Starting From The Micro: A Pedagogical Approach to Designing Interactive Architecture

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Abstract

The paper outlines a pedagogical approach whereby a number of technology-intensive skills can be quickly learned to a level of useful practicality through a series of discrete, yet cumulative explorations with the design goal of creating intelligently responsive architectural systems. The culmination of such explorations in creating full-scale interactive architectural environments leads to a relatively unexplored area of negotiation whereby individual systems must necessarily manage environmental input to mediate a behavioural output. The emerging area of interactive architecture serves as a practical means for inventing entirely new ways of developing spaces, and the designing and building environments that address dynamic, flexible and constantly changing needs. Interactive architecture is defined here as spaces and objects that can physically re-configure themselves to meet changing needs. The central issues explored are human and environmental interaction and behaviours, embedded computational infrastructures, kinetic and mechanical systems and physical control mechanisms. Being both multidisciplinary and technology-intensive in nature, architects need to be equipped with at least a base foundational knowledge in a number of domains in order to be able to develop the skills necessary to explore, conceive, and design such systems. The teaching methods were carried out with a group of undergraduate design students who had no previous experience in mechanical engineering, electronics, programming, or kinetic design with the goal of creating a responsive kinetic system that can demonstrate physical interactive behaviours on an applicable architectural scale. We found the approach to be extremely successful in terms of psychologically demystifying unfamiliar and often daunting technologies, while simultaneously clarifying the larger architectural implications of the novel systems that had been created. The authors summarize the processes and tools that architects and designers can utilize in creating and demonstrating of such systems and the implications of adopting a more active role in directing the development of this new area of design.
Introduction

The emerging field of Interactive Architecture is gaining prominence in recent years. We refer to the term “Interactive Architecture” in the context of this paper as systems that are specific to the “tangible” and “physical”, and related to spatial “environments” in the broadest sense to include architecture. The increasing presence of sensors and actuators in domestic contexts calls for the need of architects and designers to develop the skills necessary to explore, think about, and design intelligent and adaptive architectural systems. The majority of students of architecture or environmental design however have not been exposed to this new field. The challenge in developing a course on Interactive Architecture lies in the highly technology-intensive nature of the subject matter, involving knowledge and skills that cross boundaries into engineering, computer, and behavioural sciences.

From the onset, the authors of this paper were conscious of the difficulties design students might experience. We contend however, that such difficulties are best tackled by removing the psychological barrier design students tend to have towards computing and engineering. We believe that this is best achieved by having students work on a series of small, explorative hands-on model-making exercises that are incremental in nature, and which gradually incorporate engineering and computing components. Based on this approach, the authors have developed a course to enable students to have hands-on experience in designing Interactive Architectural environments. This paper reports on the design, delivery, and project outcomes of this course taught at several different Universities of both architecture and design to both undergraduate and graduate students. The authors also argue that when the design tools evolve together with the developing design concept, crossing of boundaries becomes easier, facilitating the acquisition of new knowledge in other domains.

Developing Skills for Thinking

Course Objectives

This course was conceived to develop the skills necessary to explore, think about, and design and has been taught at the School of Design of the Hong Kong Polytechnic University, in the Environmental Design Department at Art Center College of Design in Pasadena, California, at the Southern California Institute of Architecture, (SCI_Arc) in Los Angeles, California and at MIT in Cambridge, MA. The primary objective of the course outlined above has been extremely consistent during each offering. The course addresses kinetic function as a technological design strategy for building types and objects that are efficient in form, and inherently flexible with respect to various contexts and a diversity of purposes. The idea is to create spaces and objects that can physically reconfigure themselves to meet changing needs.

Course Design

The course (used plurally) was predominately design-build based and supported by lectures that provide the necessary conceptual framework. The course begins with an introduction to theoretical concepts and precedent in architectural applications of Responsive Kinetic Systems. Basic engineering concepts in mechanical structures were also introduced. Simultaneously, students were asked to explore various mechanical motions and joints from found objects and structures that intrigued them, and then select one structure to examine closely its underlying mechanics. They were then required to re-build and re-model the mechanical structure to replicate and expand its basic kinetic capabilities.

Next, students were introduced to basic concepts in electronics, as well as BasicStamp, a programmable IC chip with an integrated circuit for the incorporation of sensors and motors. While learning to work with BasicStamp, students were asked to think about applying the motors to their mechanical joint explorations, as well as using sensors to trigger the motion. At this point, the concept of behaviours was introduced, and students were asked to both design and rationalize the intended behaviours of their mechanical structure, and apply these interactive behaviors towards an architectural application. It is in this manner that the students’ initial model explorations gradually grow in complexity, integrating first automatic functions, and later, more complex autonomous behaviors, and lastly architectural applicability and conceptual insight.
Strategies for Delivery

Most of the topics on electronics, computation and mechanics were covered only in a very basic, introductory manner. The approach used in this course was different from typical design courses in that rather than starting from macro: finding a problem, then research, then design, we started micro: designing the mechanical structures first, then ‘grow’ the system by adding sensors and motors, then designing the behaviour of this system, then develop the application of this system in the larger context of use. The objective behind this methodology was to allow students to focus on the core of the responsive system itself, that is, the fundamental mechanical structures and how to embed this with interactive and intelligent behaviors. This approach also minimizes the daunting psychological effects students might experience if from the onset, they were told that they have to develop a structure or building that is intelligent and that can physically demonstrate

Figure 1. Two-D joint exploration

Figure 2. Three-D joint exploration

Figure 3. Assembled structure

Figure 4. Final kinetic model

Figure 5. Chair module (half-risen)

Figure 6. Table module (fully raised)
interactive behaviors. By going micro, students did not feel the pressure of confrontation by venturing into unknown territories. This hands-on demystification process is very important for crossing interdisciplinary boundaries. The challenge here lies in having the students learn a minimum, in order to be able to achieve a greater sum than the additive parts, in the sense of being able to embed kinetic structures with behaviors that demonstrate, as opposed to simulate, one’s design ideas and intents in intelligent and responsive systems. Through discretely gaining elementary interdisciplinary confidence, the ultimate goal is for students to be able to overcome psychological barriers and have the confidence to communicate with engineers and programmers their design intentions in an effective manner. Such confidences can have a strong effect in architects taking a more active role in directing the development of interdisciplinary design directions. To do this, designers need to have at least a superficial knowledge base of both the engineering in terms of mechanics and fabrication and also the computational substructures in order to develop the necessary skills and the conceptual and intellectual framework for designing.

Application Examples: Scaled Architectural Mechanics and Robotics

Several student projects are outlined below that illustrate the methods and processes used in designing interactive systems at a scalar level for understanding mechanical motions. These particular projects are all from a course taught at Hong Kong Polytechnic University. Similar scaled exercises are also carried out as for initial skill-building in the context of the full-scale projects outlined later in this paper.

Design Example One: Kinetic Chair/Table Systems

This interactive design project for kinetic chair/table systems demonstrates the simplified prototypical kinetic attributes that first grew from a simple exercise in mechanical design. The simple mechanical model of cardboard that demonstrated the motion grew to a precise mechanism with gears and motors and sensors. The design in its final stage retained the base mechanical principles yet grew discretely to demonstrate a full range of attributes relative to kinetic function, human interaction, adaptive control and realistic operating conditions. The model incorporated sensors and motorized control in order to prototype the behaviours of the systems as opposed to simulating them. The project is a specific application scenario that actually affects the nature of the architectural construct (the room). Specifically, the design project is a networked system of individually responsive chairs that function together, transform from an invisible floor module to a congregation of six chairs when half-risen, or a table when fully raised. Primary design considerations were to affect the physical space and to create a module of furniture that is adaptable both to the number of users as well as to be physically present when it is necessary and invisible and out of the way when it is not in use.

Design Example Two: Caterpillar Kiosk

The Caterpillar Kiosk project has employed a mixture of prototyping tools and techniques from early mechanical joints explorations throughout to final design implementation. It demonstrates how tools and design co-evolve, with the tools facilitating the design process as opposed to directing it, an argument that will be further discussed in the paper. The final design is a hybrid structure: the core mechanism, responsible for the piston-like motion, is built with fabricated materials; this is further integrated with, and also affecting, the navigation mechanism built with LEGO gears and motors. Primary design consideration was to provide a temporary shade and shelter in areas where it is most needed, and when it is needed. The idea is to embed this mobile caterpillar structure with both light sensors and motion sensors, such that it will navigate autonomously towards the direction of strongest UV index, but will stop once it senses human motion within it. When it is not moving, people can then gather inside the structure and enjoy being shaded from strong sunlight or even heavy rain. Application environments are perceived to be vast open areas like parks or beaches. While not in motion, the caterpillar structure could be used for other temporary activities like public performances, or as a temporary catering facility. The final model here also incorporated sensors and motorized control to in order to demonstrate through prototyping the behaviours of the systems as opposed to simulating them.
Several additional projects are shown below that demonstrate a wide range of application examples in architecture. The applications grew out of the simple mechanical explorations with varying degrees of complexity. A diverse range of prototyping materials were also employed in these final models in order to clarify architectural issues of structure, transparency, lighting, etc. Typically it was desired that the computation, (control boards and sensors) be seamlessly embedded into the structures rather than being openly expressed as an architectural quality, and that the mechanics and motorization be openly expressed. We find it important to note these differences in attitudes towards mechanics and computation and although such differences are not quantified here, we note that perhaps they are a result of the familiarity and acceptance that students have with mechanics in the real world as opposed to things computational and that architectural expression may change as more designers explore, design and familiarize themselves with such systems.

Application Examples: Full-Scale Architectural Environments

Several student projects are outlined below that illustrate the methods and processes used in designing full-scale prototype systems that can demonstrate interactive behaviours.

Design Example One: Interactive Restaurant Design Process

This interactive design project for an interactive restaurant was a collaborative project of an entire studio. After students have a practical grasp on the basic mechanics and robotics they begin to collaboratively design a full-scale interactive environment. (in this case an interactive restaurant.)
Specifically, the design project is a networked system of individually responsive systems that function together as an architectural space. Students in the classroom learn to go between various aspects of realization from robotics to cad-cam fabrication, to standard construction techniques such as welding and timber framing. In almost every instance, design modifications are made as a result of misunderstanding the physics of full-scale mechanics.

Figure 11. Wall system combining intelligence with traditional

Figure 12. Transparent materials employed for intelligent skylight

Figure 13. Exposed mechanics with hidden computational

Figure 14. Complex behaviour hidden behind simple architect

Figure 15. Intelligent solar reflectors with hidden mechanics and computation

Figure 16. Full scale prototype of intelligent solar reflectors
As the level of completion of the architectural environment as a whole neared completion we found that a great deal of negotiation occurred in terms of sensing and response. The space had a number of individual systems that were designed as independent systems and only later in the process did the realization come that the input for the individual systems should not be a direct relational input of human behaviours but rather the translated and cumulative effect of behaviours on other systems in the space. The façade reacted to people outside of the space, the interactive bar reacted to people preparing to enter the space, the floor reacted to the people in the space, the ceiling reacted to the floors and the vanity reacted to the
people temporarily leaving the floor and translates this to the façade and to people outside of the space. Thus completing a cyclical and synergistic effect of behaviours wherein each project is a key component in the larger system.

**Figure 23.** Aesthetics of the robotics are expressed as design elements

**Figure 24.** Aesthetics of the spatial interactivity are expressed as design elements

**Figure 25.** A chair inflating where and when a user decides to be seated

**Figure 26.** Chair and ceiling system working together

**Figure 27.** Pneumatic control manifold expressed as a design element

**Figure 28.** Interactive waiting lounge dealing with psychological proximities

Design Example Two: Interactive Spa/Urban Retreat (iSpa) Design Process

This interactive design project for an interactive spa/urban retreat was another collaborative project of an entire studio. After students have a practical grasp on the basic mechanics and robotics they begin to collaboratively design a full-scale interactive environment. (in this case an interactive
Students once again learn to go between various aspects of realization from robotics to cad-cam fabrication, to standard construction techniques such as welding and timber framing. In almost every instance again we found that design modifications are made as a result of misunderstanding the physics of full-scale mechanics. We believe that the hand-on experience of making mechanical connections, wiring circuits, programming, lighting, and acoustics serve as a tremendous exercise in bringing to light a great number of unforseen issues both in terms of mechanics and electronics that build the skills and confidence to communicate as designers to expert fabricators and technicians.
Design Example Three: Interactive Spa/Urban Retreat (iSpa) as a Functional Environment

As the level of completion of the architectural environment as a whole neared completion we found once again that a great deal of negotiation occurred in terms of sensing and response. The space had a number of individual systems that were designed as independent systems and only later in the process did the realization come that the input for the individual systems should not be a direct relational input of human behaviours but rather the translated and cumulative effect of behaviours on other systems in the space. This project evolved to a degree that both acoustics and lighting became major factors in the overall design. Most of the projects were dealing with psychological and sociological issues that could only be understood and translated through a combination of systems as opposed to any singular system.

For instance, as the floor system began to become very difficult to walk upon, a path had to be carved within the space for circulation. As another system required low lighting levels, it required the function of the lighting system to become a navigational system for circulating throughout the space. Once again, as realistic conditions were developed in a design-build fashion, new problems evolved that required the modification of existing concepts to complete the interactive architectural environment. We believe that such issues of interactivity in terms of real human behaviours and response are very difficult to design and are more clearly understood only as they evolve in a holistic fashion. The group designing of the system as a whole then makes explicit the negotiation that must occur in designing interactive spaces and environments with inclusive architectural considerations as opposed to objects or stand-alone systems.

**Figure 35.** Full-Scale environment dealing with typical spatial division

**Figure 36.** Full-Scale environment dealing with 3-d spatial division

**Figure 37.** Cleansing interactive entry

**Figure 38.** Biorhythmic light room
Design Example Three: Interactive Zoo (iZoo) Design Process

The iZoo is an interactive architectural space that fosters human connections, floods the senses, is educational and manipulative. The design project is the collaborative effort of 22 SCI_ARC students for a course in “Interactive Environments”. This course was once again a combination of full-scale-hard-core-construction, CAD/CAM manufacture, robotics, and the translation of robotics to full-scale real works to create a space with behaviours that you can interact with. After students have a practical grasp on the basic mechanics and robotics they begin to collaboratively design a full-scale interactive environment. (in this case, based upon the conceptual ideas inherent in a zoo. Students once again learn to go between various aspects of realization from robotics to cad-cam fabrication, to standard construction techniques such as welding and timber framing. In almost every instance again we found that design modifications are made as a result of misunderstanding the physics of full-scale mechanics. We believe that the hand-on experience of making mechanical connections, wiring circuits, programming, lighting, and acoustics serve as a tremendous exercise in bringing to light a great number of unforeseen issues both in terms of mechanics and electronics that build the skills and confidence to communicate as designers to expert fabricators and technicians. We found an increasing number of students that found ways to make things work that were not the “correct” way but that did in fact work. For instance rather than learn to program a voltage regulator to dim a lighting device, the student used traditional lighting dimmer switches that were controlled by servo-motors that he had a good grasp on and the project worked perfectly. Another student could not get an external amplifier to work correctly with the power that was supplied with the BasicStamp yet wanted a much so rather than solve the technical computational problem, he simply built an acoustic box around the output that he had and placed a microphone on the speaker output that he had and ran that through the amplifier and once again was able to get a very nice output. These means of problem-solving are quite unconventional for traditional students of architecture but are invaluable in learning to think of ways to get a desired result with what is available both physically and technically and are often more valuable than learning a direct technical skill and applying it to get a known result.
Design Example Three: Interactive Zoo (iZoo) as a Functional Architectural Environment

This project stands out from the previous two examples in that the intent of the interactivity was not focused upon practical or functional problem-solving but was aimed at articulating the conceptual ideas inherent in a “zoo”. Conceptual ideas such as Manipulation, Learning, Roll-Playing, Privacy, and Human Connections were the stimuli here for developing the individual projects. In almost every instance again we found that design modifications are made as a result of misunderstanding the physics of full-scale mechanics. There was a great deal of negotiation for space for individual projects that included issues of lighting and acoustics. A number of the projects had specific needs in terms of these issues that differed from adjacent projects and transitional areas had to be collaboratively worked out between them. Also worthy of note is the fact that the design was initially an open-plan whereby visitors could wander as in a typical art gallery from exhibit to exhibit. This concept was changed rather late in the process out of the need to clarify each piece with a physical dedicated space that was off of a linear circulation route. This change allowed the individual projects have increased...
Figure 45. Large scale lighting requires collaboration of many individuals

Figure 46. Spatial construction at a human scale

Figure 47. Circulation was defined out of necessity near the end of the project

Figure 48. Shared lighting and acoustic needs were vigorously negotiated

Figure 49. Although visitors exceeded design expectations, individual projects developed means to clarify spatial needs
clarity for dedicated understanding and interaction yet increased the difficulty for making a cohesive space. The issues involved in the making of a cohesive environment in terms of lighting colouring, textures, and acoustics were of great concern to everyone involved. They were not completely defined until quite late in the process and after the circulation had been changed. We feel however that within the context of a more generous design time frame that they would have been worked out at an earlier stage in the process as a guiding principal.

Evolving the Design Tools with the Design

This paper also argues that the design tools (most of which were borrowed from other disciplines) used in the design and prototyping processes, plays an important role in the evolution of the design itself. In particular, how the tools used in prototyping behaviours with real-time feedback influences the processes utilized in designing, and consequently, have a profound effect upon that which is actually designed. The integration of such tools for simulation (rather than representation) into the process of designing lies in an understanding of anything as malleable to idiosyncratic designing needs. In computing, this is comparable to chunks of codes easily becomes reusable ‘tools’, facilitating individuals in developing other codes. The tools as used in teaching this course in Responsive Kinetic Systems, we argue, develop new heuristics if such methodologies can in turn be tracked; they can more aptly facilitate novel tools. The tools and the design, on the generalized level as well as the specific, ought to evolve together. When we are designing with a tool, the heuristics of the process are thereby directed through the affordances and limitations of the tool. However, when the tools used evolve with the design, the heuristics are facilitated by the tools, and not necessarily limited by their parameters. Process then is directed or to motion capabilities for their intended structures along the way. This co-evolution of the design with the design tools has in part, been made possible by the lack of preconception to limitations of the tools themselves on behalf of the design students. In this sense, designers very naturally ‘break the rules’ and consider the tools as pliable as the developing design concept. This in turn has actually facilitated the crossing of boundaries and subsequent acquisition of hands-on knowledge in the said domains.

Architects Directing the Development of Interactive Architecture

Building is a hugely complex endeavour and it is not possible to design a building without consulting many specialists (architects, engineers, construction managers, lighting consultants, mechanical engineers, acoustical experts, financial advisors, and legal experts, etc.) [Cuff 1991] But collaboration is difficult as each specialist comes from a different educational foundation [Kalay 1999], and has goals and criteria and methods that
are different from others. Intelligent responsive architecture, being a more complex building type, will require the collaboration of even more specialists. However, the heterogeneous backgrounds of the participating professionals in the building industry are often a source for misunderstandings and misinterpretations of the communicated information, leading to errors and conflicts. [Kalay 1999]

To overcome this, the paper proposes that architects should take courses on simple mechanics and computation in order to accumulate a superficial knowledge base in these domains. This will enable the architect to share the perspectives and general concerns of other specialists, and to better communicate his design intentions, ultimately facilitating better collaboration amongst the team. Further, we are really at a point in the profession where intelligent responsive systems are possible and even feasible from an economic standpoint. It is both timely and important that architects should take on a more active role in directing the development of this area of design. The idea is not for architects to do structural calculations on a building, nor to develop the computation that controls the behaviour of a responsive system. The traditional role of the architect will not change, but he will have new roles of engineering and consultancy, defining and designing the next generation of responsive buildings.

Conclusion

This paper has described a method for teaching Interactive Architecture as an exemplar of a pedagogical approach to nourish the future generation of architects and interactive systems designers. Design in the new millennium, whether it is a building or an object, will inevitably be increasingly technology-based. Architectural environments will increasingly be smart and responsive and capable of complex behaviours. The motivation lies in learning to create dynamic environments that can physically re-configure themselves to meet changing needs. The goal is to make spaces that behave, respond, interact, and adapt like human beings. The central issues explored are human and environmental interaction, embedded computational infrastructures and kinetic engineering. At the intersection of these areas exists a widely unexplored area of design tuned to address today’s dynamic, flexible and constantly changing needs. It is therefore, timely for architects and designers to equip themselves with foundational understandings in domains like engineering and computation, in order to assume a leading role in helping to shape this future. In fact, the evolving design thinking is one of holistic and experience-based, with the user’s needs and experience taking central stage. That is, the success of intelligent responsive architecture not only lies in designers becoming more fluent with technology, but also having a paradigm shift from ‘space-and-flow-conscious’ to ‘human-need-and-experience-conscious’; from the mindset of designing a library building, to a mindset of designing the enabling factors to support the experience of acquiring knowledge. The goal for the designer is to have enough skills in the areas of interactive design to communicate design intentions through first-hand knowledge. Such communication skills can have a strong effect in architects taking a more active role in directing the development of interdisciplinary design directions. To do this, designers need to have at least a superficial knowledge base of both the engineering in terms of mechanics and fabrication and also the computational substructures in order to develop the necessary skills and the conceptual and intellectual framework for designing. Changes in conventional thinking about what an environment can do as opposed to what an environment is will ultimately revolutionize the way we use space.
References


