The Office of Robotic Architectural Media,
Bureau for Responsive Architecture
The School of Interactive Arts and Technology
at Simon Fraser University
Surrey, British Columbia, Canada

CAAD for Responsive Architecture

by Tristan d'Estree Sterk

Introduction

In the late 1960's through to the mid seventies a dramatic turn took place within architecture. Questions about the success of modernism and a looming energy crisis caused architects to search for new design methodologies to make buildings that better fit the needs of society. Amongst others, Gordon Pask, Cedric Price, Nicholas Negroponte, Yona Friedman and Charles Eastman explored the role that computers could play in satisfying this goal. Nicholas Negroponte proposed that three distinct roles would result: roles of improving design documentation systems, generative design systems, and finally a role in developing intelligent spaces into which computers are embedded. [1]

Many years later in 2005, while working at Skidmore Owings and Merrill, I recalled Negroponte's words at a talk by Robert Diamant, a former managing partner of the office. [2] Robert spoke of the changes that he witnessed throughout his career. He provided a vivid picture about how computers shaped the discipline by giving it a new series of design tools; tools similar to the documentation and generative ones mentioned by Negroponte. From these tools two significant developments changed our profession. Firstly computational tools enabled architects to design for a new type of client – the developer – a client whose needs could only be satisfied by mastering rapid design development, testing and documentation procedures. Secondly the rapid design processes that computers enabled opened the door to completely new methods of working. Skidmore, Owings & Merrill responded to this by building new types of design methodologies suited to quickening design processes and different studio arrangements. By dissolving traditional barriers, SOM did away with the traditional separation between conceptual and technical design processes. Interdisciplinary teams became the norm and new more technically sophisticated designs emerged. [3]

Architecture isn't static. New pressures are introduced into design when social and technological values change. Innovation and advancement occurs when these pressures are answered in new ways. [4] It is under this light that the positive and negative aspects of building processes become visible, especially as the needs of society outgrow and come into conflict with older buildings and design methodologies. As such one can say that even though today's buildings work well, they aren't perfect and they often needing adjusting and replacing.

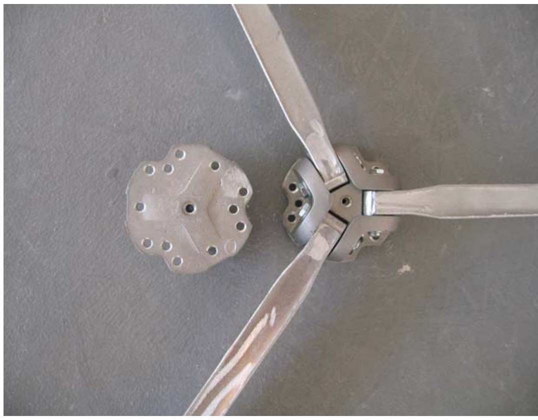
A full-scale prototype of an actuated tensegrity structure for use within a responsive building envelope. This prototype was built from cast aluminum pieces that were first rapid prototyped from form•Z models. The structure is programmable and responsive to its surrounding environment. In the photograph above the structure is not yet clad.

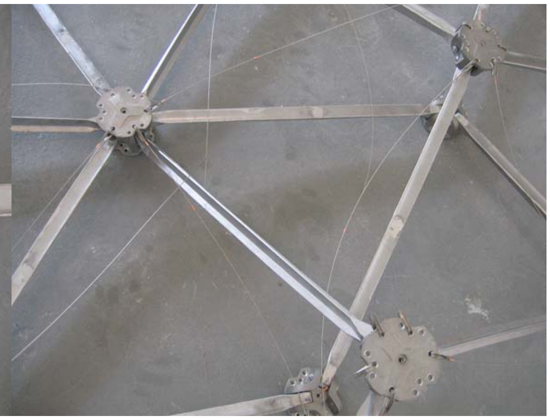
On top of this other significant problems have emerged. Very serious environmental issues now face our societies. Edward Mazria [5] provides a brief summary of the relationship between architecture, energy and the environment in a paper called "It's the Architecture Stupid!" [6] Mazria says that energy use within America can be accounted for within three basic sectors, the architectural sector, the transportation sector and the industrial sector. The architectural sector consumes 48% of all energy used, while the transportation and industrial sectors consume 27% and 25%, respectively. Furthermore the architectural sector generates 46% of the America's annual CO_2 emissions, a figure that is set to rise and that is already double that of any other sector. If these trends spread to encompass cities around the globe the architectural profession must come to address its impact. As such, the primary duty of today's architects must be to reduce energy consumption within building practice. Architects must learn how to use fewer materials more intelligently to produce environments that help people live in more sustainable ways.

Reasons for Supporting Responsive Architecture

Responsive architectures are those that actively change in response to new environmental conditions and patterns of use. But more than being a series of smart systems attached to a dumb building frame, responsive architectures actually consist of intelligent frames, skins and systems. [7] These buildings change shape and color. They have intelligent systems within them and around them. They track the sun gradually and they adjust their shape to improve shading in the summer or day lighting in the winter. They shake snow from their roof. They even change shape to reduce wind loads or improve the way they ventilate. [8] But most importantly responsive architectures provide architects with ways to produce more sustainable buildings. Unlike the conventional boxes that we live in, these buildings adapt to the natural environment to improve the way that people live. They address suitability and socio-technical issues in three key ways. Firstly they provide a means to reducing the mass and embedded energy used within buildings without sacrificing robustness. Secondly they enable architects to produce a new class of building envelopes that actively adjust and shape themselves in relation to the natural environment, its seasons and weather. With this they offer great potential in reducing the energy used within buildings. The third, less quantifiable benefit that responsive technologies bring to architecture is that of a new aesthetic. Like modernism this aesthetic is the product of the way systems are assembled. The systems within responsive architectures operate very differently from conventional architectures. They bring a series of new design strategies, formal tendencies, and grammars to the discipline. The impacts that ultra-lightweight and responsive systems have upon building design are substantial. Yona Friedman reminds us about the impact that such changes have upon our tools when he said that as the tasks of architecture change so too must its methods. [9]

We are practicing at a time when static and unintelligent building technologies are being superseded by intelligent systems. As architects we must realize that, for the first time since the rise of modernism, shifts within the profession are being driven not by the mastery of industrial tools or machines, nor by the challenges of effective computer use, but by the very real need for us to stop harming the natural systems that support our existence. Importantly these new technologies enable architects to re-conceptualize building processes and also revisit the older tacit knowledge that architects draw from. The age-old knowledge that the shape of a building is intimately linked to its performance can now be understood, realized and advanced in very new ways. The impact that these changes will have upon architectural design will be profound. Going back to Friedman we must realize that this change will result in revisiting the tools and design methods we use to produce buildings. Computer aided architectural design (CAAD) systems must be a part of this process – a point emphasized within Ganapathy Mahalingam's recent article entitled "Model behaviour" [10] Five Features for Supporting Responsive Architecture:





CAAD systems describe architectural form. Some describe the interchange between form and environment. Others describe the parametric relationships between members while others-still describe the forces that structural members carry. Responsive architectures are not adequately described within conventional CAAD systems because the assumptions that conventional systems make prevent sound responsive models from forming. Though beautiful and very evocative the models produced within conventional systems simply do not translate into working responsive buildings or systems. Five key features for the production of these systems are now discussed.

ONE) **Enabling Design with Variable and Controllable Rigidity**:

The fundamental requirement from which all responsive architectures are built is that of variable and controllable rigidity. Responsive structures, be they frames or skins, alter their shape and structural characteristics most effectively by changing rigidity. Within engineering fields rigidity is often termed stiffness, referring to the ability of an elastic body to resist deflection or deformation when forces are applied. Stiffness is a property of materials as well as structures. Structures with variable rigidity or stiffness incorporate controlled systems that either compress or induce tensile forces into a system. These forces can be localized or spread across an entire structure.

Four processes must come together to support the design of systems that have variable rigidity, these are:

1) Structural modularity: Modular approaches help because they enable designers to limit the complexity of a system while also addressing constructability.

2) Structural connectivity: The ability to define connections between structural modules so that complete structural systems can be simply produced.

3) Structural loading: The ability to provide feedback about load transmission and the paths of load transmission with changes in rigidity.

4) Structural shape: The ability to accurately test the geometrical (shape) limits of a structural system must also be supported.

TWO) **Making Mathematical and Control Models Available to Designers**:

Models assist designers to analyze and test the systems that they are responsible for. In particular models help designers rapidly develop and refine processes that control the rigidity of responsive structures. Relevant mathematical models have been developed and they should be integrated within these CAAD systems. Such models include those that:

1) minimize mass
2) determine the equilibrium states of structures
3) locate actuators
4) determine the energy required to change the shape of a structure
5) calculate the frequency and location of dampening systems
6) minimize structural fatigue.
7) calculate load transmission, and
8) calculate thermal loads

Other models that predict the structures ability to harvest energy are also being produced. [11] Finding methods for integrating these models into the toolset of architects and multi- disciplinary teams is important. It is worth recalling a few of Robert Diamant's words at this point. Skidmore Owings and Merrill must be credited for being the architectural office that led the world when it came to the implementation of CAAD systems. SOM used computers to produce beautiful buildings that challenged the limits. They used these buildings to advance the technical abilities of the profession and advance knowledge. These advances were made possible by pioneering a generation of CAAD tools that incorporated engineering knowledge within design processes. It is within this spirit that our field must now produce a new generation of tools.

THREE) **Expanding the Quantity and Quality of Environmental Parameters**:

A major problem within current parametric processes is a lack of support for expanded environmental models. Expanded environmental models are those that include the necessary spectrum of environmental stimuli to model building responses, a set of four stimuli are required:

1) Light
2) Humidity
3) Temperature
4) Air pressure

These stimuli support connections between response mechanisms and the environmental factors that surround responsive buildings. They are the minimal needed to produce contextual information about sun location, wind direction, wind speed, precipitation, and temperature. CAAD systems must be able to simulate these processes before they will prove useful tools for the design of responsive buildings.

FOUR) **Enabling Designers to Construct and Test Responsive Behaviors**:

The three previous elements scaffold together to form a rich platform for producing responsive architectures however they do not, by themselves, help designers construct and test responsive behaviors. A two-part framework that supports the integration of software (control) onto hardware (the modular building structure) is required.

1) Control Packaging: a frame that ties structural models to mathematical control models to give designers a means to hook ideas about control to ideas about structure. This author suggests packaging behaviors via subsumptive methods similar to those developed by Rodney Brooks for producing robots.. [12]

2) Packet Distribution: Methods need to be developed for distributing control packages across complete buildings.

FIVE) **Tying Artifacts to Real World Outcomes**:

The final step in producing a CAAD

tool that can assist in the development of responsive architectures is to provide a means for collecting and embedding real world data into the system so that more accurate design decisions can be made. Only a small conceptual step exists between monitoring the performance of a responsive building that has been constructed and occupied and embedding relevant data collected from that product into a model but the ramifications of this final step are potentially very large. Architectural practices who follow this method of design will be responsible for collecting environmental and energy consumption data for buildings that they design and maintaining confidential databases of this information. While the data held will be rich and helpful in monitoring buildings it can also be used as a reflective design tool that improves practice. New architectural analysis and building industries may be born and extend the way in which architects practice and evaluate design outcomes.

Conclusion

Computer aided architectural design systems are successful when they tie design processes to real world outcomes in consistent ways. They must also provide convenient tools to help designers solve problems.The tools we use are fast becoming obsolete. New building technologies that are responsive are increasingly being applied within architecture and with this change new design challenges that require new sets of tools are emerging. If architects are to embrace responsive technologies and integrate them into the very core of architecture (rather than applying them superficially to cover dumb building frames and skins) a new generation of CAAD tools is required. These tools will support a different view and approach to design and they will make new assumptions that enable more appropriate ties to form with the real world. At the 2006 ACADIA conference held by The University Of Kentucky, a plenary session [13] about the future of architecture asked what next? What are the low hanging fruit of responsive architectures and what can we do today to progress toward this future? Without doubt much work needs to be carried out before the types of systems within this paper are built and in common use within the architectural community. Until they are, responsive architectures will remain within the domain of the special few who craft their own tools – this would be unfortunate.

A united effort between the specialists who produce responsive architectures and those who craft CAAD tools must soon occur. Without this, the discipline will suffer and significant opportunities to advance the profession will be lost. This paper represents a first attempt at forming this discussion. It also represents an open invitation to join forces and produce these tools.

Notes

[1] Negroponte, N. (1975) *Soft Architecture Machines*, Cambridge Massachusetts: MIT Press, pp1- 5.

[2] Robert Diamant spoke at Skidmore Owings and Merrill's Chicago office in an informal round table discussion (12.00 pm Thursday 4 August 2005). The blurb that advertised his talk was sent in office email and it read: "Robert Diamant, former SOM Managing Partner, worked on a number of classing SOM projects with Bruce Graham, Walter Netsch, Myron Goldsmith, Fazlur Khan and other notable partners. These projects include the John Hancock Center and 60 State Street in Boston."

[3] For information about one of the key players within Skidmore Owings and Merrill's technical achievements read about Fazlur Khan at http://www.fazlurrkhan.com or within the following book: Khan, Y., (2004) Engineering Architecture: The Vision of Fazlur R. Khan, New York: W.W. Norton & Company, Inc.

[4] Turner, G., (1986) *Construction Economics & Building Design*, New York: Van Reinhold Company Limited.

[5] Mazria is acknowledged by The American Institute of Architects as a leader in sustainable architecture within the United States.

[6] Mazria, E., (2003) "It's the Architecture, Stupid!" in *Solar Today*, May/June 2003, pp. 48-51.

[7] See works by this author: http://www.orambfra.com/earlyPrototypes/index.html.

[8] See recent articles: (1) http://www.wired.com/news/technology/0,71680-0.html (2) http://edition.cnn.com/2006/TECH/science/09/08/smart.buildings/ (3) http://www.economist.com/science/displaystory.cfm?story_id=E1_RPTNNDD (4) http://newcityskyline.com/ResponsiveArchitecture.html.

[9] Friedman, Y. (1975) *Towards A Scientific Architecture*, MIT Press, Cambridge Massachusetts, pp. 1 or: Friedman, Y. (1972) "Information Processes for Participatory Design", in *Design Participation*, Proceedings of the Design Research Society's Conference Manchester, September 1971. Academy Editions, London, pp. 45-50.

[10] Mahalingam, G., (2004) "Model behaviour" in *Intelligent Building And Design Innovations*, Issue 6, 2004: pp.36-38.

[11] This work is being done by Robert Skelton, partner at The Office For Robotic Architectural Media & Bureau For Responsive Architecture. See: http://www.oramBFRA.com.

[12] Brooks, R., (1986) "A Robust Layered Control System For Mobile Robots", in *IEEE Journal of Robotics and Automation*, pp. 14-23.

[13] The plenary session was entitled "Smart Futures" and was moderated by Mahesh Senagala and Anijo Mathew. Participants: Michael Fox, Murali Paranandi, John Nastasi, and Tristan d'Estree Sterk

Tristan d'Estree Sterk founded The Office For Robotic Architectural Media & The Bureau For Responsive Architecture in 2000. He has received international attention for designing buildings that change shape in response to user needs and the natural environment. Among other prizes he has been awarded first place in the prestigious Emerging Visions Prize given by the Chicago Architecture Club. E-mail: tsterk@orambra.com. Web: www.orambra.com.