can detect the sun and determine whether or not the building needs to be rotated.

8.3. BLUR BUILDING

Discussing kinetic architecture should recall the attempt of Diller and Scofido to have a building constructed of different materials, a building called 'blur pavilion'. They constructed a metal building that sprays countless tiny drops of lake water from thousands of jets. The fleeting sculpture will be even in rain by high-pressure spraying technology as mass of fog that changes from minute to minute (Figure. 6) (Scofidio & Diller, 2002).

They gave the basic idea of liquid form in architecture that is supposed to respond and be formed according to its and users' needs. They used computers to adjust spray strength according to the different climactic conditions of temperature, humidity, wind speed and direction.

Figure 6. Blur Building

9. Conclusion

An intelligent building is therefore a building that has the ability to respond (output) on time according to processed information that is measured and received from exterior and interior environments by multi-input information detectors and sources to achieve users' needs and with the ability to learn. Having specific achievements in mind to reach by intelligent building is very important to know before programming the system. The actual need of intelligent building can clear by looking to the result and requires needs that can be accomplished out of such system. Productivity, for example, is essential need for all companies; the environment in the office spaces can determine large factor of being productive as employee or not. As very simple example, in my office, I can't work for more than 3 hours continuously just because of low temperature. Feeling cold to a degree of leaving the office to an outdoor area to gain some sun heat for ten minutes and then go back to office. The maintenance decided to send the technician almost daily to check with people and higher the temperature. The waste in work time because of air conditioning is decreasing the level of productivity in the work that is wasting resources of any company.

The achievements that can be reached by having intelligent system cover most human life aspects. Productivity, efficiency, energy savings, entertainment, delight, and comfort, return investment, low life cost, and increase building life are some examples of these achievements.

Intelligent building should have nervous system consisting of embedded sensors and actuators that control most real time information. Accordingly, the building will have the ability to react statically and kinetically. So, altering the form and maintaining building body internally and externally will be some examples of building abilities. The nervous system represents integration among all systems, so intelligent building will be liquid form that changes according to surrounded environment or/and its current mode. As human, users should able to know if the building happy, sad, sick, or relaxing. The building, on the other hand, should be able to recognize users' mode and act according to their modes.

According to definitions of deferent used terms, it should be clear that Responsive architecture include any spaces, building and architecture elements that respond to users' needs. Responsive architecture should not be limited to one or two forms of responses; it should cover all forms of responses static, kinetic, internal, and external. Additionally, the Responsive Architecture is necessary an intelligent architecture unless that the respond is a result of intelligent process.

Kinetic Architecture is not intelligent unless that the kinetic is a result of intelligent process. The tent is kinetic shelter that can be folded and transferred. The new intelligent architecture should have all type of responses that serve its function.

References

Culshaw, Brian: 1996, *Smart structures and materials*, Artech House, Norwood, MA.

dECOi: aegis: 1999. Hyposurface, autoplastic to alloplastic, *Architectural Design*, Sept.-Oct. 1999, pp. 60-65.

DeMaria, Michael J.: 2002, *Home Smart Home*. http://www.networkcomputing.com/1301/1301f33.html

Fox, Michael: 1999, Intelligent Kinetic Systems, In Preparation for MANSEE 99: *1st International Conference on Managing interactions in Smart Environments*, Dublin, Ireland. http://www.architectureweek.com/2002/0918/building_1-1.html

Johnstone, A. and Janet: 2002, *Maximize Your View with Rotating Home*. http://www.rotatinghome.com/

Oosterhuis, Kas: 2000. Peaux reactives = Smart skins for the hyperbody, *Techniques et Architecture,* Apr. - May 2000, pp. 88-94

Oosterhuis, Kas: 2003, *Hyperbodies: Towards an e-motive architecture*.

Ralfonso: 2004, Kinetic Art, http://www.ralfonso.com/exocentric_spirits.htm

Scofidio, Ricardo and Diller, Elizabeth: 2002. Blur: *The Making of Nothing*, Abrams.

Snoonian, Deborah: 2003, *Nanometers? Tiny sensors embedded in concrete will collect physical and chemical data*. http://archrecord.construction.com/features/digital/archives/0404dignews-1.asp

Sterk, Tristan: 2003, Using Actuated Tensegrity Structure to Produce a Responsive Architecture, *ACADIA 2003*.

Warson, Albert: 2002. Revolutionary Domes. Architecture week 18 September,