Building Upon Negroponte:
A Hybridized Model Of Control Suitable For Responsive Architecture:

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Abstract: Responsive architecture is commonly defined as a type of architecture that has the ability to alter its form in response to changing conditions. While this description is successful in capturing the gist of the topic, it does not provide us with the more detailed understandings required to build it.

The knowledge required to build a truly responsive form of architecture is substantial, an understanding of architecture, robotics, artificial intelligence and structural engineering are all beneficial. The links that are required between each knowledge base to actuate and control the responses of this type of architecture further complicate matters – suggesting potential reasons for the ambivalence of architects towards deeply exploring to the topic or extending it beyond the aesthetic application of an event-based architecture.

This paper will build a model of responsive architecture that explains one possible approach to the topic, emphasizing ways to build it and control it in the process.

Keywords: Controlling responsive architecture, Controlling networks of response buildings

Introduction:

As someone interested in building a responsive architecture that is functional enough to be used for all scales of building, including housing, performance spaces, theatres, and also skyscrapers, I discovered that the amount of precedent material within the field was small, and that the material which did exist focused upon the aesthetic rather than functional aspects of responsiveness. I also discovered that the few sources of documentation that did exist offered little explanation about the computational models and the physical systems that are required to control these types of buildings.

Looking back, the major documents that describe the features of architectural responses are those written by Nicholas Negroponte. Negroponte's work, the most important parts of which are published in his books called, "The Architecture Machine", 1970; "The Soft Architecture Machine", 1975; and his multiple papers entitled "The Semantics of Architecture Machines", of 1970, comprise the first significant attempts to define and produce a responsive architecture. Within his work, 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. This cross-fertilization of ideas lasted for about eight years.

As an established body of work, Negroponte's ideas remain as advanced concepts that are still valid and important to the field. However, while they remain worthy targets for design efforts, they do not take into account more recent developments within the fields of robotics and artificial intelligence that are used within responsive systems today. For example, whole branches of robotic techniques that enable very simple, unintelligent behaviours to scaffold into more sophisticated behaviours have been developed since Negroponte's work. By using these techniques, new methods for producing responsive architectures are made available.

This paper results from the struggle that this author has had to develop a current model of responsive architecture that extends Negroponte's original work with recent developments. It will propose a very simple model of architecture, designed to separate the components of buildings into two main classes of parts – the serviced spaces that we occupy and the external shells that shelter us. It will then propose how each of these parts may be controlled, focusing upon the examples of a responsive building envelope (or structure) and a responsive internal partition system. The proposed control model, will inform a framework upon which a variety of mechanisms suitable to controlling responsive architectures, in intelligent ways, may hang. Finally, the paper will also propose how several responsive buildings may be networked together to produce intelligent clusters of buildings that solve larger responsive problems.

A Discrete Model Of Architecture:

Before discussing the control mechanisms required within responsive architecture, a model for integrating the needs and wants of users into architecture will be proposed.

The model consists of three different functional components, these are; 1) the needs and wants of building users; 2) a building structure that includes a sheltering building envelope; and, 3) a configuration of spaces that are serviced (for example heated or lit). Figure one represents the different ways in which the needs and wants of users are (or are not) met by each element. It also suggests that the ideal form of architecture is one

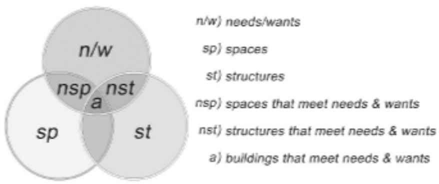


Figure 1. The three components of a discrete model of architecture.

that is composed of a well-balanced mix between space and structure.

Historically architects often conceived of these two different sets of needs and wants in quite different ways, each of which left their mark upon architecture within different types of design processes. The strategy of each process focused upon either: 1) the structure of a building and its envelope, emphasizing an 'outside-in' approach to building; or 2) the quality of internal spaces, emphasizing the 'inside-out' approach to design. Once again, the needs and wants of users are reflected within the balance of building components and their arrangement. The results of these processes were nearly always one-off designs that balanced the spatial and structural needs and wants of users within a unique building. It is at this time that we also need to remember that new buildings are not the only products of architectural endeavour, and that designs may also be required to modify existing buildings to make them suitable for changing client needs or new users. Such changes to buildings often demand that new spatial configurations and structural solutions be produced – raising questions about how flexible building designs need to be. (Heath 1984)

As suggested by this discrete model of architecture, responsive architectures are also composed of parts that can be divided into the two functional categories of structure and space, and furthermore that the needs and wants of users drive the design of each. However, responsive architectures are also composed of responses. Practically, responses provide this class of architecture with the means of catering to changing conditions, by responding tirelessly – increasing the potential flexibility of a building by an order of magnitude. Conceptually responsive architectures treat the needs and wants of users as a set of ever changing conditions – which are useful for determining the next architectural state of a building.

Control demands that both the conceptual and practical elements of responsive architecture are taken into account. One must understand that by connecting building elements to actuators, processors and sensors (that detect environmental stimuli), responsive architectures that can change their shape, spatial configuration, and services, all become possible. Practically it is important to realize that within responsive buildings each different type of responsive element, be it a structural component, heater, moving partition, or light, needs to be controlled quite carefully and usually separately in order for the responses of that element to be useful for building occupants. The antithesis of this emphasizes the point. For example, if the shape of an envelope, as well as the light and heat levels of a building were all driven by the presence of a stimulus such as the wind, then the resulting building might only function correctly when the wind blows. To increase the functionality of the building, one must ensure that the appropriate connections between a stimuli and a response are formed. Thus connecting a radiator to a temperature gauge provides responses that are generally more useful than those made by connecting a radiator to a windsock.

The possibilities of producing useful responses within this type of architecture are numerous but demanding of much study. One of the current obstacles of performing research within this field is the lack of precedent buildings upon which responses can be tested. As of yet, there is no sure way of knowing if what we think may be useful, is useful, in built form.

It should also be quickly noted that all of the responses discussed thus far could be produced from 'low-level' processes. The responses generated by discrete elements do not necessarily require anything other than 'sub-symbolic' forms of artificial intelligence. (Brooks 1986)(Brooks 1992) However, this is not to deny the fact that 'high-level' responses are also possible and in many cases very desirable. (Nilsson 1992)(Coste-Manière and Simmons 2000) High-level processes use 'symbolic' forms of artificial intelligence to produce responses that can be very sophisticated. Favored by Negroponte, these responses are employed by him to produce helpful responsive architectures that can recognize users and guess at their actual intentions. (Negroponte 1975)

A Model For Controlling Discrete Responses:

The functional divide used to control structural responses that shelter, and spatial responses that service different user activities, as well as the divide between high-level and low-level responses provides a base from which a new model of responsive architecture may be proposed. The model that results borrows the general structure of the model proposed within figure one, and combines it with symbolic and sub-symbolic processes to produce a form of responsive architecture that relates user needs to actual building components and their responsive behaviours, be they generated by low or high level processes.

The model, described by figure two, has three major parts, two types of connections between parts, and one implied connection that has been given the label “resulting architecture”. The parts consist of: 1) user input, which provides users with the means of controlling or manipulating responses that extend throughout a building; 2) a building structure that has a responsive capability which enables it to respond directly to environmental loads; and 3) spatial response that are used to control the partitioning and or servicing of internal spaces. The connections between these parts come in two forms, those being, 1) requests made as indicated by the labels of spr or str, and 2) exceptions as depicted within items spe and ste. Together all of these elements combine to produce a form of architecture informed by the changing state of sets of responding components.

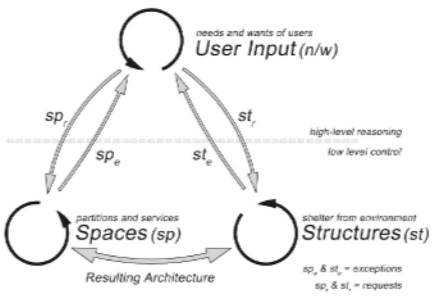


Figure 2. The proposed hybridized control model for use within a functional responsive architecture.

Each part of this model can also be related to the processes that drive them, with low-level processes being used within spaces and structures in a ubiquitous, distributed way, and high-level processes connecting the needs of users into the model. This split between high and low level processes is the result of the natural abilities of each component to work effectively within a role, the cost implications of their integration within architecture, robustness, safety, and user-friendly design. The interconnections between each are the product of communicating user needs and wants to components in as simple a way, as possible.

An example of how this model operates to control a responsive building envelope, as well as a responsive partitioning system now follows. Each building component will be described before it is related to the proposed control model. Within this example, the building envelope will be composed of a tensegrity structure (for a detailed description of the structural system please refer to a second paper by this author written for the forthcoming October, ACADIA 2003 conference). The envelope is made by joining many hundreds of structural units into a network of parts that are capable of distributing loads dynamically. Each unit consists of two tensegrity elements, an actuator, a sensor, and a small micro-controller. Each actuator is controlled by its own micro-controller that has access to a very limited amount of sensor data (figure three illustrates both the actuated structural unit and a larger building envelope composed of many hundreds of units). The internal partitioning system also described within figure three, consists of a sliding wall mounted upon tracks. It also has two sensors that monitor the spaces that lie upon each side of the wall and a small, embedded microcontroller that connects the input from each sensor to the responses of a small actuator used to move the position of the wall.

The task of the framework proposed by this paper in figure two, is to coordinate the activities of each building element to achieve a state that reflects user needs. Thus if a user needs more space two types of example responses might be produced. The first of these is a simple response made by the partitioning system when it monitors a changed pattern of use on one of either side of the wall. After monitoring this change, the microcontroller sends a signal to the actuator that results in the wall slowly sliding back, in retreat, to increase the amount of space available for use. However in the process of moving back the second sensor, which monitors levels of use on the alternative side of the wall, senses that an obstacle is preventing any further movement, causing the wall to halt. At this point, if the degree of activity within the active room is still high enough to warrant additional space the micro-controller must flag the event – effectively saying that it has done as much work as it can within this case. Now it is the building's turn to take action and call upon a second process to increase the amount of space available. To enable this, the low-level

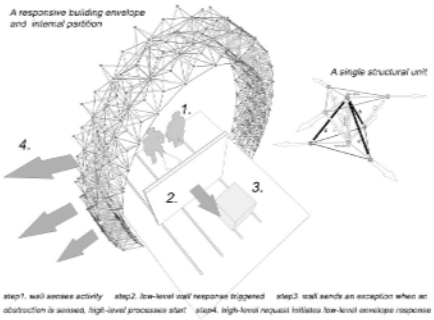


Figure 3. A structure and internal partition working cooperatively in response to changing patterns of use

responses produced by the partition must be connected to another process.

This paper proposes that different responsive systems should be connected from lower to higher levels of intelligence. By forging connections to higher rather than lower level processes, the preferences of users can be taken into account within responses that shape the architecture of a building. We will now continue the example by noting that the partition's flagged event results in an exception being sent to a centralized, higher level, intelligent control system. The centralized control, being connected to a network of lower level, discrete distributed control systems throughout the building, handles the exception by comparing the current state of the building (determined by assessing the state of each discrete, actuated component) to a future state that recognizes changing patterns of building use. When compared, the system may then remedy the perceived shortage of space in one area by requesting that a second system also be engaged – in this example, the second system will be the building envelope itself. The building envelope will expand until the micro-controllers within it sense that the structural system has reached its limit, then stop, and pass its own exception back to the high-level system.

Networks of Hybridized Control:

The example provided to demonstrate the operational aspects of a functional responsive architecture are best described by a "hybridized" model of control. (Coste–Manière and Simmons 2000) Hybridized models are commonly used within the field of robotics to allow separate reasoning processes of a reactive (or low-level) and deliberative (or high-level) nature to be present within the same model. Together these two processes facilitate the efficient and easy mixing of low-level control with higher-level reasoning in a manner that suits responsive architecture for the following reasons:

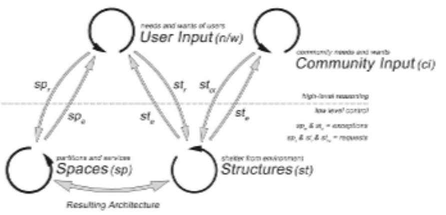
1) Controlling complexity: Buildings are complex systems and hybridized models help to simplify tasks by delegating smaller, simpler, tasks to low-level processes before engaging higher levels of computing power to solve harder tasks that involve many components.

2) Balance and stability: Hybridized systems make it possible for people to use high-levels of control to coordinate and shape the outcomes of large numbers of low-level processes while not compromising the functionality of processes that are critical to achieving a safe building. This

approach also encourages safety through a redundancy of parts and responses.

3) User-friendly design: By splitting control into sets of high and low level responses users need to know less about a building in order to operate it safely – users interface with a single high-level processes that then interfaces with several hundreds of low-level processes to produce a controlled outcome.

But aside from just offering benefits to single buildings the hybridized model that is proposed by this paper can be extended to control networks of responsive buildings in cooperative ways. Conceptually, the extended model illustrates how a responsive architecture can affect a community of buildings by coordinating their responses at larger scales. Practically, the



extended model uses exactly the same types of processes that occur within the single building – as depicted in figure four.

The reasons for producing networks of responsive buildings become clear when examining another operational example. This example will consider how a network of tall buildings or skyscrapers can respond to high winds in order to reduce the shear loads imposed upon their structures (thus increasing the structural efficiency of a building).

Considering the individual tall building first, one may envisage that a responsive envelope, which has the ability to change its aerodynamic profile, provides a building with the means of minimizing a wind load to reduce the amount of structure required to support itself. However, if these buildings are clustered close to each other one must also accept the inherent risk that a responsive neighbour may inadvertently deflect wind loads back onto another building – with potentially disastrous ramifications. Thus, the model of a

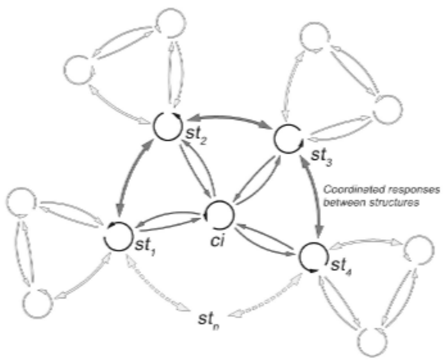


Figure 5. The framework of a responsive network that stretches across a cluster of buildings.

Figure 4. Extending the proposed model – to enable responsive networks between buildings.

single responsive building, within this type of environment, is not likely to gain (at least at a structural level) from responsive processes.

To correct this situation a network is used. By networking responsive buildings together it becomes possible to produce a new model that is more efficient. A networked model reduces the likelihood that unfavourable deflections will occur between buildings by tying the consequences of a responsive action (as produced by one building) to the resulting conditions that are experienced by all neighbouring buildings. For example if a building adopts a new aerodynamic shape to reduce its own structural load, but this new shape inadvertently deflects wind on to a neighbour and that neighbour cannot rectify this increase by reshaping itself, then a corrective action must be flagged by the system. This event must trigger a reliable process within the first building that causes it to cast less wind upon the second building, or alternatively use the broader responsive abilities of the entire network to do this same job.

Within this new model the addition of a second set of high-level processes connecting the low-level structural responses of one building, to the low-level structural responses of another, results in a network between buildings that enables each response to be efficiently coordinated. Furthermore, by inverting this example from the negative impacts of wind to the positive impacts of other environmental conditions one may note that these networks have the potential, not just to shelter buildings from disastrous conditions, but also alter the responses of buildings to better utilize favourable conditions.

Conclusion:

This paper proposes a model suitable for controlling functional responsive architectures by connecting responses to changing patterns of building use. The framework that results from this proposition depends upon both sub-symbolic and symbolic forms of intelligence, with connections between each type of intelligence enabling responses to be coordinated. The paper also proposes that this framework can extended to enable networks of responsive buildings a means of responding to larger sets of conditions in cooperative, beneficial ways.

References:

Brodey, W.M. and Lindgren, N.: 1967, Soft Architecture–The Design of Intelligent Environment, Landscape, 17(1), pp. 8-12

Brooks, R.: 1986, A Robust Layered Control System For Mobile Robots, IEEE Journal of Robotics and Automation, 2(1), pp.14-23

Brooks, R.,: 1992, Intelligence Without Representation, in D. Kirsh (ed), Foundations Of Artificial Intelligence, MIT Press, Cambridge Massachusetts, pp. 139-160

Coste-Maniè, E. and Simmons, R.: 2000, Architecture, The Backbone Of Robotic Systems, Proceedings of the 2000 IEEE International Conference on Robotics & Automation, San Francisco, California, pp. 67-72

Heath, T.: 1984, Method In Architecture, John Wiley & Sons, New York.

Negroponte, N.: 1975, Soft Architecture Machines, MIT Press, Cambridge Massachusetts

Negroponte, N.: 1970, The Architecture Machine, MIT Press, Cambridge Massachusetts

Negroponte, N.: 1970, The Semantics Of Architecture Machines, Architectural Design, September

Negroponte, N.: 1970, The Semantics Of Architecture Machines, Architectural Forum, October

Nilsson, N.J.: 1992, Logic And Artificial Intelligence, in D. Kirsh (ed), Foundations Of Artificial Intelligence, MIT Press, Cambridge Massachusetts,