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Michael Fox
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Foreword

Right now I'm looking at a 3-D printing device with some amazing technical specifications. (Actually, with a quantity discount, I was able to acquire six.)

Through a high-resolution layered deposition process, it prints varied curved-surface three-dimensional shapes that respond to the signals it receives. The print material is high-density calcium carbonate—amazingly strong and fully recyclable. The precise mix of this material can be adjusted, at the deposition point, to produce many different colors and textures. The forms that it produces are all of the same type, but each one is precisely customized to its particular context.

Best of all, this device is self-replicating. It can produce a new generation of printers that execute essentially the same code. This code can evolve from generation to generation, and specialists in the engineering of this sort of system are now discovering strategies to intervene with more radical reprogramming.

It is, of course, an oyster. And that's just the beginning of its advanced architectural capabilities. In addition, oysters are self-siting. An oyster larva has a light sensor (a rudimentary eye), a few actuators (cilia for swimming), an attachment device (a little sticky foot), and just enough embedded circuitry to integrate these elements into a simple problem-solving system. If this system doesn't get eaten first, it will find a suitable place for the young oyster to grow, and then securely attach itself to that spot.

Furthermore, oysters like to attach themselves to other oysters. (Or, if you prefer, they behave like developers—simply choosing spots where it seems that predecessors have already done well.) That's enough to initiate a self-assembly process. Over time, this process generates large oyster beds—megastructures, composed of individual living pods, that might have been the envy of the Metabolists. The shells of the pioneers form a foundation from which the bed rises free from the muck of the sea floor and into a zone of more abundant sunlight and nutrients. Within the structure, the shape of each unit is beautifully adapted to the shapes of its neighbors.

Once it is settled, an oyster initiates an automatic hardware upgrade and begins to respond to its environment in a new way. It gets rid of the eye, the cilia, and the foot, and activates new gear and associated logic in their place. Oyster 2.0 devotes itself to slightly parting its shells, straining plankton out of seawater, and closing up again if something unwelcome hits its gills. Simple sensors, actuators, and feedback loops of the kind that were investigated by the pioneers of cybernetics now control its responses to its changing environment.

For creatures that scarcely have central nervous systems, this isn't bad. Oysters respond to changes in their environment on three time frames. In real time, they open and close their shells as necessary. Over their individual life spans, they select sites and adaptively build structures that respond to local conditions. And, over many generations, they construct much larger-scale configurations that respond to long-term topographic and hydrographic patterns.

So consider the oyster, with its capacity to create huge, complex, responsively varied structures through distributed intelligence and action, self-replication, elegantly simple principles of self-organization, and real-time connection of actuators to sensors. Through the evolution of its capabilities, it has already figured out the principles of intelligently responsive architecture.

As this book demonstrates, human architects are now starting to catch up.

—William J. Mitchell

Introduction

This book looks at the potential of interactive architecture (IA): what it is, how it can impact our lives, what is necessary in its design, and where we are headed. *Interactive Architecture* outlines a vision for the future through contextualizing and understanding the current landscape of projects and trends in IA, and its integration of new emerging technologies. The current landscape of interactive space is built upon the convergence of embedded computation (intelligence) and a physical counterpart (kinetics) that satisfies adaptation within the contextual framework of human and environmental interaction. Rather than explicitly explaining why interactive systems are necessary, meaningful, or useful, we state that the motivation to make these systems is found in the desire to create spaces and objects that can meet changing needs with respect to evolving individual, social, and environmental demands.

Advancement will only be accomplished when interactive architectural systems are addressed not primarily or singularly, but as an integral component of a larger vision that takes advantage of today's pervasive, constantly unfolding, and far-reaching technology. It is hard to anticipate how quickly the types of interactive architectural systems outlined in this book will be widely adopted, but it is not difficult to see that they are an inevitable and completely integral part of how we will make buildings in the future. To a great extent, the success of creating such systems in architecture will be predicated upon the real-world test bed. The future of architecture will utilize unique and wholly unexplored methods and applications that address dynamic, flexible, and constantly evolving activities. It is up to architects, designers, and users to understand the foundations of the subject matter in order to extrapolate a vision of architecture to come.

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In order to create a historical outline of interactive architecture as put forth in this book, it is necessary to first clarify its definition. The current terminology abounds with terms such as "intelligent environments," "responsive environments," "smart architecture," and "soft space." This book is concerned with only the physical and tangible, which automatically eliminates a wealth of digital media projects that are in fact "interactive" but that are not considered here as "interactive architecture." Additionally, interactive architecture is, by definition here, a two-way street. As Usman Haque puts it, such systems must utilize a definition of interaction as circular, or they are merely "reacting" and not "interacting." A truly interactive system is a multiple-loop system in which one enters into a conversation: a continual and constructive information exchange.[1] As people interact with architecture, they should not be thought of as "users" but instead as "participants." Marcos Novak uses the term "transactive intelligence" to define architectural intelligence that not only interacts, but that transacts and transforms both the user and itself.[2]

We begin with an overview of the theoretical work of a number of people working in cybernetics in the early 1960s who laid much of the groundwork in interactive architecture. These early ideas rooted in cybernetics were picked up at the time by a few architects who solidly translated them into the arena of architecture. At that time the computational means were not quite evolved enough that the proliferation of concepts in cybernetics could gain a strong foothold. The computational world did begin to advance quite rapidly, however, tangentially skirting the field of architecture in a much more pragmatic and market-driven fashion. Cultural and corporate interests played major roles in influencing interactive architecture through the development of numerous market-driven products and systems that directly involved users in the real world. In the 1990s, interactive architecture began to gain a stronger foothold as ideas became both technologically and economically feasible. It was also at this time that the long history of kinetics in architecture began to be reexamined under the premise that performance could be optimized if it could use computational information and processing to control physical adaptation in new ways to respond to contemporary culture. More recent developments have begun to signal a shift from a mechanical paradigm of adaptation to a biological paradigm. The prevalence of the organic paradigm is beginning to alter the conceptual model that we apply in order to comprehend our environment and, consequently, design in our environment. Organic theory emerges from nature and possesses evolutionary patterns that produce forms of growth and strategies of behavior, optimizing each particular pattern to the contextual situation.[3] Consequently, the organic paradigm of kinetic adaptation has driven a profound set of developments in materials, autonomous robotics, biomimetics, and evolutionary systems, whereby the adaptation becomes much more holistic and operates on a very small scale.

In the 1960s, Gordon Pask and other cyberneticians made advancements toward understanding and identifying the field of interactive architecture by formulating their theories on the topic. Pask, who later collaborated with a number of architects in the 1970s and 1980s, developed a "Conversation Theory," which served as the basis of much of the architectural development in interactive architecture at the time.[4] Rather than an environment that strictly interprets our desires, he says, an environment should allow users to take a bottom-up role in configuring their surroundings in a malleable way without specific goals. Haque points out that such early theoretical foundations had difficulties establishing much of a foothold; Pask's trouble, in particular, was a lack of marketing potential in his physical proof-of-concept models. The realm of such proof-of-concept prototypes was essentially driven out by the development of the digital computer. By the mid-1960s, in fact, funding was waning for bottom-up approaches to artificial intelligence and cybernetics such as neural nets, evolutionary programming, cybernetics, biological computation, bionics, and so forth. Most research in these areas had to adapt to what could be implemented digitally in order to be funded.[5] Around the same time, the architect William Brody published a rather visionary article in 1967, which proposed that we teach our environments first complex, then self-organizing intelligence that could eventually become evolutionary.[6] Nicholas Negroponte, the founder of the MIT Media Lab, also speaks of similar ideas in his seminal book called *The Architecture Machine*, although the applications he described were more concerned with digital media and design processes than the physical built environment.[7] Charles Eastman further developed the model of Adaptive-Conditional Architecture in 1972 by expanding upon the earlier ideas of Pask and Norbert Weiner,[8] in which architects interpreted spaces and users (participants) as complete feedback systems. Eastman proposed that feedback be used to control an architecture that self-adjusts to fit the needs of users. These cybernetic ideas essentially describe such responsive actions of users and architecture as "dynamic stability," which can be visualized with the often-cited analogy of a boat at sea constantly manipulating its rudder against the variable environmental conditions of wind and current to maintain a straight course. However, it is important to note that Eastman's model was essentially that of a machine-led approach. Andrew Rabeneck made a very pragmatic interpretation in 1969 by proposing the use of cybernetic technologies to produce an adaptive architecture that would increase the useful life span of a building through adaptation.[9] Tristan d'Estrée Sterk proposes a hybridized approach combining the machine-led approach and the cybernetic technologies in architecture.[10] This notion of hybridization has prevailed today in modern robotics, whereby simple automated feedback is coupled with higher-level deliberative processing.[11]

Cedric Price was perhaps the most influential of the early architects to adopt the seminal theoretical work in cybernetics and extend it to an architectural concept of "anticipatory architecture." Many of his unbuilt projects, such as the Fun Palace in 1961, influenced an architecture of process that was indeterminate, flexible, and responsive to the changing needs of users and their times. His Generator project was an important "early investigation into artificially intelligent architecture that was designed with no specific program, but only a desired end-effect, in mind."[12] In order for something to be considered "intelligent" in this context, it must be able to learn about its world and develop its own ability to interact with it. John Frazer, who was a systems consultant on the project, extended Price's ideas, in positing that architecture should be a "living, evolving thing." This theory is summarized in the book *An Evolutionary Architecture,* which shows examples from the work of nearly thirty years with students, and collaborations with Pask himself. These projects include many built constructions and prototypes from work at the Architectural Association in London.[13] The work relies heavily on biological and scientific analogies and the sciences of cybernetics, complexity, and chaos. Frazer's work is valuable, as it extends beyond the design process to the built works themselves. He outlines eight aspects of evolution that all produce change at a variety of scales, and the basis of all such conditions is information. He makes a strong environmental case for such ideas without actually advocating the replication of natural ecosystems. He states, "Natural ecosystems have complex biological structures: they recycle their materials, permit change and adaptation, and make efficient use of ambient energy."[14] At that time, these ideas were perhaps an interesting counterpoint to static architecture; now, however, they have become keywords for architectural environmental responsibility.

Up to this point, we have looked at the early theoretical ideas behind interactive environments, and a number of architects attempting to project them into an architectural horizon. After examining this theoretical groundwork, it is important also to understand the historical development that was happening, somewhat in parallel, in digital computation and human

Intelligent environments are defined as spaces in which computation is seamlessly used to enhance **ordinary activity.**

interaction. Until recently, aside from the more visionary theorists mentioned above, the notion of intelligence in the context of interactive environments revolved around a central control system for everything; these systems were called "smart environments." Without diving too deeply into the history of computers and their integration with architecture here, to summarize, in the 1980s and 1990s, an explosion of development began to take place within the field of computer science. Out of this, fields such as "intelligent environments" (IE) were formed to study spaces with embedded computation and communication technologies, creating spaces that bring computation into the physical world. Intelligent environments are defined as spaces in which computation is seamlessly used to enhance ordinary activity. Michael Mozer, who led the development of the pioneering Adaptive House in the late 1990s, speaks of the "intelligence" of the home as that which arises from the home's ability to predict the behavior and needs of the inhabitants by having observed them over a period of time.[15] Instead of being programmed to perform certain actions, the Adaptive House essentially programmed itself by monitoring the environment and sensing actions performed by the inhabitants, observing the occupancy and behavior patterns of the inhabitants, and learning to predict future states of the house.[16] Another approach was that of MIT's Intelligent Room project, directed by Michael Coen, which was created to experiment with different forms of natural, multimodal human-computer interaction (HCI) by embedding computational smarts into everything with which the users come into contact. The goal was to allow computers to participate in activities that have never previously involved computation and to allow people to interact with computational systems the way they would with other people.[17]

The developments in IE were essentially fueled by the concept of "ubiquitous computing" (a term coined in 1988 by Mark Weiser as a postdesktop model of human-computer interaction). Ubiquitous computing can be defined as computation thoroughly integrated into everyday objects and activities, and it is often regarded as the intersection of computer science, behavioral sciences, and design. In ubiquitous computing, users engage many computational devices and systems simultaneously in the course of ordinary activities, and may not necessarily even be aware that they are doing so. Weiser described this as "the age of calm technology, when technology recedes into the background of our lives."[18] At the intersection between computer science and architecture grew the seminal work of the MIT Architecture Machine Group, which developed a number of seminal projects during the 1970s and 1980s in media and interface design and even computationally enhanced environments.

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Clearly, corporate and cultural interests also played important market-driven roles in the development of interactive architecture. These roles were extremely important, as they directly involved the users out in the real world; however, they were not integrated with the earlier theoretical architectural concepts of interactivity. In the 1950s, widespread developments were taking place in environmental control systems within buildings as a direct derivative of the introduction of sensors with remote signaling allowing for a central control room.[19] The invention of the "remote control" also came along at this time, enabling the user to assume a larger role as an operator of objects in space. The 1960s saw an evolution of system control and management as the control room turned into a hardwired control panel with the capacity to record information and alert users of problematic parameters. Mahesh Senegal points out two diametrically opposed perspectives that prevailed at this time: that of a life defined by pragmatic convenience and that of a life controlled by the machine, whereby the users become dependent upon their environments.[20] While both perspectives survive today to some extent, we have come to embrace every new technology with the promise (perhaps illusionary) of convenience, but for the most part, without the fear. The 1970s signaled a turn toward a promise of environmental efficiency, when architects sought to justify technology that could improve building performance and consequently save money. Energy management systems were introduced as well as microprocessors but, for the most part, the architecture world had yet to embrace the promises of such technologies from an interactive standpoint.

The 1980s, perhaps stirred by the introduction of the personal computer, heralded a shift in user thinking or outlook, whereby the connotations of "enslavement" began to be replaced by "empowerment."[21] The PC became the interface that replaced the central console control, distributed direct digital control replaced conventional control systems, and communication could be programmed to take place on local area networks. Such developments also clarified the problems of integration, whereby many non-communicative independent protocols hit the market for individual products at the same time. A new need consequently arose to standardize the methods by which different types of hardware could communicate with one another; this, however, was not satisfied, as the protocols were proprietary and economically very valuable. The result was that many noncommunicative independent protocols hit the market for individual products at the same time. Incompatibility is still a major battle being fought today, which will be discussed further in Embedded Computation.

The driving force behind the renewed interest in adaptable architecture is the technologically influenced and **changing patterns of human interaction** with the built environment.

Eventually architectural academia began to assemble comprehensive prototypical projects based on real-world, market-driven developments. Numerous academic "smart home" and "smart workplace" projects were initiated in the 1990s that relied heavily on available technological advancements. It was a time when wireless networks, embedded computation, and sensor effectors became both technologically and economically feasible to implement. This feasibility fueled experimentation with many of the ideas of the early visionary architects and theoreticians outlined above that had been stifled by the technical and financial hurdles of their day. It was at this time that architects began to reinvestigate the economics of obtaining cheap computational hardware and increased aptitude to integrate computational intelligence into architecture. The interactive architecture workshop at the Bartlett School of Architecture was initiated in the early 1990s as a pioneering forum for actual architectural pursuits under the guidance of Stephen Gage. Also, the use of the Internet undoubtedly played a major role in both the technological and intellectual dissemination responsible for progress in the field. Since the 1990s, numerous architecture schools have expanded their programs to incorporate interactive design.

It is relevant to note that in the late 1990s, a long history of kinetics in architecture began to be reexamined under the premise that performance could be optimized if it could use this newfound computational information and processing to physically adapt.[22] Architecture began to revisit traditional kinetic aesthetics with new technological innovations, spurred on by Robert Kronnenberg with a series of exhibitions and conferences on transportable environments. The traditional problems of motion, stasis, and order were challenged, redefined, and transformed by new possibilities, and strategies opened up through technological innovation, particularly technologies and new approaches to mobility and transportation related to contemporary nomadic culture.[23]

The driving force behind the renewed interest in adaptable architecture is the technologically influenced and changing patterns of human interaction with the built environment. Today's intensification of social and urban change, coupled with concern for issues of sustainability, amplifies the demand for interactive architectural solutions.

These technologically driven human behavioral patterns are beginning to facilitate a paradigmatic shift from the mechanical to the biological, from a standpoint of adaptation. Change in the mechanical world is cyclical, but there is no development, as the factors are continually repeated with set outcomes; the organic paradigm is developmental and reciprocal: it

Technology transfer from similarly integrated interactive developments in other fields will continue to predicate, impact, and **evolve** with interactive architecture.

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emulates life. Organic theory emerges from nature, an environment that possesses evolutionary patterns that produce forms of growth and strategies of behavior, optimizing each particular pattern to the contextual situation.[24] Thus, the organic paradigm of kinetic adaptation has driven a profound set of developments in both robotics and new materials whereby the adaptation becomes much more holistic and operates on a very small internal scale. Technology has provided recent unprecedented insight into the workings of microscopic natural mechanisms and advanced manufacturing of high-quality kinetic parts with new materials including fabrics, ceramics, polymers and gels, shape-memory alloy compounds, and composites.[25] In the same vein, we cannot ignore those structures and systems being explored at even smaller scales, such as the nano. Nanocomposite materials are being developed that are self-sensing and self-actuating to improve strength, reliability, and performance. The combination of new materials and robotics at a very small scale opens up a fascinating area that is relevant to interactive architecture in bionanotechnology. Interactive architecture could greatly benefit from the integration of biological functions and nanoscale precision.

Technology transfer from similarly integrated interactive developments in other fields will continue to predicate, impact, and evolve with interactive architecture. Such transfer is particularly clear with respect to the innovations in aerospace design, automotive design, interface design, and digital media. Interestingly, the forecast of development can be retrospectively viewed in industries other than architecture: "nearly 80 percent of all innovations within automobiles are derivatives of electronic systems."[26] Until recently, nearly all innovations were related to manufacturing and fabrication.[27] The "drive-by-wire" technologies in the automotive industry replaced the traditional mechanical and hydraulic control systems with electronic control systems using electromechanical actuators and human-machine interfaces. This technology, of course, was predicated on fly-by-wire technology in the aircraft industry. Both are derived from the application of embedded computation, which is now quickly taking center stage with respect to the built environment. Will we soon see the age of "live-by-wire" and "work-by-wire" technologies? Recent developments in the area of interface design will also eventually play out in interactive architectural environments. A boom in sensor innovation and manufacturing has signaled the availability of previously unimaginable means for gathering data and information.

In this book, interactive architecture is positioned as a transitional phenomenon with respect to a movement from a mechanical paradigm to a biological paradigm. Most of

In this book, interactive architecture is positioned as a transitional phenomenon with respect to a movement from a **mechanical paradigm to a biological paradigm**.

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the interactive architectural projects presented here are based on mechanical principles of adaptation. However, a number of related fields are beginning to adopt a direct analogy with the underlying design and operational processes of nature through biologically inspired principles. A biological paradigm of interactive architecture requires not just pragmatic and performance-based technological understandings, but awareness of aesthetic, conceptual, and philosophical issues relating to humans and the global environment. Further, it repositions the role of the designer as a catalyst of design that evolves. The organic paradigm also ensnares a reinterpretation of the scale at which designers work and view the world. Interestingly, this issue of scale is inherently tied to manufacturing and fabrication. While recent innovations have been derived through electronics, we are beginning to see a renewed upsurge of innovation in manufacturing and fabrication that is heavily influenced by both biology and scale. It is also important to mention that many early examples of interactive architecture were based on developments in digital media, and IA will continue to be articulated through the accessibility (both economically and technically) of nontangible forms of interaction.

Interactive Architecture outlines the foundations and future visions of IA. The foundations of the field reside in physical change and embedded computation, and will be understood by placing them into their respective contextual timelines. The trends in these two fields have begun to emerge into what we now consider to be interactive architecture. This field is in its infancy, and there are many exciting directions to be explored and researched. This book examines a number of different projects that exemplify characteristic qualities and show specific details about where they fit into the contemporary timeline of IA. After examining where we currently are and how we have gotten here, this book concludes with speculations on the future horizons of IA and the emerging technologies and trends. In the future, we will find that architecture can significantly influence our lives by interacting with us and consequently shape the ways in which we interact with each other. If architecture is to continue to respond to the technological innovation that surrounds it as a profession, then we may no longer ask "What is that building?" or "How was it made?" but rather, "What does that building do?"

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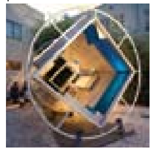
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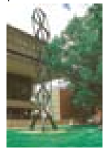
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Trends in Kinetic Architecture

Everywhere we look, a discourse is taking place about intelligent architectural environments regarding how spaces and objects can have the ability to gather information on user activities and anticipate what users might do in the future. An obvious question arises: what is architecture physically doing with all of this information in terms of using it to adapt? This is where kinetics becomes important; physical adaptation necessitates kinetic movement at a variety of scales and applications. Kinetics, in the context of this book, will be defined generally as either transformable objects that dynamically occupy predefined physical space, or moving physical objects that can share a common physical space to create adaptable spatial configurations. Robert Kronnenberg defines such systems as buildings or building components with variable mobility, location, and/or geometry.[1] The means by which the above is carried out will be discussed in both mechanistic and biological terms. Kinetic function is identified here primarily as technological design strategies for building types that are inherently flexible with respect to various contexts and a diversity of purposes. The first section of this chapter examines basic trends in kinetic architecture and provides a historical context with general concepts of application. The second section builds on this by further examining specific details relating to the mechanics of these kinetic systems. The final section looks toward the future of kinetics by examining the role and importance of materiality and a natural evolution from mechanical to biological systems.

Arguably, the most innovative designs utilizing kinetics arise from unique situational use, and it is this use that is a driving force in the changing and evolving patterns of human interaction with the built environment. The ability to not only monitor but also physically

Kinetics, in the context of this book, will be defined generally as either **transformable objects** that dynamically occupy predefined physical space, or **moving physical objects** that can share a common physical space to create adaptable spatial configurations.

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control environments is unveiling important implications and applications. There is great potential for dynamic architecture that arises from understanding what a space or object is currently doing and how it can aid in promoting or accommodating a specific task. Some of this understanding relates to dynamically changing architectural elements or spatial layouts that address desires to have public or private space, to optimize thermal, visual, lighting, and acoustic conditions, and to promote sharing or collaboration in space. This understanding boils down to examining how architecture can extend the notion of enhancing our everyday activities by assisting users in accomplishing specific activities or possibly suggesting new ways to interact with space and other users to complete tasks. William Zuk states in his classic book *Kinetic Architecture* that "our present task is to unfreeze architecture, to make it a fluid, vibrating, changeable backdrop for the varied and constantly changing modes of life. An expanding, contracting, pulsating, changing architecture would reflect life as it is today and therefore be part of it."[2] Kostas Terzidis explains that "deformation, juxtaposition, superimposition, absence, disturbance, and repetition are just a few of the techniques used by architects to express virtual motion and change." He clarifies the polarity that while the form and structure of the average building suggest stability, steadiness, sturdiness, and immobility, the introduction of motion may suggest agility, unpredictability, or uncertainty and may also suggest change, anticipation, and liveliness. The integration of motion into the built environment, and the impact upon the aesthetics, design, and performance of buildings, may be of great importance to the field of architecture. "While the aesthetic value of virtual motion may always be a source of inspiration, its physical implementation in buildings and structures may challenge the very nature of what architecture really is."[3] Kronnenberg lists a number of benefits in his book *Transportable Environments 2*, including image, function, security, flexibility, energy use, reliability, user-friendliness, and life-cycle costs.[4]

In architecture, the notion of kinetics implies relationships of cause and effect. A number of things typically happen to architecture to which it must adapt: the set of pressures (user demands relating to activity in space) and original purpose of the building changes, whereupon it must either be remodeled, or torn down and replaced. Zuk argues that a solution is to design a space that can meet any functional demand.[5] To be able to design such a space requires an exploration of the dynamics, flexibility, and adaptability of the architectural environment. One way to begin exploring the dynamics is through rethinking architecture beyond conventional static and single-function spatial design. Emphasis is on the dynamic

One way to begin exploring the dynamics is through **rethinking architecture** beyond conventional static and single-function spatial design.

configuration of physical space with respect to constantly changing needs.[6] While we examine these dynamic spatial needs, it is important that we understand that adaptation is not quite as simple as merely satisfying needs. Pan states that "needs and desires change, permitting new options to be employed, allowing greater freedom of geographical movement, accepting personal whim, recognizing changing roles and functions, encouraging personal identity, reflecting mutations in economic levels, and adapting to any change which affects architectural form."[7] Christopher Alexander suggested that the concept of a form inclueneced by need, however, is not inclusive enough and that it is essentially too inactive. Instead, form ought to be influenced by the concept of pressure, which is a set of forces: a series of interacting and nonisolated elements in which a change in any one force affects the whole. The set of pressures thereby acts upon and generates form.[8] Zuk clarifies that there are both physical and nonphysical forces that become the form generators, which can then be interfaced with technology.

The technology Zuk refers to in the specific scope of this chapter is kinetics, while in the context of the book, it is interactive architecture. It is increasingly necessary to develop architecture that recognizes the fluidity of the set of pressures to which form must respond and of the technology that allows us to interpret these pressures and the situations in which they exist. Continual change is implicit in the concept of development, which suggests that a time-oriented developmental principal should be considered for each generating system within the set. We must find techniques that will permit continued evaluation of dynamic demands and of the possible advantages to changing the way space is arranged to enhance these activities. Consequently, as the inherent technology of kinetics improves, our ability to understand the dynamic nature of these demands will also change.

Historically, kinetics in architecture has had its roots in pragmatic adaptability. This pragmatic adaptability spans many different scenarios—from a nomadic need for mobility in order to follow sources of food, to adjusting to the landscape for cultivating crops, to accommodating to changing climatic situations, to running from enemies—which show there has always been the need to adapt and be mobile. Kronnenberg states that because of the way in which the world is changing technologically, socially, economically, and culturally, it is probable that flexible, transformable, transportable design is as important now as it was when, in past millennia, the nomadic way of life was the dominant one across the planet.[9] Labelle Prussin explains how villages and individual compounds of primitive cultures were

Today's intensification of social and urban change, coupled with the need for sustainable responsibility, amplifies the **demand for novel architectural solutions**.

in a constant state of flux: "The indigenous builder is constantly remaking and remolding his place to suit the constantly changing relationships inside and outside the family unit."[10] The form of a village is determined by the geology of the area, which directly influences the patterns of the agriculture. The settlement patterns that result are nucleated if land rotation and crop cultivation is necessary, or dispersed if compound farming is possible.

Today architecture finds itself in a position to revisit its traditional kinetic aesthetics using new technological innovations. Traditional problems concerning motion, stasis, and order can be challenged, redefined, and transformed by these recent innovations as they open up new possibilities for new architectural strategies, particularly new technologies and approaches related to the mobility of nomadic culture. The driving force is in the technology influencing the changing patterns of human interaction with the built environment. Gary Brown argues that mobile technology has enabled self-sufficiency, which has increased nomadic tendencies. He claims that architectural and urban space today has lost its specificity as defined by a particular architectural description of programmatic needs. Traditional building typologies are shifting in response to technologically influenced social changes. In response to new social mobility, typologies begin to blend and become interchangeable. "A universal type of space has developed, one designed around this mobile technological relationship that draws together formerly distinct typologies of education, administration, servicing, and certain aspects of production, communication, and entertainment."[11] Walk into any coffee shop today, and you witness a resurgence of the culture that once existed in the nineteenth century, fueled by a "connect anywhere" culture: "The café was a library, study, meeting place and an address, a place which blurred the distinction between being at home and being out-and-about."[12] In a world where the contemporary coffee shop has blurred similar boundaries, kinetics must provide dynamic forms capable of meeting a range of pressure changes inherent in a society that demands a physical space for meeting, where the individuals may or may not all be physically present. One does not have to look far to identify many other nomadic types, such as the enormous population of elderly motor-home owners "who have left behind the idea of permanent home to embrace a home that is truly mobile, with a different view every evening."[13] The scope of pressures of form therefore must encompass not only the individual, but also the collective social organism, including the family, neighborhood, city, metropolis, and so on. Cultural and other concerns such as ideologies, moral and ethical codes, economic conditions, standards and principles, The implications of kinetic architecture touch upon **building performance** on the one hand and **aesthetic phenomenology** on the other.

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and political situations and convictions must also be included in the nonphysical category of these pressures.[14]

Generally, pressures can be categorized as "pragmatic" or "humanistic." The implications of kinetic architecture touch upon building performance on the one hand and aesthetic phenomenology on the other. Pragmatic applications, which have previously been described, are concerned with solving needs and optimizing solutions. The general implications of utilizing such systems in architecture include, but are not limited to: space efficiency, shelter, security, transportation, safety, and, of course, economics. Kinetics is employed for pragmatic adaptability today, and its various applications range from creating full mobility to interior reconfiguration. One can also go to any modern convention hall and see a diverse array of architectural-scale exhibits that are assembled within a matter of days and can just as easily be disassembled and moved to the next convention location. There are also numerous examples of kinetic interiors, including furniture and systems in contemporary office environments that are adaptable to the scale of the individual user.

Humanistic pressures are concerned with how such changes in our architectural environments actually affect us, both physically and psychologically. There is a cognitive appreciation of motion that lies in the interpretation of complexity derived from simplicity. From E.J. Marey's chronophotographic studies, to the motion and efficiency studies of the Gilbreths, to numerous examples in modern art, such as Duchamp's *Nude Descending a Staircase*, there has been and continues to be a history of exploration into how to describe and capture motion.[15] With respect to the phenomenological aspects of motion in architecture, we need to understand that there is always a person experiencing the space (usually also in motion) with a specific vantage point, and so the motion must also be choreographed with the understanding that the vantage point is also dynamically changing. Harsh Kabra states, "Imagine a design where all is in motion. The result is a moving image, the behavior of which becomes the responsibility of the designer; an architect, much like a cinematographer, programs human experiences of moving through the spaces he designs. Informing this preconceived kinetic architecture are real people who transform these spaces into places, imbuing them with life and meaning."[16] Kostas describes the architect of the past as a virtuoso performer, whereas "the future architect may become the composer of symphonies in form, space, and color."[17] Chuck Hoberman suggests that there is a psychological association between transformation and life, which everyone perceives at an emotional level: "When one sees

Novel applications in spatial optimization arise through addressing how transformable objects can dynamically occupy predefined physical space.

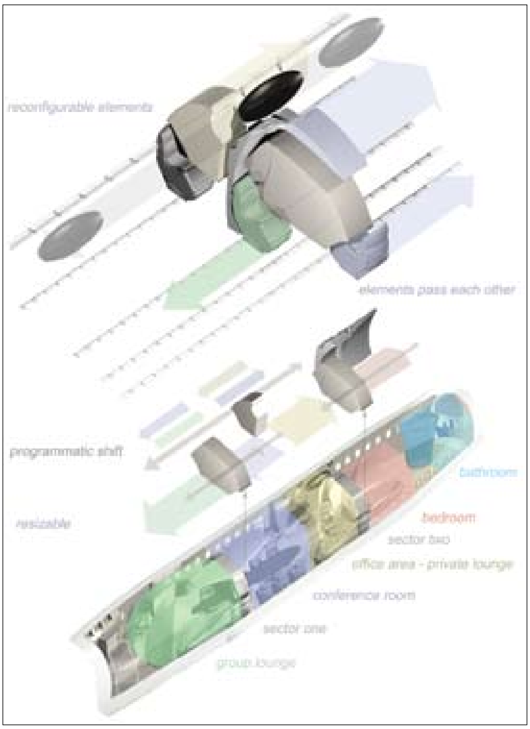
this special behavior [of transformation], one feels it in one's body—perhaps a physiological connection, because there is a sensation, a physical sensation and a mental and perceptual sensation."[18]

Brown points out five key strategies for bringing about such movement to architecture: architecture can be preprogrammed to self-destruct; architecture can grow over time; architecture can be designed to be constructed with its imminent disassembly in mind; architecture can be designed as a framework for universal facilitation; and architecture can be designed as a transformer, adopting more than one geometrical form of stasis.[19] We break down the application of kinetics into four general categories of use in architectural environments: spatial optimization, multifunction design, contextual adaptability, and mobility. Within these categories, applications may address the pragmatic, the humanistic, or both. After a general overview of the subject, we will examine how this knowledge can be applied to specific types of projects. Later sections in this chapter will examine several kinetic projects in more detail and speculate on the future of kinetic design in architecture as a means of understanding and appreciating the benefits and capabilities from pragmatic and humanistic perspectives, rather than how kinetic systems are mechanically employed.

The kinetics for spatial optimization systems are generally described as how systems can facilitate flexible spatial adaptability. Multifunction design differs from spatial optimization systems, because these systems specifically provide the means for a plurality of optimized states to address changing use. Additionally, contextual adaptability is defined by how kinetics can be employed to dynamic or unknown contextual situations. Lastly, we look at kinetics and mobility whereby the kinetics serves as the obvious means for practical transportability and deployability. > Fig. **1**

We can define spatial optimization as a kinetic environment that can, from a practical standpoint, serve as a means for adjusting spatial configurations based on changing stimuli triggered by environmental and/or human actions. Optimization scenarios should be examined both physically and organizationally for the development of a system that has the ability to accommodate spatial adaptability. As an example, on any particular workday, only twenty-five workers use an office space that was designed to accommodate forty employees. Could the physical space be optimized by kinetic means to use only what physical resources are necessary at any given time, while maximizing what is available? Classic examples of this type of spatial optimization are common in such spaces as convention centers, banquet halls,

> Fig. 1: MIT Kinetic Design Group, *Domus Magazine Competition/Boeing*.



Multifunction design can be defined as how movable physical architectural objects can share a common physical space to provide the means for a plurality of uses.

and school gymnasiums. These are typically large, open spaces with a built-in transformable infrastructure. Such systems can provide differing configurations that are both facilitated and limited by the infrastructure. Novel applications in spatial optimization arise through addressing how transformable objects can dynamically occupy predefined physical space. Applications may range from multiuse interior reorganization to complete structure transformability in response to unexpected site and program issues. It is important to understand that applications in spatial optimization need not be limited to interior spaces with fixed exterior configurations. Kronnenberg points out that through the application of such systems, "We can also explore how objects in the built environment might physically exist only when necessary and disappear or transform when they are not functionally necessary."[20] > Fig. **2**

There is a great potential for applications that arise from understanding what an architectural space or object is currently doing and how it can do it better. In other words, designers should take an existing design and ask how issues of privacy and public needs can be dynamically addressed while spatial sharing is concurrently optimized. Other related issues that should be addressed include acoustic and visual control. For example, each person in a space may have different desires to view and participate in activities in the same environment. These desires could be greatly enhanced by the dynamic ability of the space to optimize its shape to address issues relating to privacy and connections between people. People should also have the ability to dynamically optimize their personal connection to the acoustics of a home or workplace, regardless of whether this connection is with a television or a neighboring worker's conversation. Both visual and acoustic considerations typically also necessitate physical configuration changes that need to be spatially optimized. Whether the issue is partition walls or the direction of a chair or table or desk, it is important to understand and accommodate an inclusive range of humanistic considerations on top of the more pragmatic spatial optimization of the space. > Fig. **3**

Multifunction design can be defined as how movable architectural objects can share a common physical space to provide the means for a plurality of uses. Systems that are component-based, and therefore deployable, connectable, and producible are ideally suited to accommodate and respond to changing needs. Everywhere around us we find multifunction design in products that range from single devices such as a telephone, a camera, or a camcorder, to an all-in-one printer, copier, and fax machine, to a showerhead with many different settings. However, the current architectural-spatial discussion is limited to addressing

> Fig. **2**: Smart Glass International, *Smart Glass*.

> Fig. **3**: David Fisher, *Dynamic Architecture—The Rotating Tower*


Dynamic Architecture™
by David Fisher ©
Architect

The greatest **wealth of experimentation** with multifunction design can be found at the **interior scale**.

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single-function spaces filled with single-function elements, despite the fact that in actual configurations, this is not typically how we use our environments. The activities we perform in spaces should determine their configurations, and these changes should be quick and spatial enough to truly accommodate particular spatial demands. The kitchen in a house is only used for preparing food for a few hours of the day, and yet it is also used for discussions, eating, watching television, and so forth; however, it does not typically accommodate such activities very well and could be designed to enhance these activities. The living room of a house may sometimes be used as a gathering place for many people, a couple, or only a single person, and each of these situations could be centered around completely different activities ranging from watching a movie (with specific needs for lighting or acoustics) to playing a game or reading a book. Each situation has completely different spatial, visual, and acoustic needs. In a work environment, we also find that there are many different needs for multifunction design to accommodate a wide range of activities that may include a single person or an entire group. We should not simply consider how the space might accommodate such a range of activities and people but also design flexibility into the fabric of the building. In the workspace, we could consider how the room might expand or contract if there were one person or many people using the space or how the walls might transform to allow several smaller rooms to become one room. In architectural design, it is widely known that level changes both in the floor and in the ceiling can be used to psychologically divide spaces. A room could become more intimate with a lower ceiling that also adjusts the lighting and acoustics without changing the disposition of the walls. The walls could also have adjustable fenestration to provide a variable connection to the outside depending on the number of people in the space and their desires relating to the changing environment outside. > Fig. **4**

While multifunction design is common in many spaces, it is typically achieved through the scale of the furniture as a secondary system. The greatest wealth of experimentation with multifunction design can be found at the interior scale. There are numerous kinetic examples in architecture, from hospital rooms that have temporary divisions, to partitions in a work environment, to furniture in the house that can collapse and fold out of the way. It seems, however, that such environments tend to be used only if they are easy enough to be quickly reconfigured by a single person. Typically such applications are driven by pragmatic needs for privacy rather than by any humanistic need for spatial definition in terms of mood, acoustics, or lighting. Contemporary office furniture has taken a turn in recent years toward

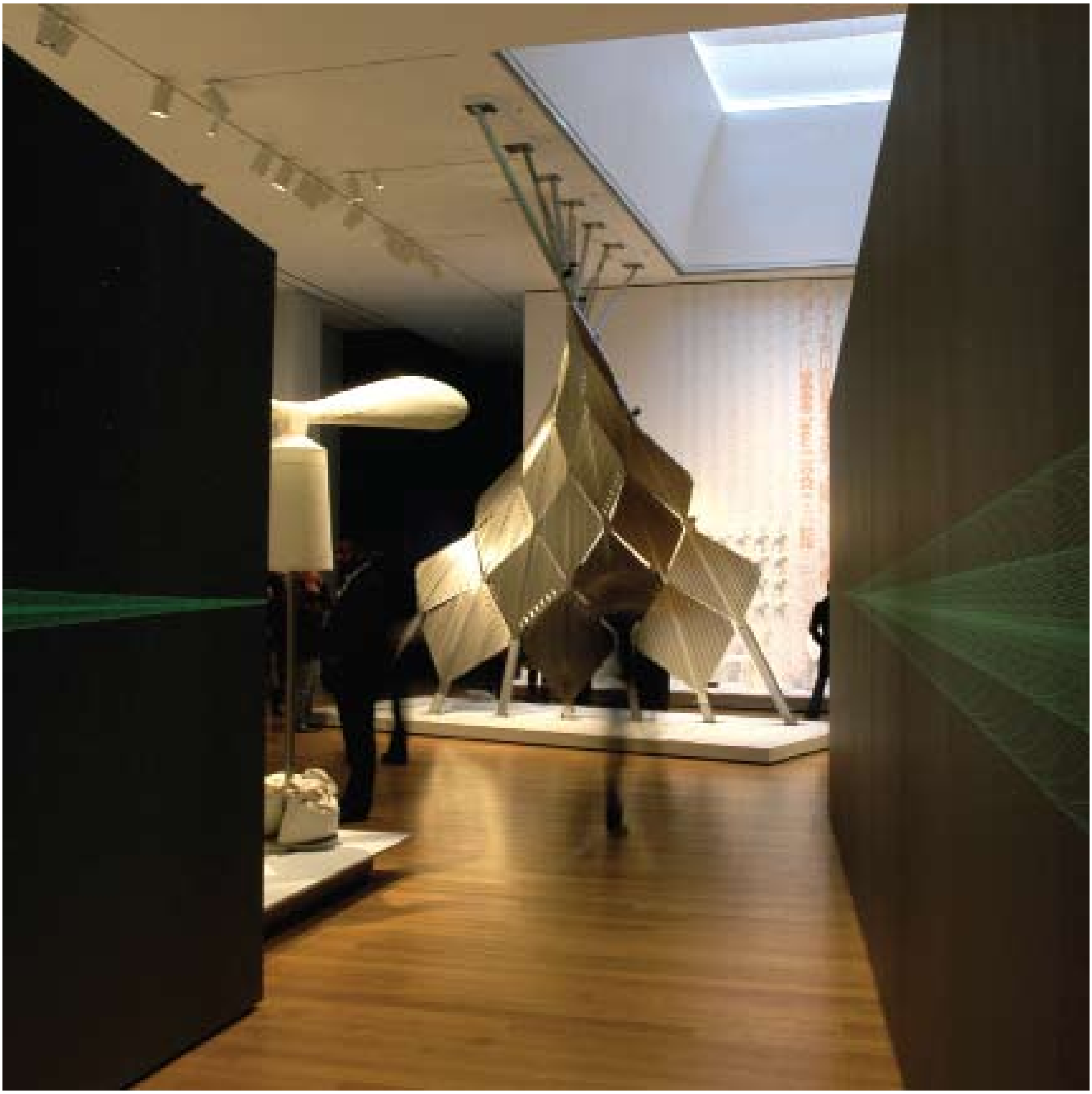
> Fig. **4**: Jimenez Lai, *Phalanstery Module*.

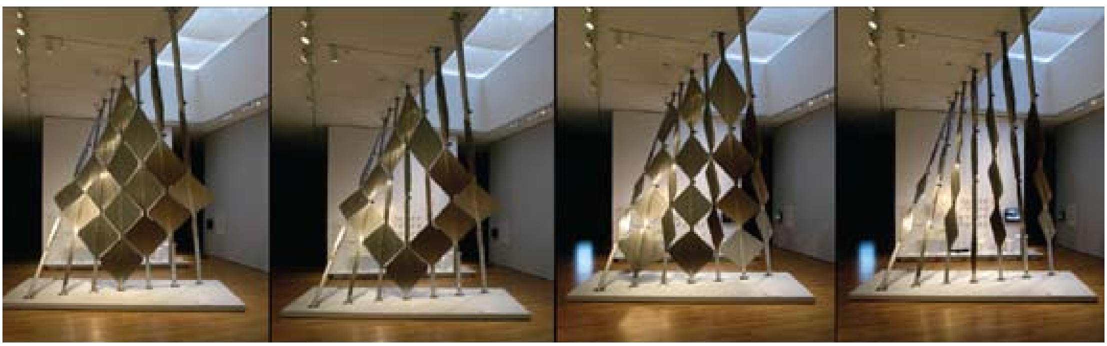
Architects are very good at developing solutions for **contextual response** as well as **flexible adaptability**, but rarely are the two combined into a single system working within our buildings.

creating individually adaptable interior "environments" that extend the notion of furniture to flexibly adjustable interior zones that include both floor and ceiling configurations as well as the traditional desk and shelving requirements. Such environments allow for an inclusive range of control over lighting and acoustics as well as storage, privacy, and spatial disposition. These small environments also consider the positive and negative spaces created by their boundaries that affect the entire office layout in a dynamic way. We can easily identify applications of multiuse design at the scale of interiors when we carefully examine how the space is actually being used on a short-term basis throughout the day. > Fig. **5**

Contextual adaptability in architecture can be categorized into three areas: form, activity, and climatic patterns. We have already touched upon activity patterns above in terms of spatial optimization systems and multifunction design, yet we should equally consider adaptability in terms of both form and climate. Although kinetic solutions in architecture have been around in some form or another since the beginning, a point of great interest today lies in understanding how such systems can facilitate adaptability in terms of contextual environmental conditions and the malleability of such conditions under dynamic urban situations. Typically the response to "contextual architecture" is an initial static condition with no ability for future dynamism; architecture is built to be static with a one-size-fits-all mentality. Architects are very good at developing solutions for contextual response as well as flexible adaptability, but rarely are the two combined into a single system working within our buildings. Contextual adaptability is typically interpreted as a response to the surrounding architectural environment in terms of types and typologies, and if it does extend itself to environmental conditions, it is set as a permanent solution.[21] With respect to the formal issues of context, in a dense urban environment, buildings are constructed and demolished, traffic and circulation patterns change, access to daylight changes, wind currents are modified, and so forth. Our buildings should have the built-in ability to adapt to such long-term changes as they occur over time. In our urban environments, the ability for contexts to evolve is stifled by only responding to a historical or vernacular context. Such contextual issues are certainly not static, but they have often imperceptibly long time frames of change. The irresponsible prioritization of contextual response, as described above, seems to happen regardless of whether, for example, a housing development in the desert is appropriate to the climatic conditions or whether the materials or labor that were originally used for the contextual architecture are still available. Contextual architecture often narrowly confirms

> Fig. **5**: Hoberman Associates, *Emergent Surface*.





Changes in site conditions are often dealt with through the **superficial addition** of window shades or landscaping and **not through the architecture** itself.

the continuity of the present with the past and rarely extends to the future in a short-term, dynamic way. Contextual adaptability, on the other hand, keeps ties with the past as it transforms into the future, whereby the context of a house extends far beyond the mere physical components that comprise the actual structure. > Fig. **6**

Environmental conditions are dynamic with respect to both seasonal weather trends and the surrounding architectural environment. With respect to global warming and the natural environment, we need to challenge our ideas about context with adaptable buildings that take a more inclusive approach to context than those merely designed to respect the architecture of historic buildings already present in an area. In areas susceptible to hurricanes, we see images on the news of homeowners boarding up their windows to prepare for the storm, and on a hot day, we see windows and doors being opened up to allow for natural cross ventilation. Thus, buildings in more extreme situations are subject to extreme ranges in weather, and yet they are typically very static especially in terms of their response to their ranges, including both the internalized systems and their response to the changing context. Changes in site conditions are often dealt with through the superficial addition of window shades or landscaping and not through the architecture itself. Such changes are predictable only to an extent defined by codes and regulations and should be dealt with beyond these parameters in a dynamic way that is built into the architecture itself. Industry and research efforts are quickly moving to this area. Philip Beesley points out that "a common approach is to augment buildings with kinetic capability, allowing buildings to alter their physical shape in response to climate conditions."[22] Brown states it quite well, explaining that "ecological issues and sustainability reintroduce the importance of appropriate architectural interaction with the local and universal environment in which it is built."[23] It is part of the general strategy to use nature as an example to design, particularly with its performance and action. Hoberman suggests the use of biomimicry as a "practical means to build structures or develop products that can change size and shape in order to have some structural benefit, a reason."[24] The engineer Guy Nordenson suggests that if architects designed a building like a body, it would have a system of bones and muscles and tendons and a brain that knows how to respond. "If a building could change its posture, tighten its muscles and brace itself against the wind, its structural mass could literally be cut in half."[25] > Fig. **7**

Mobility is the final category within "physical adaptive change," and it is perhaps the most recognizable area of kinetic implementation at an architectural scale. Mobile architecture

Mobile architecture can take on a variety of scales, ranging from entire buildings to small single-person enclosures.

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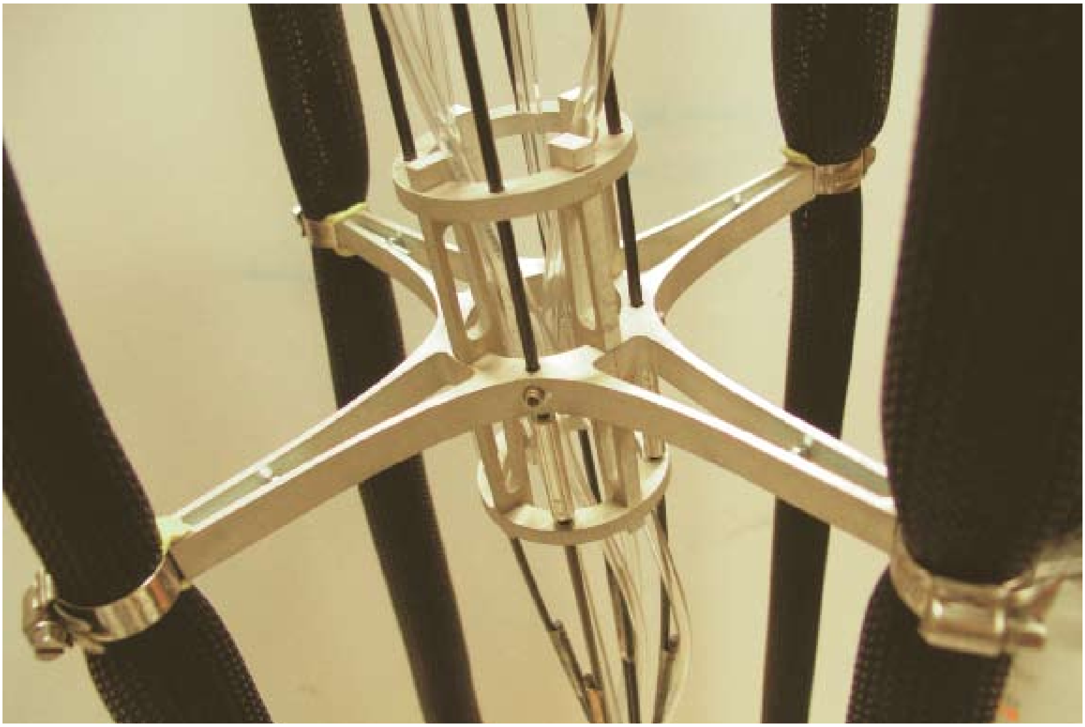
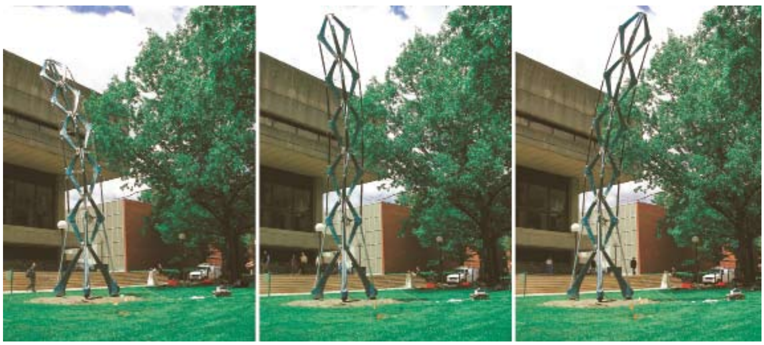
can be defined generally as buildings or building components with variable constructability, location, and/or geometry. Nomadic lifestyles continue today for both climatic and political reasons, because people may be displaced due to environmental and man-made disasters, and because technology allows for greater mobility. All mobile buildings are not necessarily implemented for negative reasons, however. We should consider the example of the elderly who annually leave their houses in colder climates to head south for the winter months in motor homes. We also find many applications in exposition and exhibit design, and overcrowding, whereby the mobility is related to a predetermined architectural life span. World expositions are a great example of fully mobile buildings: a small city is set up with temporary buildings as a means of displaying particular countries' advancements for a number of months, and then the buildings are deconstructed and either stored or brought home to their native countries and reassembled. We also see many diverse examples of mobile architecture in war zones for encampments or hospitals, and anywhere there is a greater need for activity space than permanent architecture can facilitate, such as in schools and prisons. Outdoor concerts and street fairs set up vending structures that accommodate sales and food preparation, and create small, temporary urban streetscapes, an example that can be extended to the Saturday afternoon college football tailgate party where (often sophisticated in their self-organization) architectural communities are established around vehicles in an open parking lot. Mobile architecture can take on a variety of scales, ranging from entire buildings to small single-person enclosures. Exhibit architecture can have a very fixed short-term life span ranging from a number of weeks to months. Temporary buildings such as school annex buildings can have a life span of years, until adequate facilities can take their place. Music pavilions can often have a complete life span in a single location in only a matter of hours. In each of these types, we have different needs in terms of the assembly of the structures and the architectural resolution that is required. The life cycle is often the most important determining factor of the building demands in terms of lighting, thermal performance, acoustics, and even waterproofing. While such factors are primarily based around functional use, the life cycle will often determine if there is universal compatibility allowing for unknown factors to which the temporary structures can easily adapt. Mobile architecture is also designed and implemented for a diverse range of life cycles, which has implications for everything from materials to construction connections and, ultimately, cost.

> Fig. **6**: Uni-systems, *Starlight Theater*.

> Fig. **7**: Philippe Block, Axel Kilian, Peter Schmitt, and John Snavely, *WhoWhatWhenAIR*.





Designers of kinetic systems and kinetic architecture ought to focus their attention upon the vast wealth of resources that have been accumulated over numerous centuries of engineering.

Ways and Means of Kinetic Motion

Solutions in kinetic architecture must consider in parallel both the ways and means for operability. Thus, it is important to understand and clarify the differences between the ways and means of a kinetic structural system. The "ways" can be understood as the kinetic methods by which they perform, and may include folding, sliding, expanding, shrinking, and transforming in both size and shape. The "means" can be understood as the impetus for actuation and may include pneumatics, chemicals, magnetism, or electrical systems. The ways and means must work in unison to allow for an element to be considered truly kinetic. Truly amazing adaptable spaces are usually comprised of a number of different ways and means that have the ability to work alone as well as in unison to allow for various levels of kinetic movement and responsiveness.

This section describes the ways that specific mechanical systems can be classified through examining the specifics relating to the overall system and details of the mechanical motion they employ. In the final section, we will explore the various ways that in the near future these kinetic systems will become much more holistic, influenced by biological paradigms, and how they will operate on a very small scale. However, from a widely accepted (within the architectural community) and strictly mechanical point of view, contemporary innovators such as Chuck Hoberman and Santiago Calatrava continue to demonstrate that the last word has not yet been spoken about novel kinetic implementation in architecture. Designers of kinetic systems and kinetic architecture ought to focus their attention upon the vast wealth of resources that have been accumulated over numerous centuries of engineering. The best approach here is to really understand and appreciate what exists in terms of mechanical motions and learn to bring this together to suit an architectural vision.

Embedded kinetic structures are systems that exist within a larger architectural whole in a fixed location. The primary function of this type of kinetic structures is to control the larger architectural system or building, in response to change.

We describe here three basic typologies of kinetics systems at an architectural scale: embedded, deployable, and dynamic systems. Simply put, embedded systems are an integral and necessary part of the entire building. Deployable systems allow for the inherent capability of the entire building as well, but also allow for deconstruction and reconstruction, which affords mobility, rather than motion, within a fixed structure. Dynamic structures are the most common. They are typically smaller systems within the larger building, but they are not necessarily integral components of it. Each of these categories is not mutually exclusive, and it is quite common to have dynamic kinetic systems (e.g., movable partitions and furniture components) within a building that also has an embedded kinetic system (such as a foundation that can adapt the entire building to seismic conditions). In terms of the context of this book, embedded systems are almost always coupled with computational control, while deployable systems rarely are, at present, and dynamic systems are those that are historically strictly kinetic but now are becoming increasingly automated and intelligent.

Embedded kinetic structures are systems that exist within a larger architectural whole in a fixed location. The primary function of this type of kinetic structures is to control the larger architectural system or building, in response to change. Embedded systems can often take the place of other systems used to control the building as a whole, in terms of adaptability to external environmental conditions. An example of this would be to respond to variable seismic and wind conditions. One can also think of these systems as having a number of smaller elements, coupled with an intelligent logic for performing action that can allow the entire system as a whole to change its form. Using this method, it is possible to see how these elements working in unison across the spectrum of a space or object in space could display collaborative adaptive behavior. Embedded kinetic structures, which have a history within the field of active control, are the most developed of the three kinetic typologies. It is easiest to visualize and understand how their applications could be applied to pragmatic issues. For example, many systems within the area of seismic control are highly developed in the creation of buildings that can actively adapt in earthquakes. Such systems are at the heart of the term "ephemeralization," coined by Buckminster Fuller, which explains how we can literally cut an enormous amount of excess structure from our buildings when there is an active control system inherent in the building.[26] With static architecture, we typically must overengineer our buildings to account for worst-case scenarios of structural failure.

Dynamic kinetic structures are clearly the most recognizable category of kinetic systems in architecture. This typology also exists within a larger architectural whole but acts independently with respect to control of the larger context.

These kinetic structures typically exist in a temporary location and are easily transportable. These kinetic structures possess the inherent capability to be constructed and deconstructed in reverse. A great deal of contemporary precedents exist in this area, for example in exhibit design, where large convention halls have been a springboard for innovative design. This innovation is largely driven by a need to easily and quickly assemble and disassemble large architectural partitions, seating, lighting, and sound structures. They are typically placed on trucks and transported to the next exhibit, where they are reassembled again for another show. Even recently, large concerts spent a substantial percentage of their budget on stage and set designs that have the potential for deployability and reassembly. Such stage sets are scaled to the extent that they need a small fleet of trucks that are also internationally transportable via shipping containers. Apart from these recent design needs, deployable architecture has its roots in nomadic dwelling types that needed to be lightweight and durable as well as quick to assemble and take apart. The tent exemplifies all of these traits and still remains popular in modern days. Contemporary tents range from sophisticated camping tents that are relatively permanent, waterproof, and wind resistant, to other variations found in shelters that can be deployed in a matter of minutes. These types of structures are not made of various fabrics but instead consist of structural space-frames covered with fabric.

Dynamic kinetic structures are clearly the most recognizable category of kinetic systems in architecture. This typology also exists within a larger architectural whole but acts independently with respect to control of the larger context. Common elemental systems such as doors, windows, elevators, and escalators can be considered dynamic kinetic systems. We can expand this list to include less-common elements such as pull-out shelving, pull-down stairs, folding beds, and other dynamic furniture elements. Dynamic kinetic structures can be subcategorized as mobile, transformable, and incremental kinetic systems. Mobile systems would include all types that can be physically moved about within an architectural space to a different location. Transformable structures are those that can change to take on different spatial configurations and can be used for space saving or utilitarian needs. Incremental systems can be added to or subtracted from, like LEGO pieces, to create a larger whole out of discrete parts. Each of these categories is not exclusive, and often we see elements that are both incremental and transformational. Dynamic systems are only limited by the imagination and continue to be created as living trends change and new needs arise. While such systems do not affect the architectural whole, they are often built into or hidden within the architectural whole for reasons of spatial optimization.

We are beginning to see the system of reference we use as a basis for **design conception shift** from a machine paradigm to an organic paradigm.

Horizons of Kinetic Architecture

We are beginning to see the system of reference we use as a basis for design conception shift from a machine paradigm to an organic paradigm. Gary Brown states, "Organic theory emerges from nature, an environment that possesses evolutionary patterns that have a base code and an inherent program where information is strategically interrelated to produce forms of growth and strategies of behavior, optimizing each particular pattern to the contextual situation."[27] The prevalence of organic systems over machine systems theory has altered the conceptual model that we apply in order to comprehend our environment and, consequently, design our environment. The organic model is progressive: programmatic flows, fluxes, and rhythms continually generate strategic patterns within the environment, which continually generates strategic patterns as temporal ephemeral forms through convergence and divergence. Consider water, for example: a surprising phenomenon arises (surprising not in how strange its behavior is, but in how common it is) whereby its dynamic nature arises from an incredible adaptability to forces.[28] In the context of architecture, the attribute of being able to adapt to changing needs and environments is paramount in contemporary society. D'Arcy Thompson points out, "Adaptation is clearly the key to long-range biological survival."[29] Biomimicry, which is described further in "New Horizons," is basically a system satisfying pragmatic need through emulating nature. In plants, adaptive motions are called tropisms. Phototropism is a response to light; geotropism, a response to gravity; hydrotropism, a response to water; and so on. The controlled movements of the kinetic elements of animals are primarily achieved by muscular action. The most applicable form of kinetics in living things is that of "locomotion," which is defined by movement through an environment

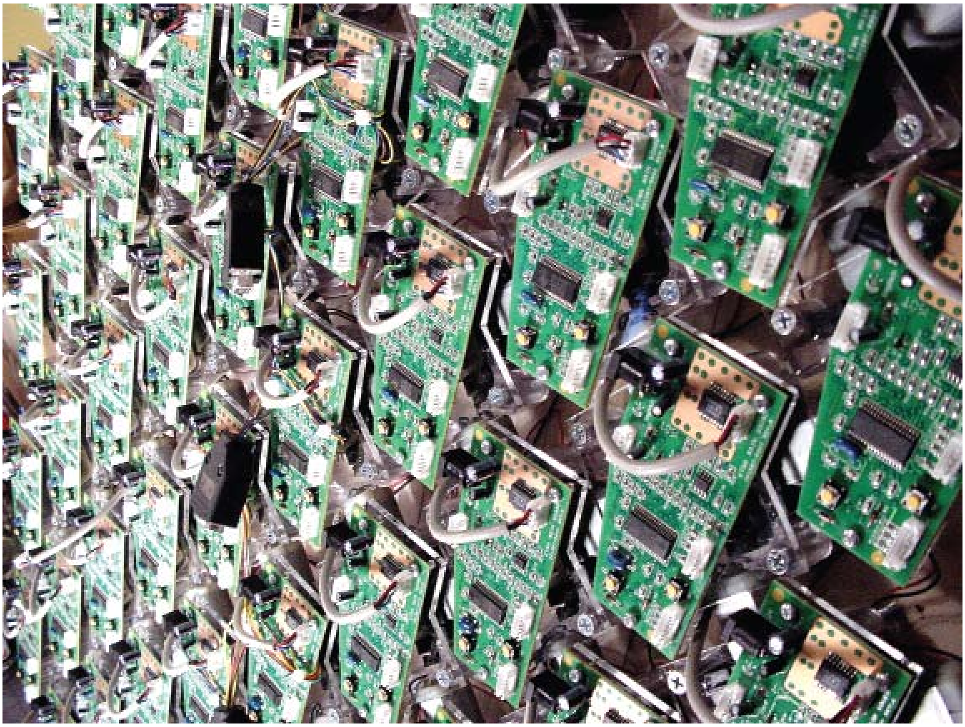
Form may change very slowly through evolution, moderately through processes of growth and decay, and very quickly by internal muscular, hydraulic, or pneumatic action.

of any medium (air, water, soil, etc.) by virtue of the entity's own controlled kinesthetic and kinetic abilities.[30] There are three biological devices for initiative locomotion, namely ciliary, muscular, and hydraulic. Form may change very slowly through evolution, moderately through processes of growth and decay, and very quickly by internal muscular, hydraulic, or pneumatic action. Growth is only mentioned here in terms of localized changes, however; growth is necessitated in higher life forms because it is impossible for a parent to produce an offspring its own size. Often growth goes hand-in-hand with proportional change and sometimes includes transformation or metamorphosis, whereby there is no physical similarity between the parent and offspring. However, an exception to the growth process "may be found in lower single-cell life forms where the cell grows only a small amount before dividing to reproduce itself almost full size," as Zuk points out.[31] An adoption of the organic concept over the mechanical can influence the way we actually see. The organic diminishes the influence of the deterministic and emphasizes the programmatic. As Brown clarifies, "Change in the mechanical world is cyclical, but there is no development, the factors are continually repeated with set outcomes; the organic paradigm is developmental and reciprocal: it emulates life, and life itself is motion; when motion ceases, life ceases."[32]

Tangential to the organic paradigm of kinetic adaptation is the profound set of developments in new materials. The specific nature of materials will prove to be of great promise for advancement in the area of interactive architecture as a result of new technologies providing both a vision into microscopic natural mechanisms and advancements in the manufacturing of high-quality kinetic parts. Along the same lines, it's important not to overlook structures and systems being explored at even smaller scales, such as the nano scale. Nanotechnology is a new area of research based on the control of matter on a scale smaller than one micrometer, as well as the fabrication of devices on this same length scale. Perhaps even more relevant to the discussion of interactive architecture is the area of bionanotechnology. This area is the logical integration of biological functions and nanoscale precision. New materials and biotechnology will be discussed further in "New Horizons". > Fig. **8**

The scenarios above map out a world where we have a wealth of potential for motion, a world in which spaces and objects can move and transform to facilitate numerous changing situations, ranging from the contextual and environmental to the programmatic. Clearly, the next step, if we have all of this potential for change, is to have a way to tell these systems both when and how to move on their own. When the motion is combined with the

> Fig. **8**: Michael Fox, *Power Modules*.



> Fig. **9**: Michael Fox, *Microprocessors for Interactive Facade*.

Our capabilities for using kinetics in architecture today can be extended far beyond what has previously been possible. Advancement, however, will only be accomplished when kinetic structures are addressed not primarily or singularly, but as an integral component of a larger architectural system.

computation for sensing and control, we have something that is analogous to the human body. The frontiers of kinetic design are to be found in how such couplings with sensing and automation technologies will foster new design innovations. Our capabilities for using kinetics in architecture today can be extended far beyond what has previously been possible. Advancement, however, will only be accomplished when kinetic structures are addressed not primarily or singularly, but as an integral component of a larger architectural system. In today's computationally interconnected world where communication is paramount, it is ironic to note that although many things in our architectural environments now possess the computational capacity to understand changing conditions, they do not have the appropriate tectonic capacity to appropriately physically respond to it. Currently advancements are being made toward creating a truly ubiquitous computational and kinesthetic material world. Interactive architecture involves the simultaneous involvement of both kinetics and embedded computation. The combination of these kinetic and computation-based systems will allow for an environment to have the ability to reconfigure itself—to automate physical change to respond, react, adapt, and be interactive. > Fig. **9**

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4 Robert Kronenburg, *Transportable Environments 2* (London: Spon Press, 2003).
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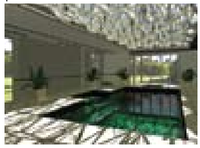
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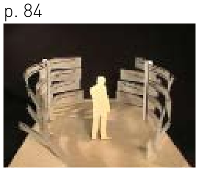
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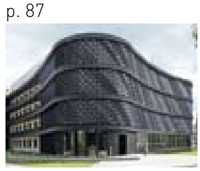
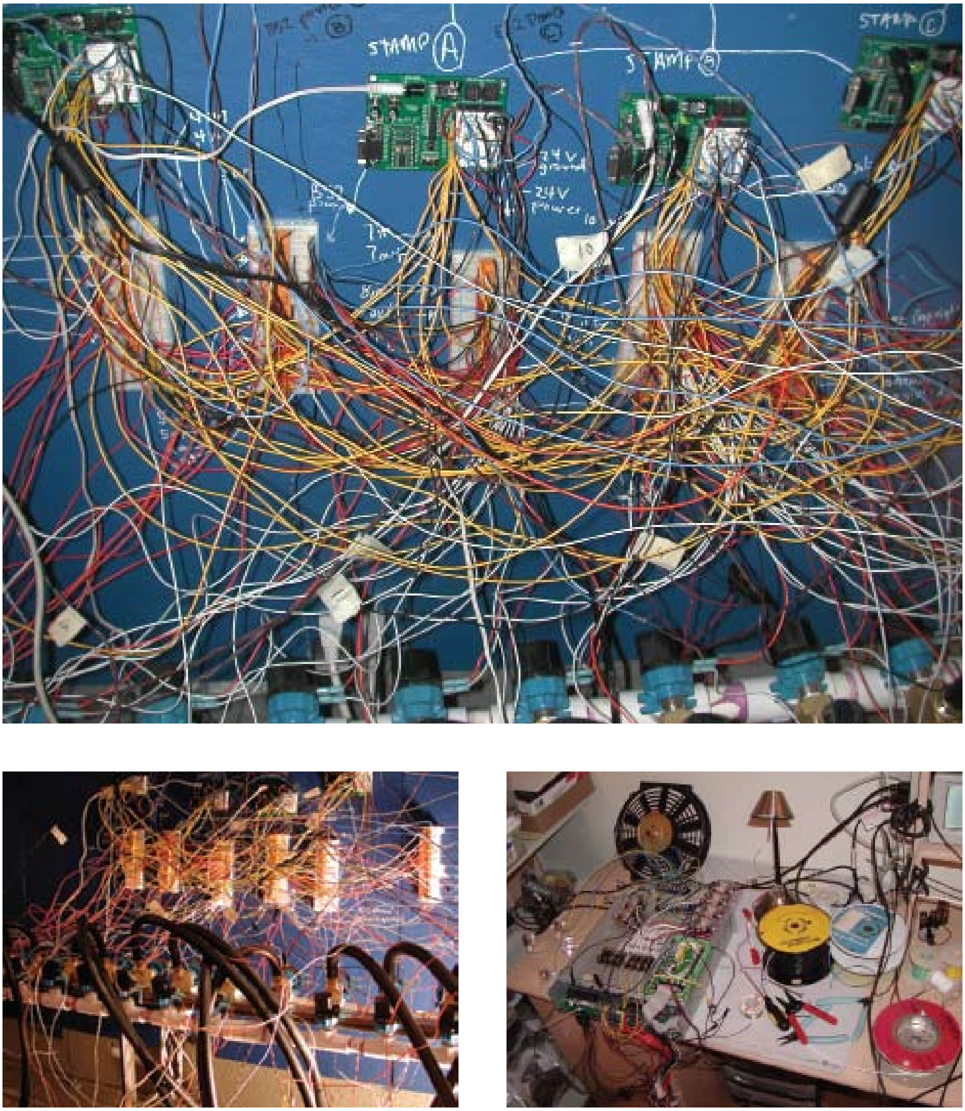


Trends in Embedded Computation

A kinetic environment without the computation is like a body without a brain: incapable of moving. To paraphrase Guy Nordenson, the computation is, in a sense, the brain that can control the behavior of the motion.[1] Embedded computation (EC), in the context of interactive architecture, is a system that is literally embedded into the building and that has the ability to gather information, process it, and use it to control the behavior of the actual physical architecture. In its physical manifestation, EC can be reduced to possessing a combination of both sensors (information gatherers) and processors (computational logic to interpret). EC is important not only in sensing change in the environment, but also in controlling the response to this change. The goal of this chapter is to outline both a historical and contemporary sense of what EC is, as well as what types of systems are currently being built and pursued. > Fig. **1**

Up to this point, we have clarified some of the methods and logic behind the way that kinetic systems adapt and interact. If one were to describe the means by which the human body can interact with its surroundings, one might say that the body was comprised of a number of different kinetic parts that have the ability to be controlled by a neurological core. Interactive architecture can be described in this very same way. This book could have been written using a "top-down" approach, first describing the logic behind interpretation and then the kinetic means to execute commands, but this would not be accurately describing the current developments in IA. Quite simply the mechanical paradigm is well developed, while the computational could well be described as still in its infancy. Numerous books and articles have been written on flexibility in architecture, modular reconfigurable systems, deployable structures, and movable space, etc., all within the context of users or the environment

> Fig. **1**: Michael Fox: typical wiring in an interactive architectural design studio.



A kinetic environment without the computation is like a **body without a brain:** incapable of moving.

directly affecting the objects or spaces. Due to the fact that so many projects have been created based on these ideas, we now have a fairly good understanding of what has been done, and the limitations and capabilities of such systems. EC is an immense topic and a rapidly unfolding area of unknown potential with respect to architecture. On the one hand, as previously described, EC is coupled with the mechanical to facilitate adaptation. This is the arena where most of the built projects in this book lie. On the other hand, EC is beginning to facilitate a paradigmatic shift from the mechanical to the biologic. Change in the mechanical world is cyclical, but there is no development, since the factors are continually repeated with set outcomes; the organic paradigm is developmental and reciprocal: it emulates life. Organic theory emerges from nature, an environment that possesses evolutionary patterns that produce forms of growth and strategies of behavior, optimizing each particular pattern to the contextual situation. "The prevalence of the organic paradigm is beginning to alter the conceptual model that we apply in order to comprehend our environment and, consequently, design in our environment."[2]

In order to understand EC in the context of where we are today and the advancements that are being made, it is important to understand how we got here. The history of EC as it relates to architecture and space is complex, as its trajectory continues to weave its way between society's demands on architecture and the technology that is available at any given time. Each of these forces has played a pivotal role in shaping the ways in which we have developed and continue to develop spaces with intelligence, empowering them to have the ability to be interactive. "Intrinsically tied to the developments of intelligence in space is the mental shift that has taken place in the user of the space. This mental shift has taken place as users have moved from directly manipulating computation in order to control space to being immersed in a fully ubiquitous intelligent environment."[3]

The origins of EC stem from the need to solve pragmatic issues around controlling environmental architectural systems, and were improved upon with technological developments. In the 1950s, spurred on by a booming construction economy, larger commercial buildings became commonplace, and a new need arose to simplify the controls of the systems in these commercial structures. At this time, users were also introduced to the first remote controls; these began to leave an impression in the users' minds and set a standard for manipulating and controlling objects. The 1960s were about further understanding the needs for users to control space and environmental systems, and using new technology to simplify

Embedded computation (EC), in the context of interactive architecture, is a system that is literally embedded into the building that has the ability to gather information, process it, and use it to control the behavior of the actual physical architecture.

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these controls. In the commercial sector, new technological advancements in the areas of recording or logging the parameters of space were being developed that allowed for temperature, air flow, pressure, and other conditions to be recorded.[4] Buildings were becoming more aware of the systems and activities that they housed. During the 1970s, EC was once again pushed to a further level of development by the pragmatic user goals of reducing energy cost and consumption, a new need was arising for managing building systems more efficiently, and new forms of building controls became widely used. At the end of the 1970s, a new invention, the personal computer, was being developed by Apple that would begin to set new standards in the control of space.

In the 1980s, users began to understand the power of computation and how it could directly affect and enhance their everyday activities. At this time, smaller and more affordable electronic hardware began to be commercially available. Manufacturing technologies allowed microprocessors to grow increasingly smaller, cheaper, and more powerful. The advent of the personal computer allowed for users to have even more control over specific devices and systems. Rather than creating an entire system of controls to manage individual objects, a user could control many different systems through one simple graphical interface.[5] The advent of these new graphical user interfaces to control software and hardware necessitated a standardized way to program them. In the late 1980s, a programmer developed Hypercard for the Macintosh, allowing for applications to be programmed in an object-oriented way through the graphic interface rather than with a command-line interface. Shortly thereafter, this software became widely available to the general consumer market for the first time, and made it possible for first-time programmers to make simple applications.[6]

In terms of embedded computation, the 1990s marked an exponential leap forward in both the mindset of users and new emerging technologies. In the past, users had referred to the control of systems in space as "automation," and this term itself had many negative connotations, among them a lack of humans' control and the ability to make changes on the fly. The 1990s saw a shift in user mentality, largely influenced by new computer software and interfaces, from thinking of controls as static automated manipulators to smart controls. Users wanted a new type of control that had the ability to vary its response depending on the input it was given. Similar to previous decades, widespread use of emerging technology further advanced the ability for computation to control networks of devices. At this time, the Internet began to be widely used, setting a new standard for how systems could be networked

As technology has advanced and as computers have become smaller and cheaper, we are seeing that we now have the potential to think of space as being organized in a computational network.

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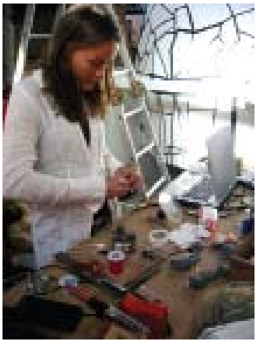
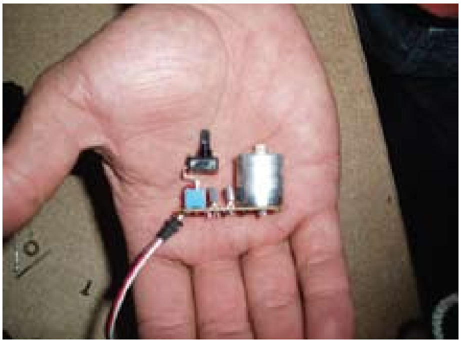
and underlining the importance of these networks. The Internet was also becoming understood as a potential platform for networking both activities and devices. Computational hardware was also becoming smaller and more affordable, and this, in turn, meant that more of it was being included in everyday products and appliances. Around this same time, the technology behind the manufacturing of sensors and input devices that could be connected to these new computers and microprocessors was also becoming increasingly smaller and cheaper. These trends in the mindset of users and advancements in technology have continued to the present day and have created a new field of computational control known as ubiquitous computation.[7] > Fig. **2**

These new ubiquitous networks have the ability to physically understand how we use space, interpret this data, and respond to this data in interactive ways. As technology has advanced and as computers have become smaller and cheaper, we are seeing that we now have the potential to think of space as being organized in a computational network. Objects can have both the fundamental logic and hardware to allow them to be extremely good at executing the specific tasks they were intended to do while simultaneously networking into a collective whole that can be controlled by an overarching logic. The idea of ubiquitous computation is about embedding hardware and software, information processors and coded intelligence, into all aspects of our lives. Ubiquitous computation was originally conceived in the late 1980s at the Xerox Palo Alto Research Center by Mark Weiser and was first described in a paper titled "Ubiquitous Computing #1." This paper predicted that computers as we know them—tabletop displays, desktop hardware, and input interfaces—would change in the future as the components themselves become increasingly cheaper, smaller, and more powerful. Advancements in the technology involved with hardware would free computation from our existing notions of what computers are, and allow computers and the way we use them to evolve as they become embedded into the physical fabric of our everyday surroundings. Ordinary objects, from furniture to building components and systems, will have the ability to sense and process information, ultimately shaping our experience.[8]

As can be seen from this brief introduction, EC is still being developed: the understanding of what is possible, and the extent of the amount of intelligence that can be incorporated into our environments is unknown. In the future, computers will become intrinsically integrated into our lives to the extent that we will design objects, systems, and our architectural environments around the capabilities of EC, and not the other way around. The main reason

> Fig. **2**: Michael Fox, typical interactive architectural design studio environment.





In the future, computers will become **intrinsically integrated** into our lives to the extent that we will design objects, systems, and our architectural environments around the capabilities of EC, and not the other way around.

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that EC is so exciting is that we cannot fully comprehend the implications of future development. There are three computational development patterns that are relevant to new types of architecture. These include Moore's Law, Metcalfe's Law, and autocatalytic processes.

A well-known standard for measuring the rate of computer technological advancement has been Moore's Law, which states that the number of transistors that can fit on a chip will continue to double approximately every two years, and computer memory will cost half as much, while taking up half as much space. Depending on the doubling time used in the calculations, this could mean up to a hundredfold increase in transistor count per chip within a decade. The semiconductor industry technology roadmap uses a three-year doubling time for microprocessors, leading to a tenfold increase in the next decade. Creating networks of information is becoming the new impetus behind the development of computational devices.

Metcalfe's Law states that the network benefit increases as a square of the number of its users. While the assumption that the value grows quadratically as the number of members grows has been proven disastrously wrong as a general all-inclusive summary of networks by the dot-com boom of the late 1990s, Metcalfe was quite correct in stating that the value of a network grows faster than its size in linear terms. This theory paves the way for the assumption that entire networks of sensors, mechanics, and code will become part of our everyday environments. The wireless architectural world is on the verge of becoming affordable, effective, and standardized.

The third influential development is that of autocatalytic processes. Autocatalytic processes can be defined as reaction product itself being the catalyst for its own reaction. In context here, such processes describe how the pace of technological change is accelerating because computers and other computational artifacts are now able to assist in the development of novel and improved components and products. Computer software is used to design better hardware, for example. In other words, the process is "autocatalytic" in that smart machines are helping to build even smarter ones. The roots of EC spring from the need to solve social demands of pragmatic system management coupled with constant advancements in technology. The constant back-and-forth between these two forces has shaped the current landscape of EC. The following sections will explore recent architectural trends and projects involving embedded computation that range from the very pragmatic with respect to architectural programmatic and environmental response, to adaptive projects that can understand and negotiate human behaviors.

Perhaps the most applicable research to draw upon in designing intelligent systems lies in an area of study called **active control research**, which focuses on the use of active control to modify the structural behavior in a building.

Active Control Research

Perhaps the most applicable research to draw upon in designing intelligent systems lies in an area of study called active control research, which focuses on the use of active control to modify the structural behavior in a building. This enhancement can be used to actively stiffen or strengthen a given structure depending on the changing demands on the system. Wind loads, seismic conditions, live (people) and mechanical loads, and even temperature make up the complexity of changing variables that buildings are confronted with on an ever-changing basis. A number of projects have been already implemented that include response to wind vibrations, environmental hazards, seismic conditions, etc. Active control systems are structures that are affected by an externally activated device, to change the response. In general terms, "The activation of external force is based on the measurement of external disturbance and/or structural response. Sensors are employed for the measurement purposes, and with the help of computers, the digital signal activates the required external force. A combination of these two methods of structural control has been used to evolve hybrid control methods, for realizing stringent control requirements."[9]

Of all of the types of embedded computation, active control research has the most extensive history, because it is easier to understand how computers or intelligence could be added to a system to solve purely pragmatic (although often unpredictable) environmental changes. Such systems have been successfully employed in numerous large buildings situated in high-wind or earthquake-prone locations. Such actively controlled structures can modify their physical properties to become either stiffer or more flexible as preprogrammed.

Active control technology includes seismic base isolation systems, passive (tuned) mass dampers and energy dissipation devices for buildings and other structures, and seismic floor isolation systems for critical spaces that house computers or medical equipment. Many systems developed in this area are already implemented in actual buildings and equipment. One of the first architectural examples is that of the Citicorp Center, designed by LeMessurier in 1979 in New York City, and constructed using a 400-ton concrete weight, the "tune mass damper." This enormous weight sits on multiple roller sleds and can freely move across steel I-beams in an x-y coordinate system. A series of sensors attached to the four corners of the building monitor the amount of wind force that was being applied to the building at any one time. A computer takes this data and issues commands causing the massive counterweight to move slowly and dampen the swaying movement of the top of the building. In recent years, Typically in active control systems there are a great deal of system uncertainties that are controlling an equally immense amount of structural complexities.

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numerous buildings and structures have employed mass dampers, mostly towers, but also bridges and other structures.

Typically in active control systems there are a great deal of system uncertainties that are controlling an equally immense amount of structural complexities. The idea is to use numerous members, be they cables as active tendons or hydraulics as muscles, to provide control through a very specific response for suppressing forces. The important point is that each individual actuating device is controlled by a decentralized controller at a local level. This model of decentralized identification and control is based on neural networks and simplifies the implementation of the control algorithm. Decentralization is a systems theory concept that is also used to describe political, economical, and other phenomena whereby the more decentralized a system is, the more it relies on lateral relationships, and the less it can rely on command or force. It has been widely adopted by computer science and been discussed (and debated) as a description of the workings of the Internet. In terms of the discussion here, decentralization is important both in terms of control and of reistance to failure. Control decentralization is applicable for systems with a great number of sensors and actuators to avoid the communications and processing bottlenecks, and inflexible global controller design. Simplified implementation based on decentralization shows great promise both in terms of the robustness of the system and economic feasibility. Although in a decentralized system there is normally no centralized control structure dictating how individual parts of a system should behave, local interactions between discrete systems often lead to the emergence of global behavior. Most architectural applications are neither self-organizing nor do they have higher-level intelligence functions of heuristic and symbolic decision-making abilities. Most applications do, however, exhibit a behavior based on low-level intelligence functions of automatic response and communication. When a large architectural element is responding to a single factor, a centralized system can be effective in executing a command to a single agent, but when there are many unknown stimuli, decentralized intelligence is the most effective way to handle the sensing and response. The more decentralized a system is, the more it relies on lateral relationships, and the less it can rely on overall commands.

Optimization through a system that learns to adapt can make buildings more comfortable, safe, and productive, as well as more efficient and therefore less costly to operate.

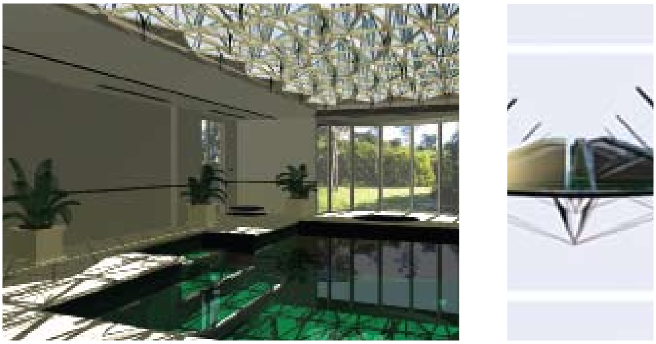
Adaptive Control

Adaptive control is an inclusive term for strategies that consist of developing control for inherently unstable systems, and is often a hybrid combination of active and passive systems. Such systems have proven to learn in just three or four user settings what the lowest acceptable energy settings are. Numerous precedents already exist in the commercial sector, where adaptive control has demonstrated to yield economic benefits under realistic operating conditions. Integrating temperature detectors or thermostats, a system can respond to various environmental conditions. On cold days, the heating could switch on, preventing water pipes in the loft or garage from freezing, and on hot days, motorized windows could open. Timed programs can be scheduled to perform certain actions at regular times on selected days of the week, such as switch the heating or air conditioning on and off, control the thermostat, or operate the garden sprinklers. > Fig. **3**

While it seems some of the more interesting recent applications to arise in adaptive control are those based on users' behaviors within a home environment, the area is much more highly developed in manufacturing industries. Applied commercially, adaptive control in manufacturing is one of the latest technologies to emerge in the instrumentation and control field. Adaptive control methods offer a means to revolutionize plant and process efficiency, response time, and profitability by allowing a process to be regulated by a form of rule-based artificial intelligence, without human intervention. Adaptive building controls can optimize everything from fire safety to security system solutions to energy efficiency. Optimization through a system that learns to adapt can make buildings more comfortable, safe, and productive, as well as more efficient and therefore less costly to operate. Adaptive control can improve building performance by automatically adjusting to fluctuations in the mechanical systems, adjusting loads, and adapting to seasonal changes in variable environments, while at the same time minimizing errors.

Every day computers are becoming more integrated in the buildings that we use and the spaces that we inhabit. Recently processors and sensors have shifted from strictly looking at environmental conditions outside the building and performance based aspects of the building to include predicting and reacting to information inside the building, which includes understanding and monitoring the changing needs of the users of space. Home automation looks at precisely such scenarios in automating a living space to changing pragmatic human information.

> Fig. **3**: Michael Fox, *Kinetic Design Group: Responsive Skylights.*



> Fig. **4**: Crestron, *Crestron TPS-6X.*

The means to **automate** a home are now packaged and sold in **easy-to-install kits** that provide the necessary equipment, including wireless sensors, timers, and the software.

Home Automation

While the control systems in the previous section dealt with building automation in terms of adapting to environmental changes, generally limited to systems designed to monitor and control the mechanical and lighting systems of larger buildings, an exciting area that is rapidly developing is focused on changes in human actions; these systems are commonly referred to as home automation, and they tackle response to human behaviors and adapt to how we use architectural space. While home automation is essentially building automation for the home, it shows a great deal of promise for the development of interesting applications. Home automation systems are definitely not new but have reached a point where they are robust and affordable enough to reach a general public audience. These systems are typically fully automated and deal with all of the systems in a home from lighting to climate to security and entertainment. A rapidly evolving area is that which includes the ability of the home to notify the owner with alerts as to potentially dangerous situations, such as motion at the front door, leaks in the plumbing, or freezing or overheating, by email or text-based messages on a phone. The primary motivators are empowerment and energy-use optimization, and involve linking all these individual systems together so that one action by the owner can cause many actions across several subsystems. Embedded computation (sensors and the processing software behind them) is becoming both more simplified and affordable, and therefore commercially accessible. Home automation systems are at the same time becoming increasingly sophisticated. "Plug and play" systems have become readily available at the local hardware store, allowing novice users to experiment and hack their own systems to make anything and everything move or respond in various other ways within their homes. As EC becomes more and more advanced, home automation systems as a whole are increasingly being used in creative and expressive ways that deal with a personalized experiential quality of space.[10] > Fig. **4**

The means to automate a home are now packaged and sold in easy-to-install kits that provide the necessary equipment, including wireless sensors, timers, and the software. Such highly commercialized systems enable users to quickly automate any electrical process with their home computer. Two technologies power almost all home automation: X10, a communications protocol that allows appliances to talk to one another over standard electrical lines, and radio frequency (RF), which is used for remote-control devices. X10 refers to a company as well as to the protocol. X10 products came on the market in the late 1970s. The

Wireless applications open up an entirely new area of potential control that allows for the user to operate devices in the home from remote locations. The ability to not only monitor but also physically control remote environments may have important implications.

system initially began as a sixteen-channel command console, a lamp module, and an appliance module. These were followed by a wall module and a timer. "The X10 protocol is the de facto standard for home automation and is used by IBM, RCA, GE, Microsoft, Radio Shack, Magnavox, Leviton, and in fact just about everyone in the HA business."[11] There have been several recent attempts at replacing X10, including the CEBus (Consumer Electronics Bus), also known as the EIA-600, which was introduced in 1984 as a rudimentary set of electrical standards and communication protocols for electronic devices to transmit commands and data. The CEBus standard was released in September 1992. CEBus was a response to make a much more robust and inclusive open architecture set of specification documents that define protocols for products to communicate through power line wire, low voltage twisted pair wire, coaxial cable, infrared, RF, and fiber optics. Another major player is LonWorks, which is a networking platform. The platform is built on a protocol for networking devices over a diverse palette of media. It is popular for large architectural projects and is the standard protocol for European Home Automation. At this point, the X10 has grabbed the mass market because of the price and ease of use, while numerous others jockey for more serious and inclusive compatibility along with CEBus and LonWorks, including INSTEON, PLC BUS, KNX (standard), System Box, Universal powerline bus (UPB), UPnP, ZigBee, and Z-Wave. Some of these standards use communication and control wiring, while some embed signals in the power line, some use radio frequency (RF) signals, and some use a combination of several methods.

There is enormous potential for applications in this area that arise from understanding what an architectural space or object is currently doing and how it can do it better. Homeowners really just want things to work reliably and do not want to be bothered with thinking about technical issues behind how they work.[12] It is important also to remember that homeowners do really understand their homes, and, more importantly, they understand their desires and the deficiencies of their homes. Homeowners also do not typically purchase systems, they purchase individual devices: this requires a level of standardization and interoperability that does not currently exist. Although most new high-end homes are now wired for home automation systems using off-the-shelf fully integrated systems, this is rapidly being replaced by wireless protocols that allow for the control of most applications. Wireless applications open up an entirely new area of potential control that allows for the user to operate devices in the home from remote locations.

Technology being used in **remotely controlled space** is allowing for higher levels of interactivity that involve much larger audiences, often even audiences unbeknownst to them.

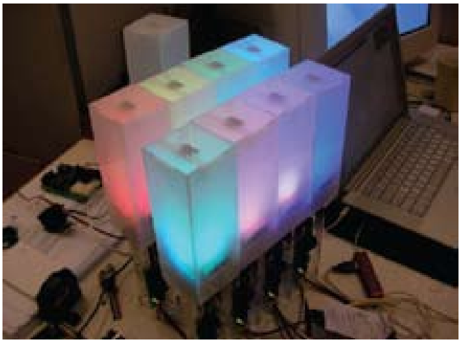
External Communication

The ability to not only monitor but also physically control remote environments may have important implications. Unlike home automation that relies on interpreting information from local sources and reacting, external communication allows local automation to take place based on information being remotely inputted into the system. Terminology includes reciprocal space, remote communication, and coexistence (discussed further in "Project Landscape"), among others that all suggest that an architectural environment can be interactively viewed, controlled, and experienced both within the confines of the space and beyond its walls. The method of controlling objects remotely has changed dramatically since its inception. External communication started when the wiring of systems began to make its way outside of space and was connected to external devices such as computers. In the last ten years, advancements in mobile technology from both a technological and cost standpoint have paved the way for people to have the ability to communicate information across networks in a new wireless way. This is giving people an unprecedented way of enacting influence on space, on activities in space, and most importantly on the people that use space. > Fig. **5**

The ability to actively control architectural spaces and physical objects in real time can open entirely new areas in entertainment and commercialization. Typically, such projects involve a robotic system that is controlled through the World Wide Web and a live camera that can allow the controller to view what he/she is manipulating. Other interesting applications include those that have adopted the paradigms of communication established through instant messaging (IM) to keep in touch with friends and family. In the same way that one might see a user name appear in IM software on a computer and know that a person is sitting at their computer, applications in the physical environment can bring this understanding out into the real world. Specifically, designers can create architectural objects that can physically adapt and change shapes to translate human networks of remote communication.

Technology being used in remotely controlled space is allowing for higher levels of interactivity that involve much larger audiences, often even audiences unbeknownst to them. As entire populations become outfitted with mobile devices and cell phones, it is becoming increasingly easier for individual members of the general public to input information that will affect huge audiences. As the technology and software that relays messages became increasingly more sophisticated, it became possible for people to log in and play rudimentary games, both with the building and against each other. As remote control

> Fig. **5**: Yasu Santo, Michael A. Fox, with students at Hong Kong Polytechnic University, *CoEx Cubes*.



As remote control becomes more integrated into public viewing, we will desire the ability for the medium to adapt to our changing needs.

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becomes more integrated into public viewing, we will desire the ability for the medium to adapt to our changing needs. Rather than solving purely pragmatic human and environmental conditions, EC and the software that powers it will evolve to allow the systems that control space to adapt to our changing desires.

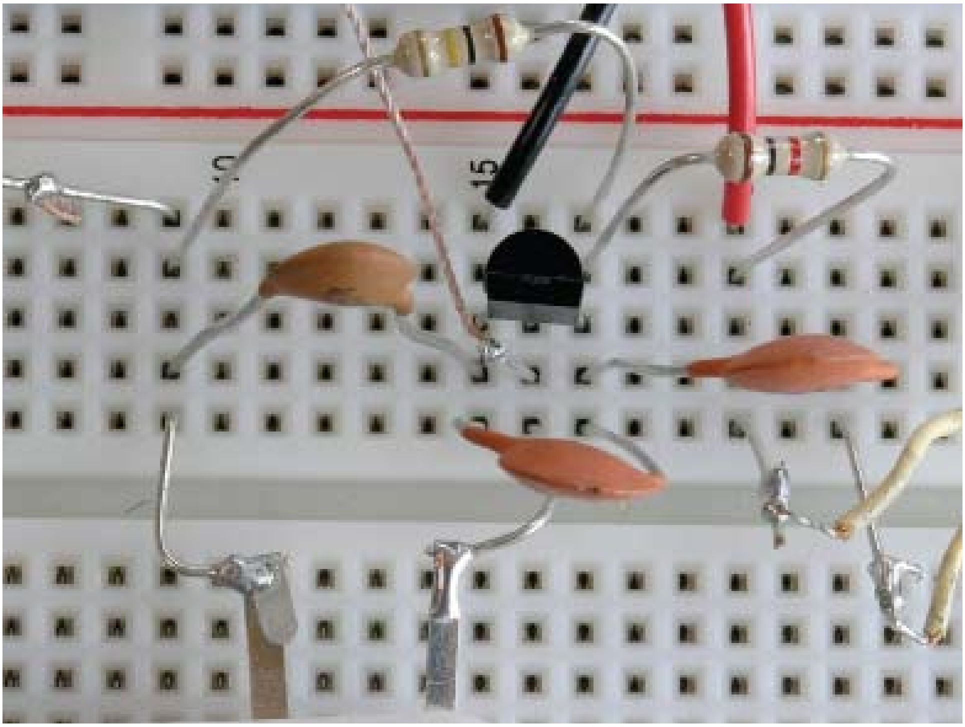
Ways and Means of Embedded Computation

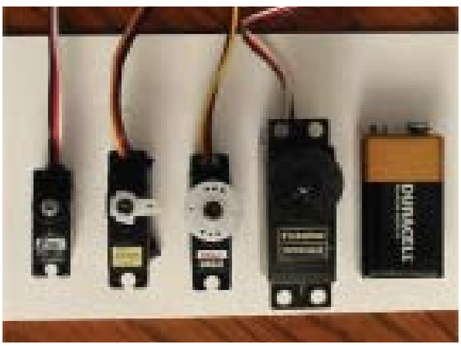
Precedents in EC will serve as the foundation for the explicit means of moderating and controlling information in interactive architectural applications. The design of the relationship between users and programmable embedded intelligence ultimately dictates the intensity of the dynamic dialogue between bodies in space and the space they inhabit. Such means can be described diagrammatically as the controlled source of actuation, specifically addressing embedded computation as a control mechanism for an adaptive function to accommodate and respond to changing demands. Such systems are used to interpret changing circumstances and direct physical change to adaptively better suit changing demands. The issue of controlling physical change is central to issues of design and construction techniques, kinetics, and maintenance, as well as issues of human and environmental information gathering.

> Fig. **6**
> Fig. **7**
> Fig. **8**

> Fig. **6**: Parallax, *Parallax BS2 Stamp, Parallax Sensors, and Parallax Servos.*

> Fig. **7**: Pneumatic Muscle



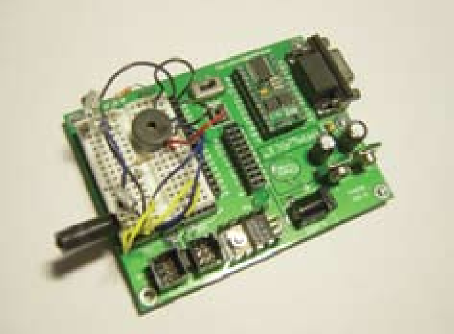


> Fig. **8**: Michael Fox, prototype controllers for interactive facade systems.

Having computation embedded in the materials that make up space means that users have the ability to direct the type of information the space receives through an entirely different method than a conventional computer interface.

When we currently think of computers and how people use them, we typically think of a system of code, most of the time in the form of images and text that can be manipulated through physical inputs, such as a keyboard and mouse. Having computation embedded in the materials that make up space means that users have the ability to direct the type of information the space receives through an entirely different method than a conventional computer interface. It allows users to use nontraditional methods of communicating that are more similar to the way that we communicate with other human beings. As the code stored inside the computation is designed to respond to different types of information exchanges, it is therefore possible for an interactive dialogue to take place between users and the space that surrounds them.

In order for an individual device to respond to some change in a building, it must first sense that change. A sensor is a device that gathers information from the real physical world such as light, motion, temperature, and so on. Sensors have become increasingly sophisticated, with the most simple being an invisible infrared beam that is broken to detect motion; more sophisticated ones can detect color definition, motion directionality, voice and facial characteristics, gait, and so forth, by which individual characteristics can be detected. The increased definition of sensors enables a more personalized response with the ability to detect not just where and what a person is doing within a space but also who that person is, whereby a response can be tailored on an individual basis. As discussed further in "New Horizons," many sensors are being developed that, when combined with processing software, can provide extremely detailed individual information. This will be commonplace in the near future as a means of providing information to the building of individual users' behaviors. As well, we now see webcams and other optical input devices in addition to conventional sound/text input as an established means of gathering information. The ability to sense who is where in a space will soon become as simple and affordable as getting on the Internet. Cameras and sensors with embedded microcontrollers, radio frequency (RF) and infrared (IR) communications, and some rudimentary sensors can be commercially purchased and set up with little technical expertise.



Microcontroller

A microcontroller is essentially a different word for a computer, in that it contains a processor, memory, and input/output functions. It is very similar to the personal computers that we are all familiar with, except that personal computers are designed to execute thousands of programs, and microcontrollers are designed to execute one program very well. Because microcontrollers are designed to do one thing very well, they can be much simpler and smaller than their multitasking counterparts. These small computers are designed to have pin connections that allow information stored in the read-only memory (ROM) to be written and rewritten directly to the controller. These pins also allow for an outward signal to be transmitted to networked or linked devices. Microcontrollers are often low-power devices. A desktop computer is almost always plugged into a wall socket and might consume 50 watts of electricity. A battery-operated microcontroller might consume 50 milliwatts. A microcontroller is often small and low cost. The components are chosen to minimize size and to be as inexpensive as possible. A microcontroller is especially good at three things: receiving information from sensors, controlling basic motors and other kinetic parts, and sending information to other computers. They act as an intermediary between the digital world and the physical world.[13]

Microcontrollers are hidden in almost all kinds of consumer devices these days, and in larger numbers. Most automobiles contain many separate microcontrollers to control the engine, cruise control, antilock brakes, and other parts. Almost all devices and electronics that are found in the home contain these as well; any kitchen appliance that has an LED or on-screen display has a microcontroller in it. Essentially, microcontrollers can be found in anything that needs onboard computational intelligence to monitor an executable action. Microcontrollers have recently become much more affordable and easier to program, which makes them appealing as a potential technology to adapt to architectural applications. PIC (Programmable Intelligent Computer) microcontrollers are prepackaged bare microcontrollers that are soldered onto a board for convenient prototyping with preloaded interpreters (a program that executes commands). These are extremely popular with developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low-cost or free development tools, and serial programming and reprogramming capability.

Sensors

As defined earlier, a sensor is a device that gathers information from the real physical world such as light, motion, temperature, etc. Current developments allow sensors to be built smaller, cheaper, and more responsive. They have become increasingly sophisticated, expanding upon simple motion-detection technology to now include more advanced types of pattern recognition. There are many different types of sensors, but they can be broken down into a few different types of categories: contact-based or non-contact-based. Contact-based sensors rely on a direct exchange of information, and this could mean physical human touch, or the presence of moisture, pressure, wind, or other environmental features. Non-contact-based sensors rely on sensing some sort of presence. Non-contact-based sensors include infrared, sonar, gyroscopic, accelerometers, tilt, light, cameras, microphones, and so on.

There are many different types of programming languages that can be used to program microcontrollers and network devices. For the most part, these different programming languages vary depending on the "bridge" being created between various software and hardware connections. Microcontrollers were originally programmed only in assembly language, but various high-level programming languages are now commonly used. Specialized languages are usually employed for a specific purpose, whereas general purpose languages such as the C programming language are good for overall controls. Microcontrollers are primarily programmed using different variations of the BASIC language. Most manufacturers of microcontrollers use their own individual software or a variation of this language for their specific controllers. Some of the more common ones include Parallax's Basic Stamp, SX-Key, Propellor, Picaxe's BASIC-like programming language, and Arduino's open-source programming language. However, all of these different languages rely on a user to code simple routines or programs to be run on the microcontroller to interpret data information and act accordingly. The sophistication of the response depends on the amount of input data and variables coded into the routines. Interactive architecture is based on the hierarchy of information exchange that takes place between a user and embedded computation. The amount of information that is transferred between a physical object or person and a computation outcome varies based on the amount of desired result. Different levels of information exchanges are more appropriate or less appropriate at different scales. For example, the relationship and desired outcome between an arm gesture and a surface on a local level is

Central to a discussion of interactive architecture is the means of controlling space. The means of controlling change range from the very simple means of direct manipulation to fully adaptive networks of systems that can learn from the users (participants) of an architectural space.

probably different than the way an entire space would behave based on receiving information from multiple participants with different agendas. Space and objects have the ability to respond to more specific types of information exchanges at different scales. Therefore the hierarchy of desired response determines the degree of computational intelligence that is embedded at specific moments in space.

Controlling Change

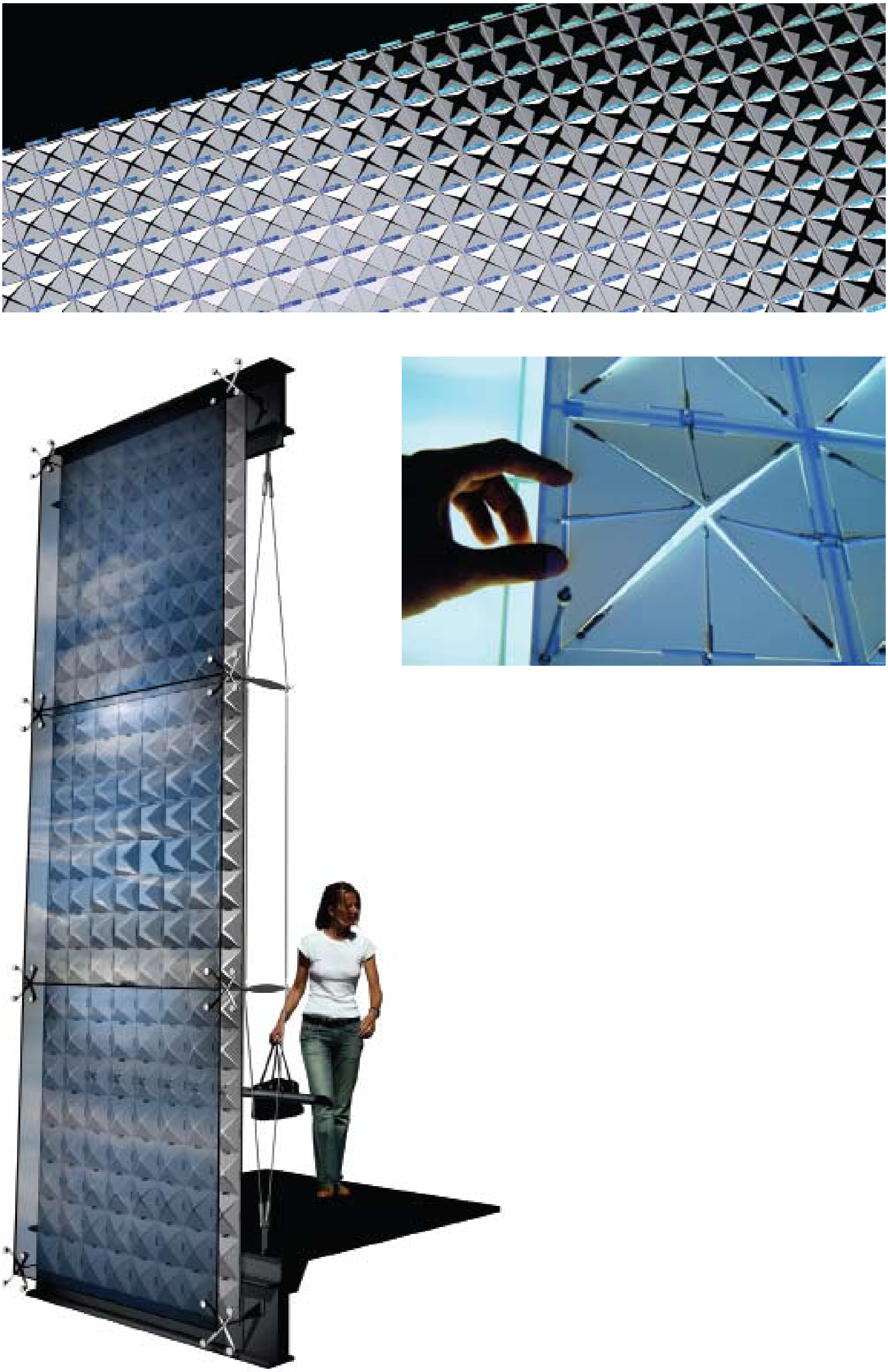
Central to a discussion of interactive architecture is the means of controlling space. The means of controlling change range from the very simple means of direct manipulation to fully adaptive networks of systems that can learn from the users (participants) of an architectural space. The methods of controlling change are not necessarily mutually exclusive, and are intended only to provide a framework for designers to understand different levels of complexity involved in how architectural adaptive response can be controlled. Andrew Rabeneck states that the basic aim of design is to avoid uncertainty through prediction, and that any technology that could assist this process would be useful to architects.[14] It is important to note that although the simplest means of controlling change are not categorically inherent in interactive architecture by definition, they serve as important building blocks for interactive architecture, which necessarily involves true interaction. As Usman Haque puts it, interactive architectural systems must utilize a definition of interaction as circular, or they are merely "reacting" and not "interacting." A truly interactive system is a "multiple-loop" system in which one enters into a "conversation": a continual and constructive information exchange.[15] Although described from an architectural point of view here, the levels of control draw upon precedent in the computer science area of "intelligent environments," which is dedicated to creating spaces in which computation is seamlessly used to enhance ordinary activity. Many research areas in this field have achieved sufficient maturity to be beneficially incorporated into interactive architecture.

> Fig. **9**

> Fig. **10**

In the simplest systems, movement is actuated directly by any one of a number of energy sources, including electrical motors, human energy, or biomechanical change in response to an exchange of information between user and computer. There is a one-to-one relationship, in real time, between input and response whereby information is translated directly into an outcome. Such systems usually involve an information exchange that is akin to an "on" or "off" state, that is, an action either triggers a response or not. Once the device is turned on,

> Fig. **9**: Sachin Anshuman, *PixelSkin02.*



> Fig. **10**: Michael Fox, Jeffery Krause, *Transformer Teleconference Center.*

In the simplest systems, **movement** is actuated directly by any one of a number of energy sources, including electrical motors, human energy, or biomechanical change in response to an exchange of information between user and computer.

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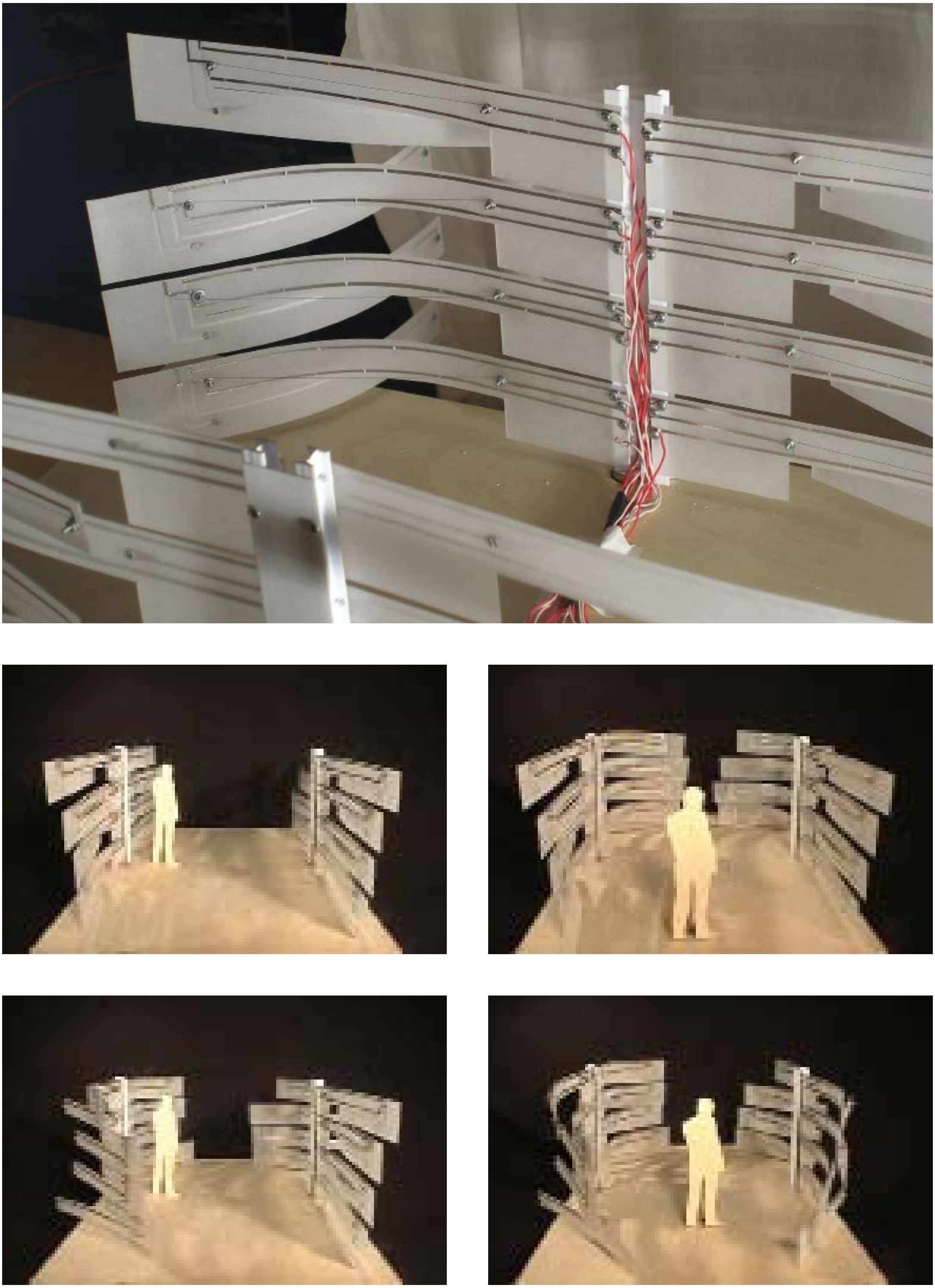
the device either runs for a predetermined amount of time or the input has to change to turn the object off. An example would be that of a light activated by a motion sensor detecting people's movement that stays on for a certain period of time and then turns itself off. More complicated direct control systems can give the illusion of intelligence through automation. Charles Eastman described such automated systems as an obvious means to dynamically improve the fit between users' desires and an architectural environment. He includes an additional level of input whereby users can enter their preferences for the automated system.[16] An example would be that of the household thermostat whereby a user establishes a temperature preference. These thermometers are nothing more than coiled bimetallic strips that serve as temperature sensors. As the room gradually changes, the thermometer coil gradually heats (expands) or cools (contracts) until it tips a mercury switch to change current, energizing a relay that starts the heater and/or fan in your home. Such a system can constantly monitor the environment and provide the dynamic means of change in a low-tech manner without computational processing. > Fig. **11**

By networking a hardware system to a software system, Friedman provided a model of architecture that gave users an interface for controlling buildings responsively. Within this model, intelligent systems give users a means of directly controlling the outcomes of design processes without the use of automation. The network that Friedman formed between hardware and software systems was composed of two interconnected feedback loops that converge upon the user.[17] Such a system is more sophisticated than the direct control described above, because it involves a level of decision making with a feedback system. Because a level of intelligence is programmed into the microcontroller, this method of control has the ability to constantly monitor incoming information and constantly update the response of the system based on user inputs. Almost all high-end appliances use microcontrollers in this manner that involves feedback for system control of sophisticated functions. An example might be a dishwasher in your home that provides digital and audio feedback as to the progress or completion of specific tasks, and can monitor for any abnormalities in the functions. It is important to note that both of these models (either involving user feedback or not) are capable of providing dynamic stability. The automated approach is essentially machine-led, while the feedback model is essentially user-led. Tristan d'Estrée Sterk proposes that the most sensible approach to interactive architectural applications is that of a hybridized approach combining the two. He describes a model of user input, combined with a building that has the

> Fig. 11: Rob Ley and Joshua G. Stein, *Reactive Void.*



Architects are eager to embrace technology that can increase optimization through adaptation with respect both to the environment and user needs, yet they must learn to recognize the interdisciplinary needs that such technologies have ensnared.

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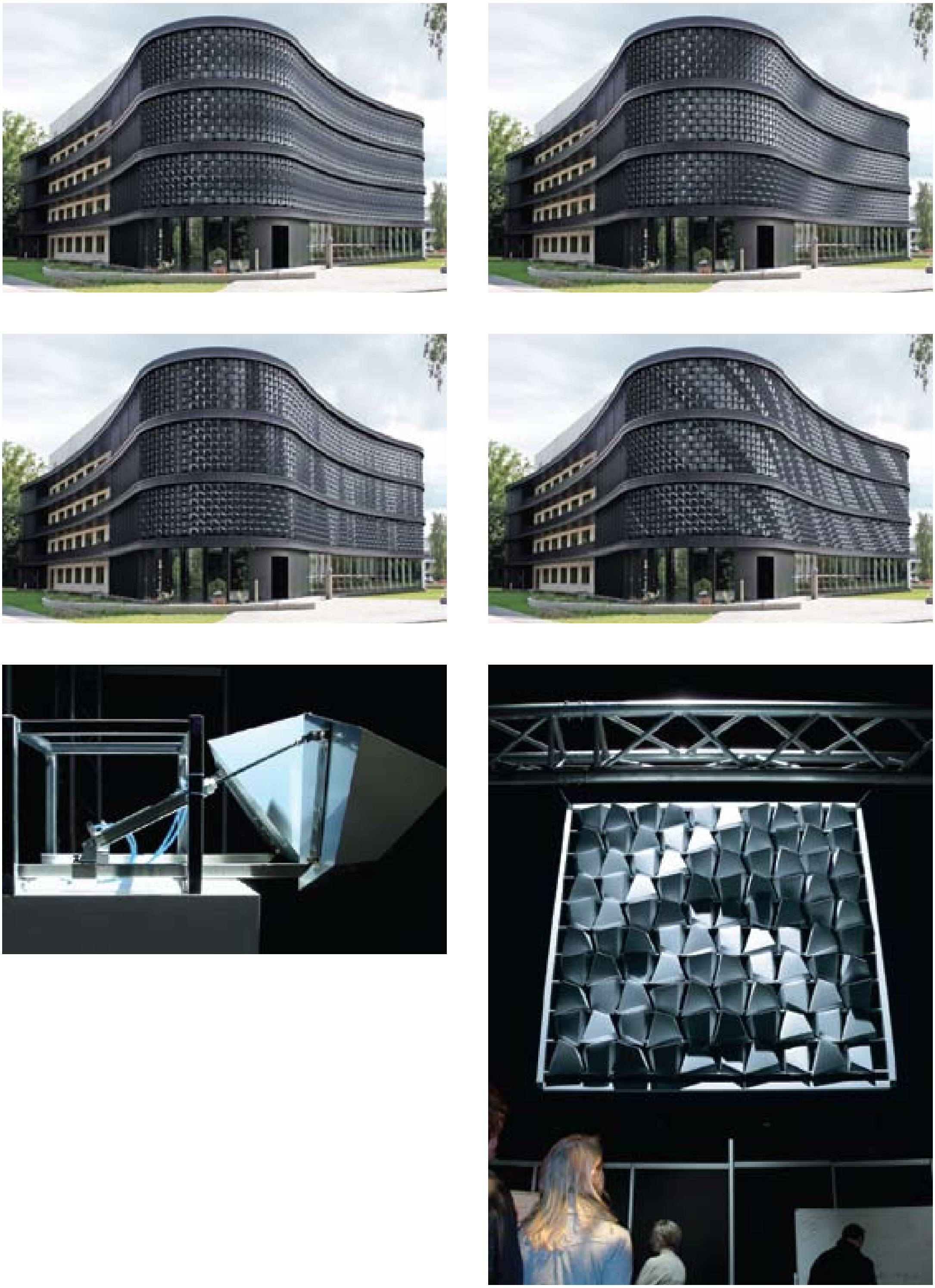
capacity to respond to larger environmental changes and a spatial response that describes a level of adaptation.[18] In adaptive control (which is discussed further in "New Horizons"), the systems integrate a heuristic or learning capacity into the control mechanism. The systems learn through successful experiential adaptation to optimize a system in an environment in response to change. The hybridized model of control was established in robotics but is useful to interactive architecture in combining the (automated) feedback systems with higher-level (deliberative) intelligent processes that include adaptive capabilities.[19] Such an approach is useful on two levels, both within discrete sophisticated systems themselves and in networks of such systems. In a typical sophisticated system, decisions are based on input from numerous sensors that make an optimized decision to send to the energy source for the actuation. This method of actuation involves a further level of intelligence, because it requires a governing hierarchical computational system to interpret information from multiple sources and act accordingly. > Fig. 12

Such a singular system may involve many autonomous sensor/motor (actuator) pairs acting together as a networked whole. The control for such systems can be either centralized or decentralized (discussed further in "New Horizons") but the important advantage of decentralized systems lies in their tendency toward failure. Unlike centralized systems, if hardware malfunctions in a decentralized system other parts of the system can continue to perform operations. The computation that is embedded in a system can be written or programmed in a way that can build upon its own experiences actually rewriting its method of making decisions. The "Flare," for instance, is a modular system that architects can purchase to create a dynamic facade for any building. Acting like a living skin, it allows a building to express, communicate, and interact with its environment through a number of tiltable metal flake bodies supplemented by individually controllable pneumatic cylinders.[20] > Fig. 13

> Fig. 12: Janis Pönisch (photographer Roel Backaert), *Dynamic Terrain.*

> Fig. **13**: WHITEvoid interactive art & design Berlin: Christopher Bauder, Christian Perstl, *Flare–kinetic ambient reflection membrane*.



Interactive architecture will be built upon expertise in embedded computation that mutually influences developments in interface design, materials, autonomous robotics, and biomimetics.

Horizons of Embedded Computation in Architecture

Clearly interactive architecture scenarios describe a future of the architectural profession in which a new level of consultancy is needed in computer science. Take, for example, an operational skylight system recording the weather patterns and associated behavior patterns for ten years. The system could use this information to more accurately and more quickly respond to changing climate patterns. It might also learn that it may be more efficient to adjust the response of the individual parts, rather than the entire system, to most efficiently channel airflow as temperatures change. If the skylight system were connected with hardware and computation to other systems of the house, the intelligence of the unit could further grow as a number of other systems could communicate toward achieving similar goals. The skylight system must manage all such environmental and building complexities, while, and perhaps most importantly, mediating the needs and desires of the individual building users.

Architects are eager to embrace technology that can increase optimization through adaptation with respect to both the environment and user needs, yet they must learn to recognize the interdisciplinary needs that such technologies have ensnared. Perhaps in the future, interactive systems consultants will be as commonplace to the profession as structural, mechanical, and HVAC consultants. Interactive architecture will be built upon expertise in embedded computation that mutually influences developments in interface design, materials, autonomous robotics, and biomimetics. It will also be built upon the pioneering foundations of a number of different projects from within architecture that exemplify characteristic qualities and application examples as described in the next chapter.

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ECT SCAPE

The current landscape of IA is built on the convergence of embedded computation (intelligence) and a physical counterpart (kinetics) that satisfies adaptation within the contextual framework of human and environmental interaction. The combination of these two areas will allow an environment to have the ability to reconfigure itself—to automate physical change to respond, react, adapt, and interact. These areas have begun to emerge into what we now consider to be interactive architecture. This field is in its infancy, and there are many exciting directions to be explored and researched. The development of both embedded computation and the physical means of adaptation are being strongly influenced by many other areas, including interface design, materials, autonomous robotics, and biomimetics, all of which are covered in "New Horizons." This chapter, however, examines a number of pioneering projects that exemplify characteristic qualities and set precedents in contemporary IA. This chapter is divided into four main areas: "Adaptable Space," "Environmental Impact," "Enhancing and Extending Activities," and "Sociological and Psychological Implications."

ADAPTABLE SPACE

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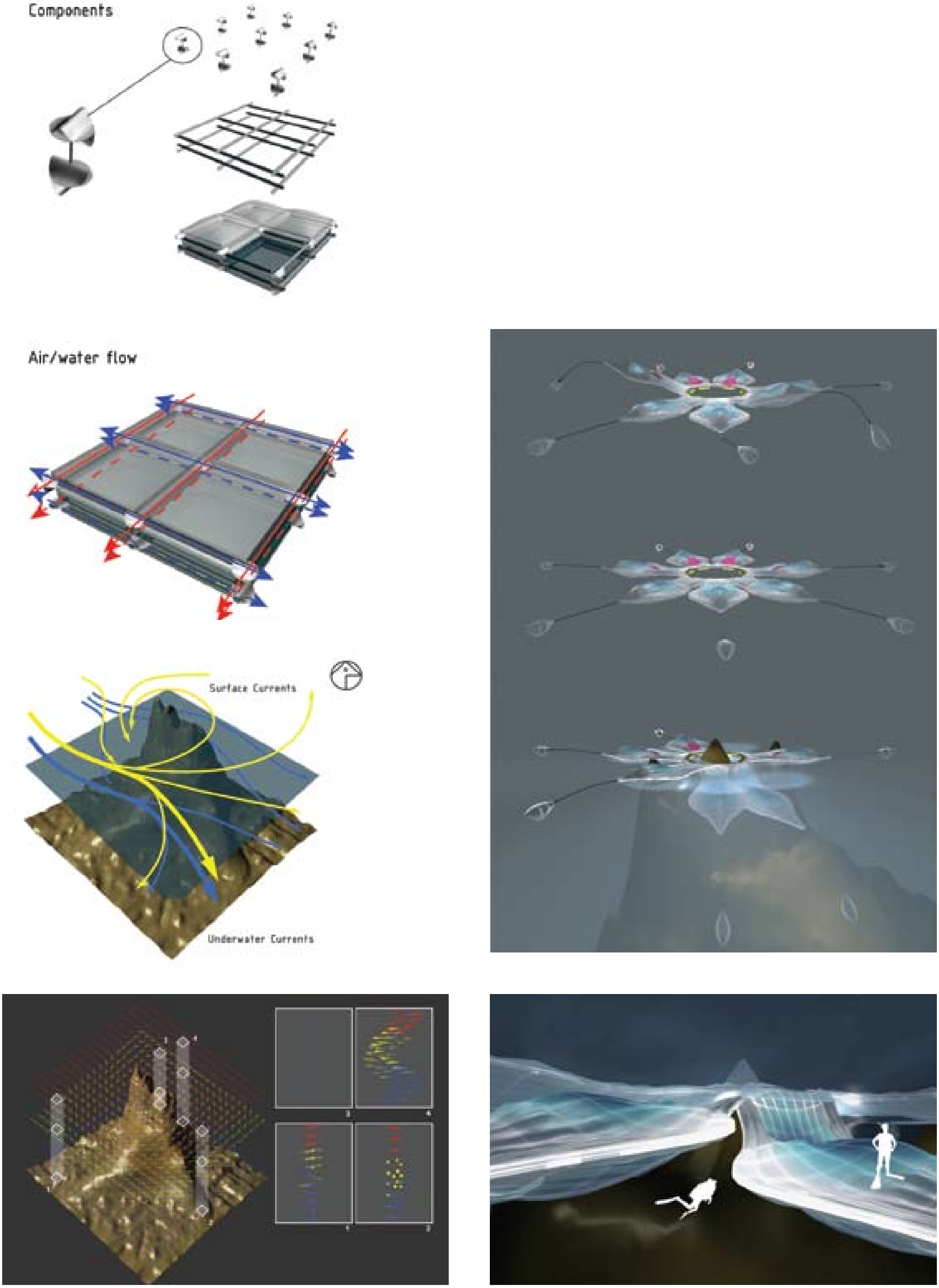
p. 100


The current landscape of IA is built on the convergence of embedded computation (intelligence) and a physical counterpart (kinetics) that satisfies adaptation within the contextual framework of human and environmental interaction.

Adaptability refers to the ability of space to be flexible enough to accommodate changing demands on a system. In much of the architecture that has been built to date, adaptability has referred to the ability of a structure to change its geometry to accommodate a certain type of activity. The adaptability in these built projects was either embedded in the logic of the creation of the system (i.e., manually adjustable modular panels and structure systems by Prouve and Fuller) or embedded in the logic of the kinematics (i.e., manually adjustable awnings and domes by Calatrava and Hoberman). In the examples covered in the first chapter of this book, kinetics referred to the physical means of providing an inherent potential for architectural change but not necessarily any means for interaction. Without simultaneous physical change and embedded computation, interactive adaptability is impossible. The main difference between adaptable space within the context of this book and older forms of flexible space is that they involve some level of interaction. Past kinetic projects relied on the user to manipulate the physical geometry of objects by manually changing the size, color, shape, or location of an object that made up the space. These projects were adaptable in that they had the ability to change in respect to the new demands on the system, but were not interactive in the sense of the object being able to sense information from a user or the environment and then adapt itself. > Fig. **2**

Adaptable space is often ensnared in issues of optimization, which in this context is the act of making something as functional or effective as possible. In spatial terms this refers to the ability of a space to accommodate specific user demands by being able to adapt to an optimized state to address a certain action. With respect to external environmental conditions, optimization is straightforward in terms of performance-based criteria. Optimization from an experiential standpoint is much more difficult, as it is based on how we determine, in our own minds, to what degree a space has reached a particular optimized state. The relationship between activity and space is a constantly changing one. The specifics of this decision can be complicated, depending on the user(s) and the specific criteria needed. As an interactive adaptable relationship is established between a user of a space and the space itself, the experience of the space becomes increasingly compelling. Adaptable space engages precisely this phenomenon of a dynamically changing experience of space that transforms both the user and itself. Applications may range from interior organizational disposition to external environmental mediation to complete structure transformability. Through adaptable space, we can also explore how objects in the built environment might physically exist only when necessary and disappear or transform when they are no longer functionally needed.

> Fig. **2**: Miles Kemp and Amiee Lee, *Begg Rock Annex.*



When the entire environment becomes an **interactive environment** that is mediating the needs of the users and the environment outside, it must **facilitate communication** through the physical space itself.

Living Environments

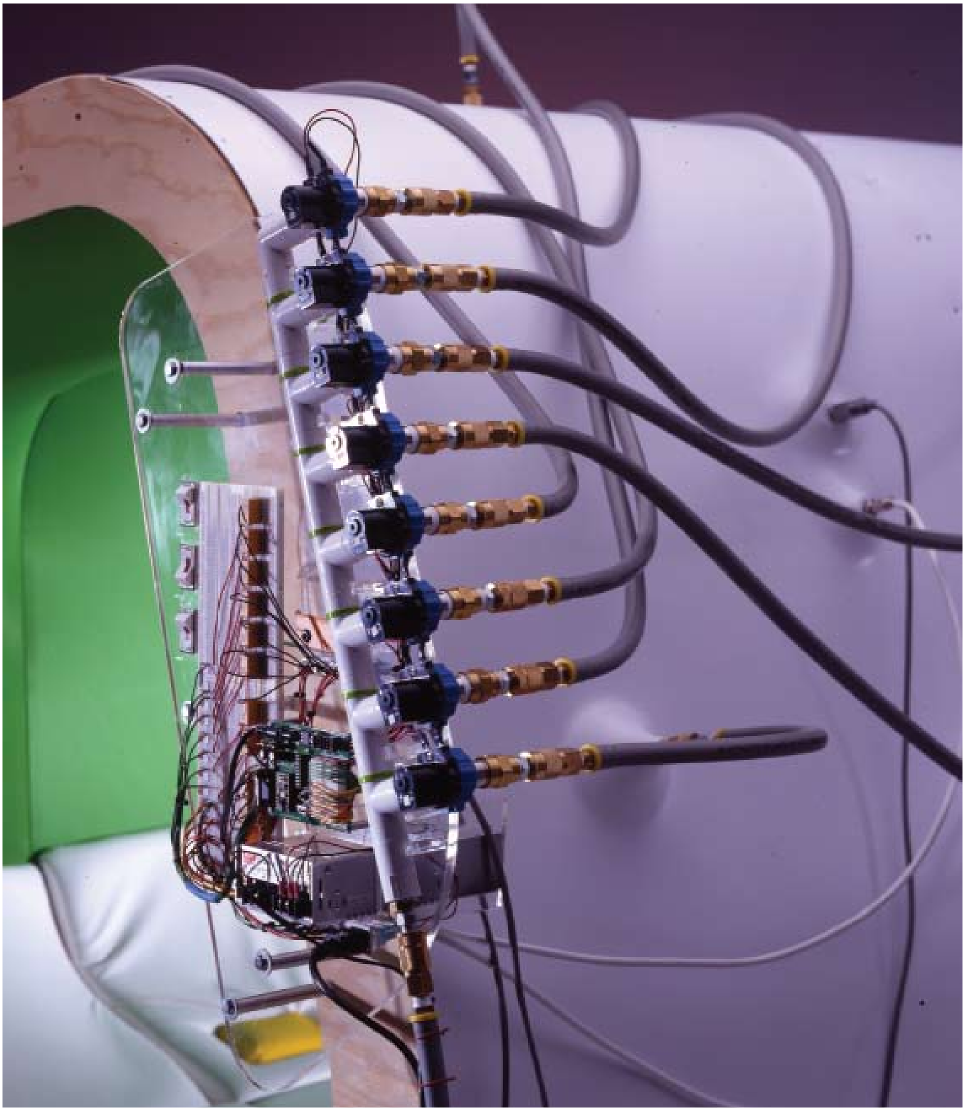
When the entire environment becomes an interactive environment that is mediating the needs of the users and the environment outside, it must facilitate communication through the physical space itself. How such an environment can describe, adapt to, or change behavior, through adjusting the conditions in which people live, particularly the communicative conditions, is determined in large part by available technology today. Interface design (which is discussed in detail in "New Horizons") comes to the forefront of this discussion as the ways in which we interact when we are living normally rather than sitting on a chair in front of a computer keyboard and monitor. The keyboard will always remain to some degree a primary device for inputting data, but the discussion changes when the environment is ubiquitously gathering and receiving data via sensors, cameras, microphones, speakers, and the like. Privacy then also becomes a major issue in our living environments when personal information is needed. If an audio conversation that is available with a video image is not novel or necessary, we will not want others to view us; if a view of our house or workspace is not necessary, we will probably not want others to see it until we have cleaned or prepared it to the way that we want to present it. One could think of architectural space as analogous to how we typically interact with our computers: When an individual accesses information on a laptop or PC, it is typically a very individual experience that is not shared with others. The interaction may be voyeuristic in both directions, and it also may be an open communication with another person. Currently there is a direct correlation between the amount of information that a system can gather and the usefulness of that system. The benefit is proportionally related to the amount of privacy one must give.

> Fig. **3**

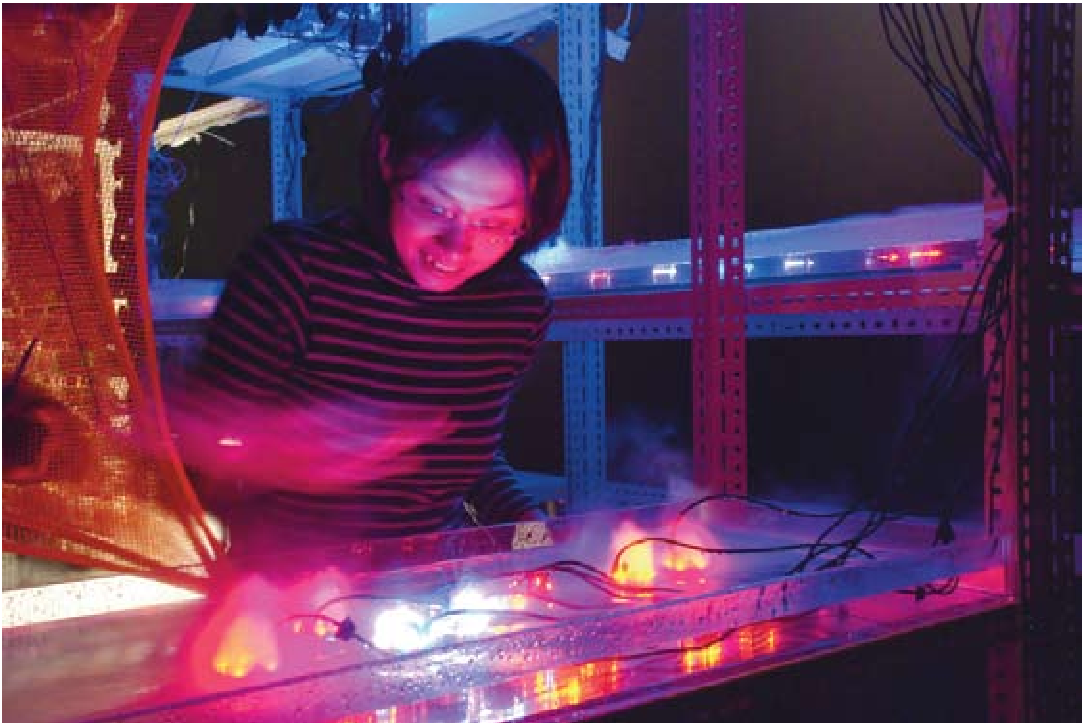
> Fig. **4**

The most developed area of living environments is the area of home automation discussed in "Embedded Computation." These systems are typically fully automated and deal with all of the systems in a home, including lighting, climate, security, and entertainment. While home automation is essentially motivated by personal empowerment, convenience, and energy-use optimization, the discussion of living environments here also integrates that of communication. An environment can facilitate communication in a number of increasingly sophisticated ways that are all directly analogous to the ways in which we communicate via our computers today. A person may share information with another person in the same

> Fig. **3**: Steve Joyner and Tina Pezshkpour, in *Interactive Design Studio by Michael Fox at Art Center College of Design.*



> Fig. **4**: Usman Haque and Adam Somlai-Fischer (with the Reorient Team), *Reconfigurable House.*



Currently there is a direct correlation between the amount of **information** that a system can gather and the **usefulness** of that system. The benefit is proportionally related to the amount of privacy one must give.

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location that could be nothing more than a video projection viewed by two people in the same space. Two people may also communicate with each other in remote locations by videoconferencing within each person's respective place. A person can also have the ability to share this communication with a group of people in remote locations by means of group videoconferencing, with many users online. All of these modes of communication seem acceptable in that one can simply turn off the connection to others when one wants; there is a clear sense of control. Issues of privacy and control must be reconsidered, however, when another person's projection evolves into a physical manifestation within the space, or if groups of people begin to interact with another person's private space. While such modes of interaction are in their infancy from an application standpoint, they are useful for understanding the balance between benefit and privacy. At this point, it may seem comforting to recall the horror by many at the initial prospect of the telephone. Many were opposed to the notion that they could eventually be reached by voice, live, by any person, anywhere, via the ringing of a bell in any room of their house.

The argument always befalls flexible office design that to make a space capable of doing **everything** is to make a space that does **nothing very well**. An interactive environment may prove eventually to make a space that can in fact do everything well.

Working Environments

Applications in interactive architecture show great promise for transforming the workplace as we know it today. Many service-oriented work environments are constantly upsizing or downsizing, depending on the amount of commissioned work within the office. It is vital that such workspaces efficiently maximize their available area. Manipulating the workspace to manage such spatial fluxes is a common practice, and often desks and worktables are moved after hours to make way for additional employees for a few weeks or moved back to place after the conclusion of the work. On a higher level of specificity, many office spaces are used only in the mornings and late afternoons when employees come in for meetings and to check email; at other times, employees are out at a remote job location. With a dynamic system, that vacant space may be effectively used during very short periods of time. At weekly meetings, a large conference room may be needed for fourteen to twenty people, and yet at all other meetings, the room may be required to accommodate only four to six people at a time. The prime target for applications in this area is the various spaces and objects around the workspace that are used sporadically during the day, and the key is how they can be used more effectively and efficiently. If, for instance, a person's desk is transformed to be used by another person when he or she is not there, the new person may have specific needs for acoustics, privacy, or lighting that differ from the default for that specific space. There are times when privacy in a workplace is necessary both acoustically and visually, and yet the demands on the same space may include communication with others immediately thereafter. Such contexts are constantly at play in collaborative work environments; such teams may also have different demands for acoustics, lighting, and surfaces, depending on the immediate task at hand. Most scenarios revert to the ideas of creating flexible workspaces that dominated office design of the recent past. The argument always befalls flexible office design that to make a space capable of doing everything is to make a space that does nothing very well. An interactive environment may prove eventually to make a space that can in fact do everything well. An interactive environment can also deal with all of the peripheral needs for spatial optimization that go beyond the effective usage of space to include lighting, wiring, acoustics, privacy, and views.

Many applications in **entertainment** embrace an educational component, whereby a new kind of **kinesthetic learning** is combined with **entertainment experiences.**

Entertainment Environments

There is a great deal of built precedent in interactive applications geared toward entertainment that range from simply providing pleasure to social engagement to educational benefits. The context is equally as broad, covering municipal, commercial, institutional, and residential situations. In the public realm, sculpture, fountains, and building facades have adopted interactivity as a vital component that the works must include to capture an audience. Museums, for instance, have rapidly embraced interactivity with respect to the demands of presenting and viewing exhibits and artifacts. Interactivity combined with spatial adaptability can serve well the temporal nature of changing displays and the ways in which visitors interact with them.

Many applications in entertainment embrace an educational component, in which a new kind of kinesthetic learning is combined with entertainment experiences. Such applications enable users to utilize their bodies as well as their minds in collaborative ways. Children seem happy to accept learning if it has an entertaining interactive component; they are engaged through the aspect of controlling the narrative. While interactive entertainment is rapidly moving into the physical realm, it is a concept born out of electronic media. Marshall McLuhan lists "three key pleasures" that are uniquely intensified in electronic media: immersion, rapture, and agency. Immersion, he says, is "the sense of being transported to another reality," rapture is the "entranced attachment to the objects in that reality," and agency is "the player's delight in having an effect on the electronic world."[1] In the world of entertainment, when an environment is engaging, it is by definition successful. From the perspective of toy design, the educational value always has commercial value as well. *Edutainment* is a commonly accepted term for entertainment that is designed to equally educate and amuse. Toy design centered on edutainment is principally engaged with bringing together the computational and the physical to enrich the educational aspect of playing. Mitch Resnick, however, argues against the prepackaged benefits of such toys in stating that he prefers "to focus on 'play' and 'learning' (things that you do) rather than 'entertainment' and 'education' (things that others provide for you)."[2] The difference can be clarified with sophisticated toys such as the LEGO Mindstorms Robotics Invention System, which is an advanced set of LEGO bricks with motors, gears, and built-in sensors (light, touch, and

The physical architecture can be used to include or exclude people from one another, to facilitate, dissipate, or focus crowds of people. In this way, in the realm of the physical world, interactive public spaces can have a profound effect on social interactions.

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infrared) controlled with a small, wireless "programmable brick" computer brain.[3] Kids can basically invent toys that think and move on their own. While the LEGO bricks eventually led to marketable robotic kits, the latest invention by Resnick's team is Crickets, which are small programmable devices that are open-ended enough to facilitate artistic creations by integrating other outside static components and parts.[4] With the low cost of microchips and other electronic components, new advances in technological toys can be reached. They can be distributed to the masses at inexpensive prices, so everyone can appreciate them. Such computationally enhanced toys will be invaluable in trailblazing the general acceptance of ubiquitous computing in the home.

Public Environments

Beyond the workplace and living environments, there are numerous places in the public sphere where interactive systems can be employed. Commercial outlets, for instance, could take advantage of profiling to make an active inventory that moves itself to the forefront to target a particular customer. Grocery stores could target their customers without profiling by moving the inventory during parts of the day when specific items may be more desirable. Music stores could tap into what people are listening to digitally as they enter the store and merchandise could dynamically adjust itself accordingly. Clothing and eyewear stores could virtually put customers into the items that are being sold. Restaurants could use all of their seating more efficiently rather than seating a party for two at a table designed for four. Such scenarios raise an important point as to how commercial benefit must be obtained through clearly defining specific consumer trends rather than necessitating profiling on an individual basis.

Interaction design in the public sphere also necessarily engages the social and cultural dimensions of space. Many art projects have utilized the medium to engage in the political arena through participation. Natalie Jeremijenko is one of several artists who explore opportunities presented by new technologies for grassroots social change. She has taken advantage of how real-time media, for instance, can challenge borders through restructured participation, and make explicit social accountability and responsibility.[5] Designers often look for opportunities to use spatially defining interaction as a mechanism to understand, critique, and promote social interaction. The physical architecture can be used to include or exclude people from one another, to facilitate, dissipate, or focus crowds of people. In this way, in the realm of the physical world, interactive public spaces can have a profound effect on social interactions. It is important to point out here that projects in the public sphere also serve an important role in testing the durability of materials as well as the time frame of particular interactive strategies within the context of unpredictable participants.

ENVIRONMENTAL IMPACT

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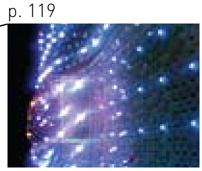


Buildings have a huge environmental impact: "The largest source of greenhouse gas emissions and energy consumption in America, as well as around the world, is buildings. Buildings account for an estimated 48% of all greenhouse emissions."[6] With such sobering facts, the architectural world has begun to awaken to its responsibilities. Edward Mazria initiated the 2010 Imperative and the 2030 Challenge in 2003 as a call upon the community of architects and designers to impact global warming and global resource depletion. Scientists warn us that immediate action in the building sector and a concerted global effort is necessary. The 2010 Imperative is a call to architectural design education whereby "the designs engage[s] the environment in a way that dramatically reduces or eliminates the need for fossil fuel."[7]

The 2030 Challenge takes a major step beyond academia in asking the global architectural community to adopt a number of targets that will eventually make all new buildings carbon neutral. The goal is to achieve "a dramatic reduction in the global-warming-causing greenhouse gas (GHG) emissions of the building sector."[8] This global initiative specifies that "all new buildings and major renovations reduce their fossil-fuel GHG-emitting consumption by 50 percent by 2010, incrementally increasing the reduction for new buildings to carbon neutral by 2030."[9] One of the challenges to sustainability is to build shelters that provide human comfort while limiting the use of resources and minimally impacting the environment. Current practices in building design and construction have not provided a satisfactory balance among these.

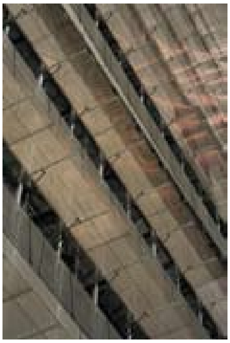
An interactive building can **dynamically mitigate conditions** to take advantage of energy-conserving strategies such as building orientation and openings to maximize opportunities for daylighting and desired solar heat gain, avoiding unwanted solar heat gain, heat loss, and thermal losses.

Energy Efficiency

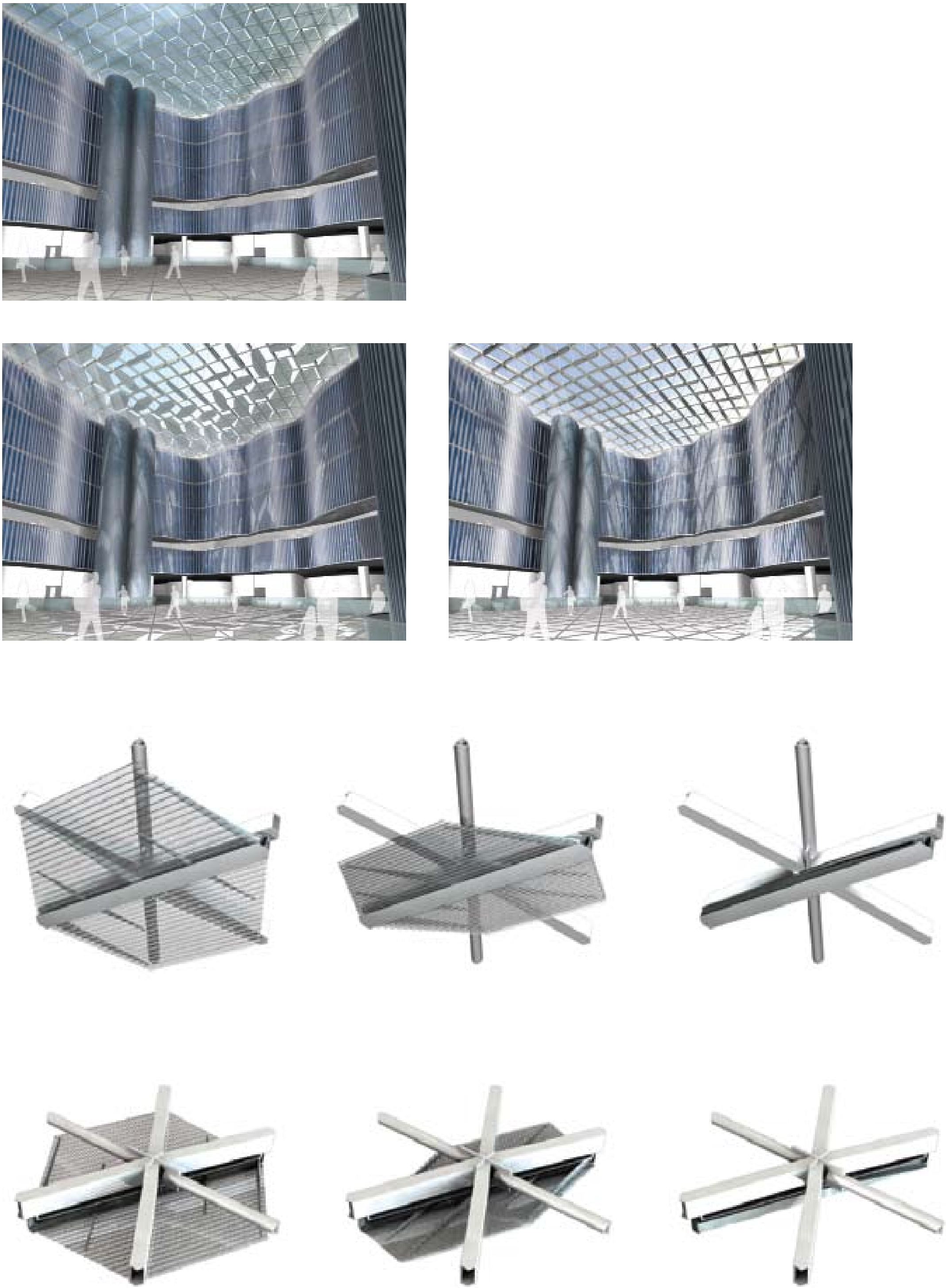
Sustainable architecture in general involves a number of disciplines and scales of action, but reducing energy consumption is one of the most important steps toward the generation of a sustainable building. For more than half a century, heating, ventilating, and air-conditioning (HVAC) systems have become essential in building design for providing comfortable living for people in different environments. While the quality of life in many places may be improved by the use of HVAC systems, the economic burden and environmental degradation are also increased by the use of nonrenewable energy for these systems. Pablo LaRoche points out: "Most of the research in architectural sustainability focuses on making the building or the HVAC system more efficient rather than alternatives to the HVAC systems." [10] This is precisely where great opportunities for interactive architecture can play an important role in carbon neutral design, by optimizing the performance of proven passive sustainable strategies. > Fig. **5**

An interactive building can dynamically mitigate conditions to take advantage of energy-conserving strategies such as building orientation and openings to maximize opportunities for daylighting and desired solar heat gain, avoiding unwanted solar heat gain, heat loss, and thermal losses due to wind-driven infiltration, as well as maximizing passive solar and passive cooling opportunities. Once a building is sited and configured for passive solar opportunities in terms of heating, cooling, and daylighting, it can be optimized with an interactive system by dynamically adjusting all of the systems throughout the day to meet the needs of the user more efficiently and accurately than the isolated components. Simple applications such as closing dampers and doors in rooms that aren't occupied or opening windows for optimized thermal conditions can potentially extend even the most perfectly designed passive systems. Cumulative benefits beyond those of the individual buildings include reducing CO_2 levels, and thereby the heat island effect. Greater and more efficient use must be made of energy systems that have less impact on the environment, especially "renewable" sources. Architects should embrace the use of wind power, solar energy, wave energy, and geothermal energy, because these are nonpolluting, renewable, and efficient. > Fig. **6**

> Fig. **5**: Morphosis, Thom Mayne (photos by Nic Lehoux), *United States Federal Building, San Francisco.*



> Fig. 6: Hoberman Associates (shading), Foster + Partners (architect), *Campus of Justice, Appeals Court (Campus de la Justicia, Audiencia Provincial).*



Perhaps the most important goal of an interactive system today should be to act as a moderator responding to change between **human needs** and **external environmental conditions**.

Active Sustainable Solutions

Perhaps the most important goal of an interactive system today should be to act as a moderator responding to change between human needs and external environmental conditions. Building performance strategies that increase the resource efficiency of the operation of buildings simply cannot be overstated. One great opportunity for interactive architecture is to examine passive sustainable systems coupled with automated kinetics and computer control to optimize their performance. Such an approach leverages simple technologies by combining systems, thereby optimizing the performance of proven passive, low-tech principles of design. An optimized system then combines distributed sensing, physical transformations, and computer control algorithms, enabling dynamic management of conditions in response to changing environmental conditions in real time. Such systems could be adapted to a broad audience of users and would benefit three parties: the building owner, by achieving thermal comfort (which is a technical term for a state of mind that expresses satisfaction with the surrounding environment) at a lower cost than a traditional HVAC system; local economies, by reducing the competition for nonrenewable fuels; and the entire planet, through the reduction of global pollution. > Fig. **7**

The challenge is to improve thermal comfort while simultaneously reducing energy expenses, consumption of fossil fuels, and resulting generation of CO_2. The benefit of an active sustainable system is that it can intelligently combine the resources of a number of systems so that when working together, the individual elements or systems achieve more than the sum of their parts. It is easy to imagine individual control of proven sustainable systems such as an active window that can shade and ventilate and gather energy through an integrated photovoltaic system, a remote system for heating water that can run through the floors, or doors and windows that can close off spaces, and to integrate these within a building to vastly improve its performance, but when these are combined with a control system that can manage all actions, the performance as a whole becomes synergistic. With a fully integrated system, the individual systems understand each other's actions and can be controlled cooperatively to optimize overall conditions.

> Fig. **7**: Michael Fox, Pablo La Roche, Phyllis Nelson, *The Green Kit: An Experience in Collaborative Teaching.*

The benefit of an **active sustainable system** is that it can intelligently combine the resources of a number of systems so that when working together, the individual elements or systems achieve more than the sum of their parts.

Ephemeralization

In an interactive building, much of the structure could be reduced by using a single system to facilitate multiple states of response via dynamic adaptability. "Ephemeralization" is a term coined by Buckminster Fuller describing the ability to continuously do more with less, in terms of technological advancement.[11] This concept can be applied to material reduction, whereby a building adapting to changing conditions is directly related to a building that uses fewer resources. The area of active control, which was discussed in "Embedded Computation," is focused on the use of control to modify the structural behavior in a building. This enhancement can be used to actively stiffen or strengthen a given structure depending on the changing demands on the system. In a building such as a skyscraper, where the majority of the structural material is there to control the building during windstorms, a great deal of the structure would be rendered unnecessary under an active controlled system. Beyond the actual reduction of structural material that fights the wind, the skin of a building can be designed to effectively embrace the positive and useful changes in the exterior environment. This can be achieved using sensors and controllers that respond to real-time climate changes to moderate and optimize the penetration of both the sun and wind into a building. > Fig. **8**

A discussion of ephemeralization also necessitates an understanding of materials used and the choices that designers make with respect to the environment. With many new materials, we can do a great deal more with less, and yet the environmental costs of those materials must also be considered. A valid life cycle assessment (LCA) is an assessment that involves the evaluation of the relevant environmental, economic, and technological implications of an object or process throughout its lifetime from creation to waste. This analysis is a whole systems approach to determining the total sustainability of a given project; it is the only type of analysis that looks at the sustainability of a product beyond just its operation. It is often used as an argument to weigh the pros and cons of a particular product. An analogy is the case of paper versus plastic bags, in which one must weigh where each bag comes from, where the bag goes after use, and the environmental impact of production. We propose detailing the most important processes associated with a product over its entire supply chain and life, but warn that this approach also requires considerable attention and time. At times

> Fig. **8**: The Living (David Benjamin + Soo-in Yang), *Living Glass.*

In an interactive building, much of the structure could be reduced by using a single system to facilitate multiple states of response via dynamic adaptability.

it can be difficult to choose between the high environmental costs of a raw material and the longevity of that material. The debates must be carefully considered, and, while there are several good software packages today to assist with such analysis, it is difficult to assess the LCA of a product with a system that actively engages in a dynamic way with environmental changes. Perhaps the greatest means by which interactive systems will positively impact the environment is by reducing energy consumption and CO_2 emissions to the atmosphere by replacing conventional, energy-intensive systems with alternatives that consider the inclusive and dynamic LCA.

Environmental Cognizance

Daily changes in the environment rarely make much of a long-term impact on the way that we organize space or build structures. Instead, space and structure are usually governed by the systems that are needed to support space. There are many opportunities in IA for connecting users to the environment outside of the building. For example, imagine how a facade might change its shape to minimize the amount of damaging UV light striking each panel during the day. If the facade gave us clues on the amount of light that was directly shining onto the panels, we would be more aware of the conditions outside. Christian Moeller's project, entitled Kinetic Light, gives visual clues as to the current weather as the facade of the building is transformed by the environment. During the day, the perforated surface of the sheet metal, which is in front of the blue facade of the building, remains grey and reserved. When the sun sets, however, it transforms its colors depending on its surrounding weather conditions. Now consider what it would be like if there were an interactive back-and-forth exchange between the environmental needs of the building and the changing needs of the inhabitants. Imagine, for example, that a building's exterior would adjust to strengthen itself against high winds while simultaneously maintaining a certain shape to allow activities to take place inside. The building has the opportunity to make inhabitants more aware of exterior conditions. The main point of adaptable structures that are environmentally aware is that

The main point of adaptable structures that are environmentally aware is that they have the ability to educate the people that use them on their current condition and the changing state of the environment.

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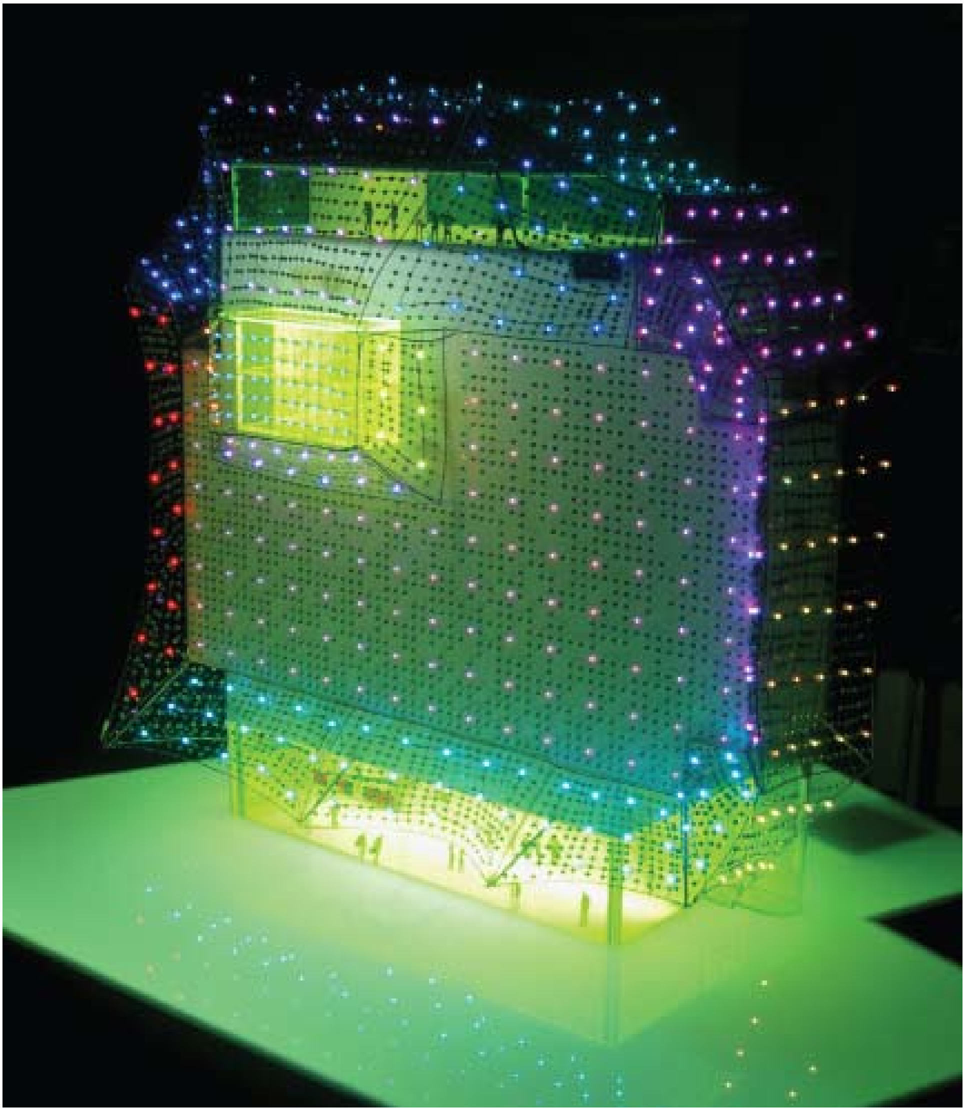
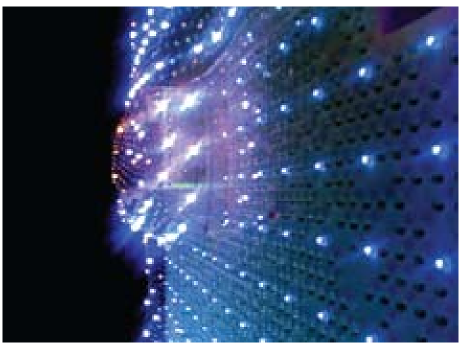
they have the ability to educate the people that use them on their current condition and the changing state of the environment. As this environmental information becomes increasingly available and apparent, we have the opportunity to become more connected to our buildings as they take on lifelike forms. This environmental awareness will ultimately lead to new intelligence, which eventually will affect the entire system. As the needs of our buildings become more apparent, we will have a better understanding of how to build them and what their needs are. > Fig. **9**

The methods that buildings use to signal environmental change are rapidly developing. Much of the work up until now has looked at methods of signifying, quite literally, the impact of the environment on the building. The information that buildings interpret may take on a different form that also influences the way we use space; a dialogue can take place between the parts of a building that interact with the environment and the users' spatial needs inside. For example, on an extremely hot day, the building might become smaller to minimize the amount of sun exposure as well as the amount of space that needs to be cooled for an inhabitant to feel comfortable. As the changing environment has a larger impact on the ways buildings behave it will, in turn, impact the ways we use space.

> Fig. **9**: Architect Enric Ruiz of Cloud 9 and light consultant James Clar, Barcelona, *Habitat Hotel*.





ENHANCING AND EXTENDING ACTIVITIES

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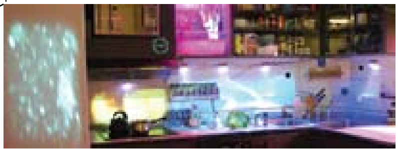

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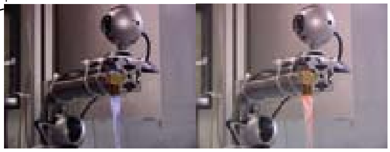

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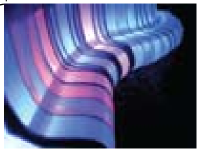

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Novel applications arise through addressing how interactive architecture can adapt to **enhance and extend our normal daily activities** as well as assist users with activities that were previously impossible or very difficult to do.

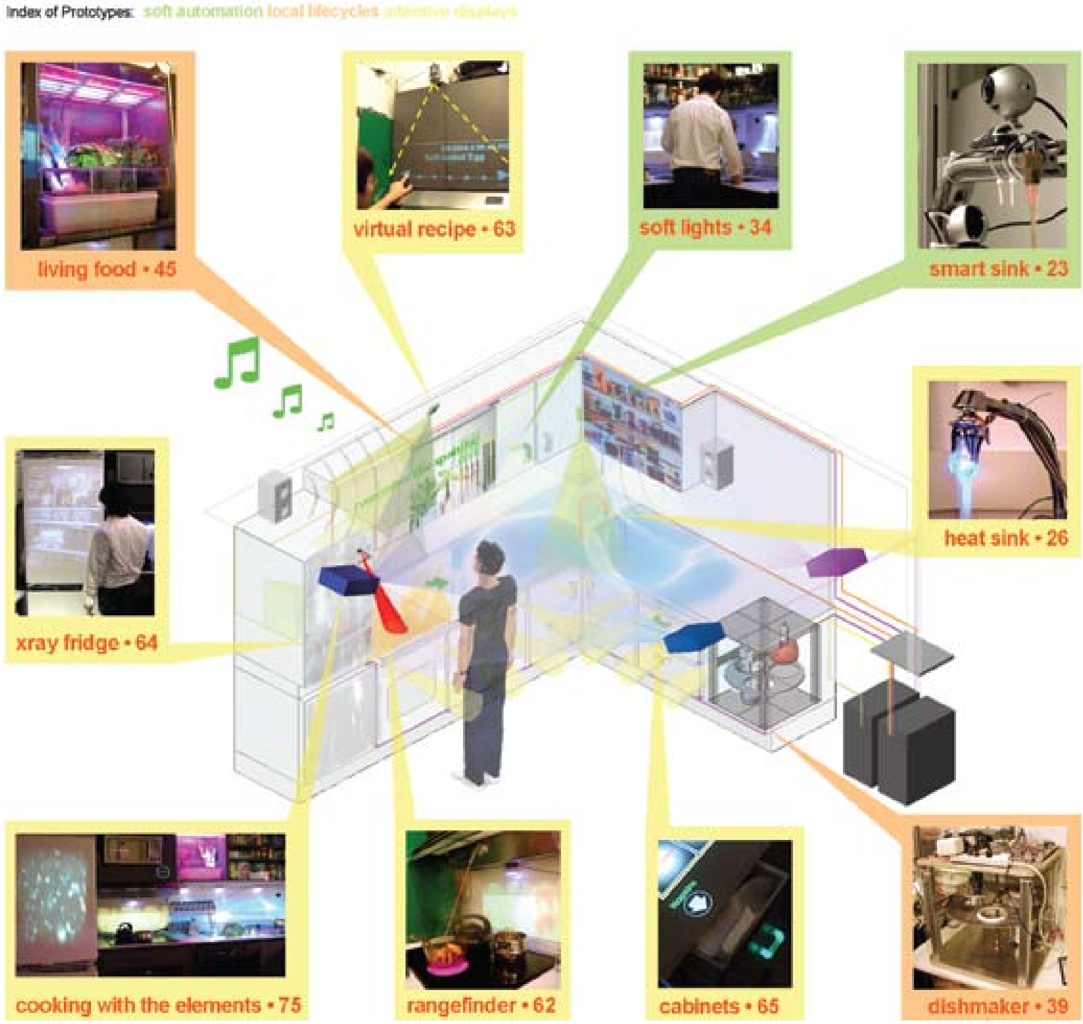
While there may be many reasons for employing kinetic solutions in architecture, we can always rest assured that they are a means to facilitate adaptability. Novel applications arise through addressing how interactive architecture can adapt to enhance and extend our normal daily activities as well as assist users with activities that were previously impossible or very difficult to do. The primary targets for enhancing and extending activities have been the military, the elderly, and the handicapped. Not surprisingly, the vast majority of the work has been both highly tectonic—dealing with recognition tasks and managing human interactions—and focused on novel applications of Internet technology. One true promise of IA lies, however, in mitigating the needs of the physically challenged and the elderly through fostering the development of environments for independent living and social participation. While it is easy to imagine an automated, even highly intelligent, interactive control of a skylight that is located in the ceiling, it is still a simple extension of an activity that one could manage to do if so inclined. The advantage of a truly interactive space is to manage the operation of many such systems and mediate them dynamically with the constantly changing desires of the users and the environment. With respect to many physical systems working together, there are many analogies in dynamic organizational systems found in nature. Such organizational systems, which are discussed in "New Horizons," deal with discrete and autonomous parts that work together toward a collaborative goal. Each architectural element can be combined with any other, has access to physical and natural resources, and can respond to individual inputs. These systems are inherently tied to a function of scale; change may occur internally at the material level, which is quite different from larger individual devices with specific goals. Mapping organizational systems in nature onto a combination of physical attributes combined with computational control can lead to new insights in thinking of building as systems. Neil Spiller states, "Humanity and consequently architecture are on the verge of a major shift in direction. As contemporary technological explorations into both biological and mechanical systems continue, a reassessment of architectural space is occurring."[12]

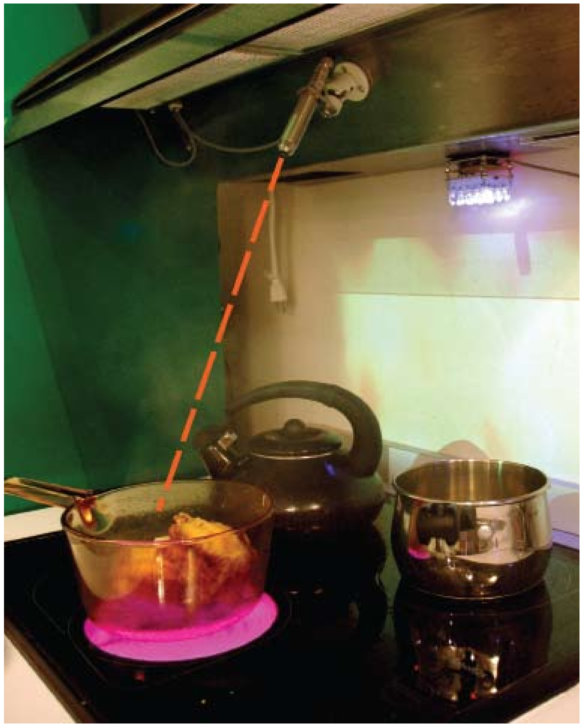
Mediated environments intervene, reconcile, and arbitrate deficiencies and extend capabilities. With regards to applications, the most innovative designs will always arise from unique situational use, yet the true economic advantages lie in applications related to the elderly and handicapped, multiuse situations, and sustainability.

Mediated Environments

Mediated environments are commonly defined as environments that are media induced: users experience spatial information in much the same way as the natural environment. The reference to mediated environments here is quite different and refers to environments that mediate users' capabilities with their architectural needs. Mediated environments intervene, reconcile, and arbitrate deficiencies and extend capabilities. With regards to applications, the most innovative designs will always arise from unique situational use, yet the true economic advantages lie in applications related to the elderly and handicapped, multiuse situations, and sustainability. Examples in this area often center on safety and security, and normal activities are often prioritized over those of convenience. Examples may range from assisting a person with getting out of a chair or reaching items on a high shelf to protecting him or her from falling down a stairway or having access to dangerous items in a kitchen. Such environments are obviously needed for those who are experiencing an onset of deficiencies whereby things that they always did effortlessly become more difficult because of an accident or because of the fact that our bodies change, physically and mentally. To remain self-supporting, people need technology that suits them in a physical, cognitive, and sensory way. Designers should carefully consider evaluating and predicting user needs, as often what one might require is a system completely different from one's initial expectation, and often the needs are gradually changing over time. Although many applications have been developed in this area, many are still in their infancy, and in many cases, the algorithms are somewhat naive, relying on people undertaking the same tasks repeatedly on a daily or weekly basis. Adaptive control, which was discussed in "Embedded Computation," will play a major role in this area of interactive architecture. > Fig. **10**

> Fig. **10**: Leonardo Bonanni and Jackie Chia-Hsun Lee, *Counter Intelligence.*



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Interactive architectural applications have already begun to redefine the level and type of care given to the elderly; this is coupled with a philosophical approach to empowerment.

Gerontechnology

There are numerous healing, nurturing, and rehabilitative opportunities for interactive architecture with respect to both the elderly and the physically challenged. Gerontechnology is a term that refers to the intersection of gerontology and technology, and necessarily includes assistive and rehabilitative devices and processes. Interactive architectural applications have already begun to redefine the level and type of care given to the elderly; this is coupled with a philosophical approach to empowerment. The last several years have marked a significant change in the way society thinks of the elderly and the disabled. In short, general expectations and demands have grown with respect to these populations. With the elderly, there is a changing attitude from both within and outside of the population that is directly tied to capabilities. A discussion of the elderly must also recognize the startling population statistics. According to the U.S. Census Bureau, there were approximately 37 million people over the age of sixty-five in the U.S. in 2004, representing about 12 percent of the overall population. That number increased to approximately 64 million in 2005, representing more than 18 percent of the population.[13] While the percentage of elderly was about 12.5 percent in 2008, this percentage must be weighed against the fact that the U.S. population is predicted to increase by one-third by the year 2050.[14] Overall, the majority of seniors' needs for technology concerns typical products and environments for everyday life. Many people like to work at home or at their place of employment until an advanced age, although perhaps at a slower pace and with fewer working hours than before. There are various reasons why these needs can differ from those in other age groups. These obstacles can be overcome by implementing technology in the work environment. Optional adjustments are often required and can include, for instance, possibilities to change settings on a PC such as increasing light, choosing larger print or more contrast, or heightening volume.

Many applications in this area necessarily include the sensing of information that is very personal; it is often important to not only understand who a particular person is, but also their current health status.[15] Typically this information is sent to a monitoring caregiver, and the matter of when alerts should be sent is a sensitive issue of both privacy and independence. Older people as well as people with disabilities desire to live normal lives, and consequently they will do things that the installers of the system have not allowed for in

Interactive technologies can allow disabled and older people to retain a level of independence within their home which previously would have been impossible

the program. It is important to devise thoughtful means by which potentially embarrassing or unnecessary alerts are sent when a situation may simply be one that the system has not accounted for. "The biggest hurdle to gerontechnology is cultural," says Cynthia Fox, "where monitoring must be fully accepted."[16] The elderly can retain their freedom by surrendering it; an interactive architectural environment can potentially restore full control and mobility, and consequent control of their lives.

Physically Challenged

Long-term care often means turning to a nursing home as the only available option. Typically, however, a considerable amount of care comes from friends, family, or professional services within the home of the physically challenged person. Institutionalized care is often a last resort, and yet the current benefits of such facilities in many cases far outweigh the difficulties involved with independent living. Architectural design issues often include the possibility for physical therapy, exercise, and activities that are beyond the typical demands of the home. It is vital that architecture convey a sense of self-control as even the perceived loss of self-control can accelerate decline in a disabled person.[17] Aging, as previously mentioned, is also associated with people whose activities are restricted because of significant physical disabilities; physical deficiencies can interfere with meaningful daily living. The ability to maintain basic daily functions is what the physically challenged person values most, and it is these basic functions that constitute independent living. Margaret M. Baltes states, "Dependency on others is seen as a product of decline and deterioration, it is therefore a physical loss that is tied to mental function both on the part of the person and of observers of that person."[18] Interactive technologies can allow disabled and older people to retain a level of independence within their home that previously would have been impossible. "Simple everyday tasks such as opening windows, drawing curtains, or even opening doors might appear as commonplace, but for many individuals these functions are almost impossible due to their impairments."[19]

From a design standpoint, a relatively new field, called universal design, has emerged that looks at assistive and mediating design with an appeal to a wide range of users, not just people with disabilities.[20] Many places such as the IDEA Center at the University of Buffalo have developed numerous prototype projects across a broad range of architectural scales, from home design modifications to urban planning.[21] The basic principles of universal design are applicable to a number of fields, including communication, products, and environments that include housing and the workplace; these principles can be very valuable in the design of interactive architectural applications.

Active Participation

Much of our daily existence and experience with architecture is made up of different types of routines and rituals. Adaptive control of an interactive space allows for enhancing and simplifying these daily tasks and creates a sense of active participation with the environment. Considering some of the different types of interactivity that take place relative to daily routines, we see that many of the projects to date have focused on enhancing pragmatic activities. It is important to recognize that, in many cases, the more an object or space has the ability to vary, the more difficult it becomes for the object to satisfy a particular need or accomplish a specific goal. There is also the possibility that the intent or identity of the object may be lost. For example, if a table is designed to be able to bend in six different places to vary its height relative to an activity, it may no longer have the flatness that is required to perform the specific task. It is still as important as ever for users to ultimately have the ability to communicate with a system to define their activities and desires. > Fig. **11**

A further method of extending and enhancing activities lies in the ability of the space to understand the layering of activity that is to take place there. Take, for example, the adaptable bathroom featured on the facing page. The different parts that users interact with frame the activity, efficiently creating space. These parts have the ability to communicate with one another to maximize the experience of an individual user at a specific moment. This becomes increasingly important as multiple users varying in size and in routine use the objects on a

> Fig. **11**: Leonardo Bonanni, Ernesto Arroyo and Jackie Chia-Hsun Lee, *Smart Sink*.

Much of our daily existence and experience with architecture is made up of different types of routines and rituals. Adaptive control of an interactive space allows for **enhancing and simplifying these daily tasks** and creates a sense of active participation with the environment.

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daily basis. A layering of different individual activities and programmatic concerns can then be addressed from within the same space. Interactive architecture has the ability to adjust in real time to keep up with the changing demands of various users while being specific enough to aid in accomplishing their respective goals. It is also important to recognize that there are different ways that buildings can intelligently adapt to accommodate the overlaps in various activities. For example, a system must recognize the overlaps in routines that take place in the more public domains of the house, such as the living room, kitchen, and dining areas. All of these activity areas involve eating, drinking, the display of media, and the ability for inhabitants to be in close proximity to communicate with one another. Imagine multiple people working, relaxing, and mingling in the same areas. Such scenarios highlight the complexity involved in the design of a space that has the ability to constantly monitor the activities taking place there and adapt to numerous different and simultaneous conditions. Such a space has the ability to offer a wide spectrum of comfort levels, appropriate materials, and dynamic spatial constructs to aid in the completion of normal daily activities. Not all types of activities would necessarily benefit through the ability to be more interactively adaptable, and not all opposing desires can be satisfied simultaneously. If two individuals in a car have differing temperature desires, they can adjust them accordingly on an individual localized level, yet in a house or workplace, such localized needs become much more difficult to mitigate within the larger spatial context. In such cases, higher levels of hierarchical rules and prioritization must come into play.

Interactive architecture has the ability to adjust in real time to keep up with the changing demands of various users while being specific enough to aid in accomplishing their respective goals.

Coexistence

Perhaps the most intriguing aspect of remote communication through built form is the impact that it may have on social interactions. Where communication is a mutually active behavior with one or more participants, coexistence is something far more subtle, passive, and subconscious. In political terms, it is a state in which two or more people are living together while respecting their differences and resolving their conflicts nonviolently. It requires more than one person to be in a physical or digital space and to have the means to recognize the others, but does not, at least in a conventional sense, require a person to react or interact for the sense of coexistence to be sustained. In a physical space, one simply needs to exist with others to achieve a sense of coexistence.[22] In many circumstances, in order to coexist in digitally networked environments, it is necessary for participants to put time and effort into presenting their statements. In other words, in a digital community we are often required to have something to say simply in order to exist. Yasu Santo describes it as a "means of communication that is just sufficient to bring a sense of coexistence to digitally networked spaces without requiring one or expecting others to actively contribute statements to maintain their presence in their community."[23] The fascinating new Pachube project under the direction of Usman Haque is a web-based service that "enables people to tag and share real time sensor data from objects, devices and spaces around the world."[24] Connections can easily be set up between any two environments and can even facilitate spontaneous or unplanned interactions. Tobi Schneider's *RemoteHome* prototype brings up some ethical questions when real-time mediated communication becomes part of our everyday environments, spaces, and furniture.[25] Projects integrating such remote communication of course raise many questions of both security and privacy, for the benefits of what can be gained from such an environment are inextricably tied to the amount of information we must give up. > Fig. **12**

In the past five years, the number of projects that remotely affect space is on the rise. > Fig. **13** Advertisers are beginning to notice that they can influence how a space is used based on the way that information is displayed in that space. Certain types of information become more or less appropriate to certain types of activities. Programming space remotely provides the programmer with the ability to monitor information and make decisions on how to change the way space is used. Such information and communication technologies in the remote

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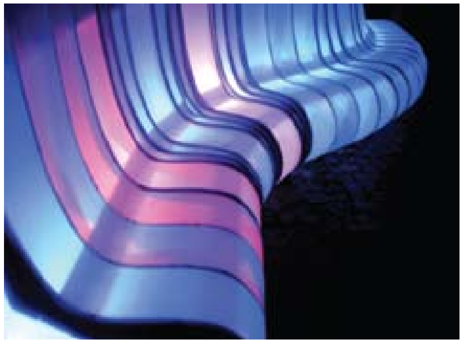
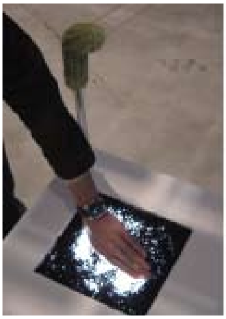
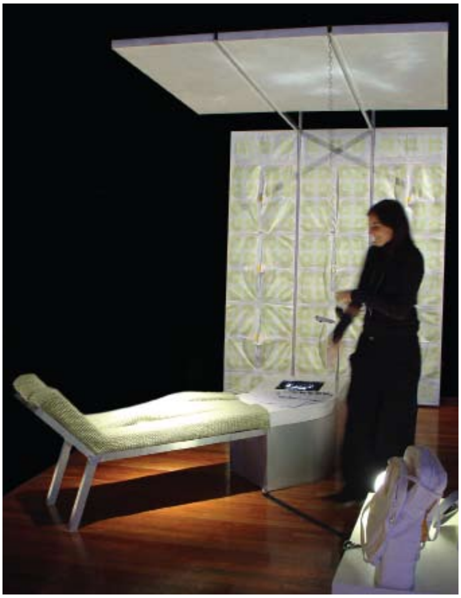
control of architectural environments can explore how a design can have a local, regional, and, potentially, global audience. In fact, according to Santo, "There are a number of ways we can be socially present in our everyday context and we experience more and more of what used to be considered virtual reality as down-to-earth everyday reality."[26] Such an approach can radically reframe the way in which a building is viewed and the role that the physical environment plays in shaping the users' experience.

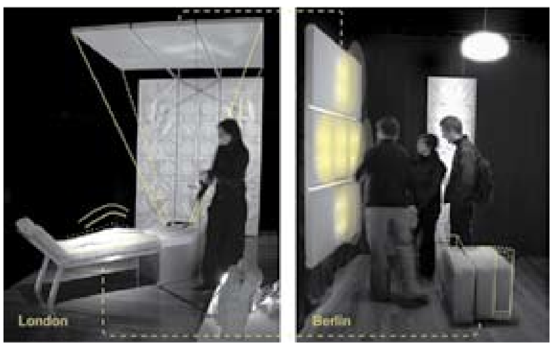
> Fig. **12**: Michael Fox, *Ex-com Couch, with Students at Cal Poly Pomona.*

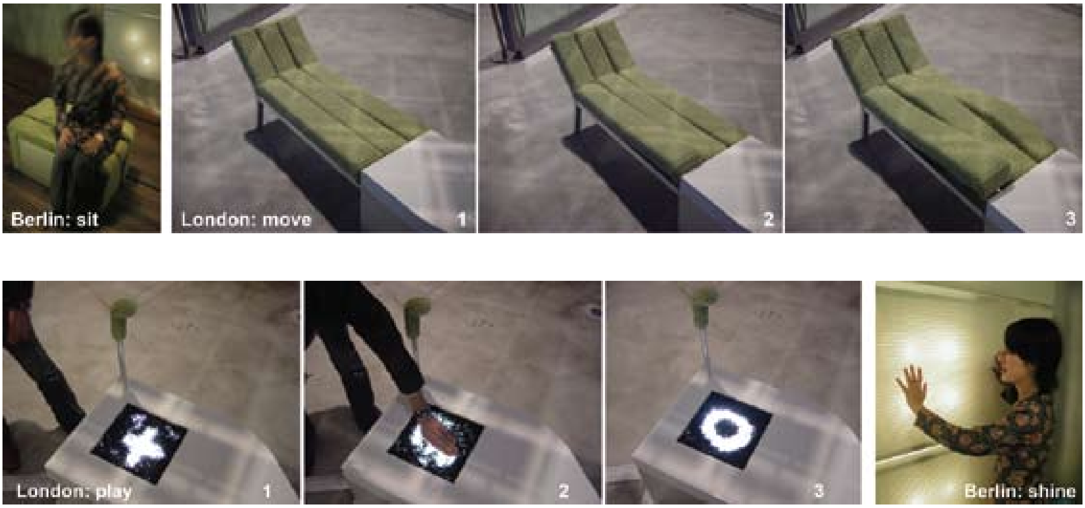


> Fig. **13**: Tobi Schneidler/Smart Studio, others: Adam Somlai-Fischer, Fredrik Petersson, Carole Collet (course director, Central Saint Martins Textile Futures), Loove Broms, Stefanie Schneidler, *RemoteHome.*





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SOCIOLOGICAL AND PSYCHOLOGICAL IMPLICATIONS

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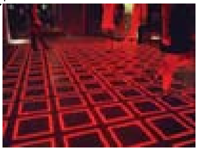
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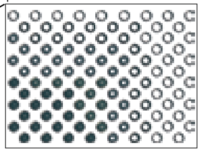
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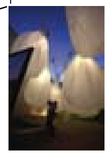
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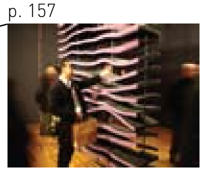
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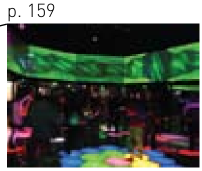
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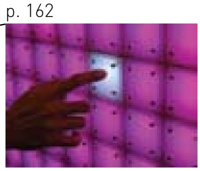
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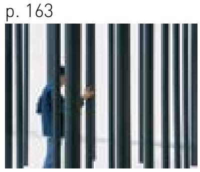
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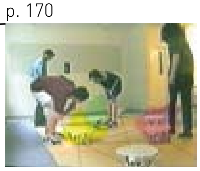
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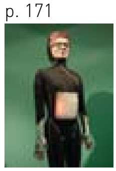
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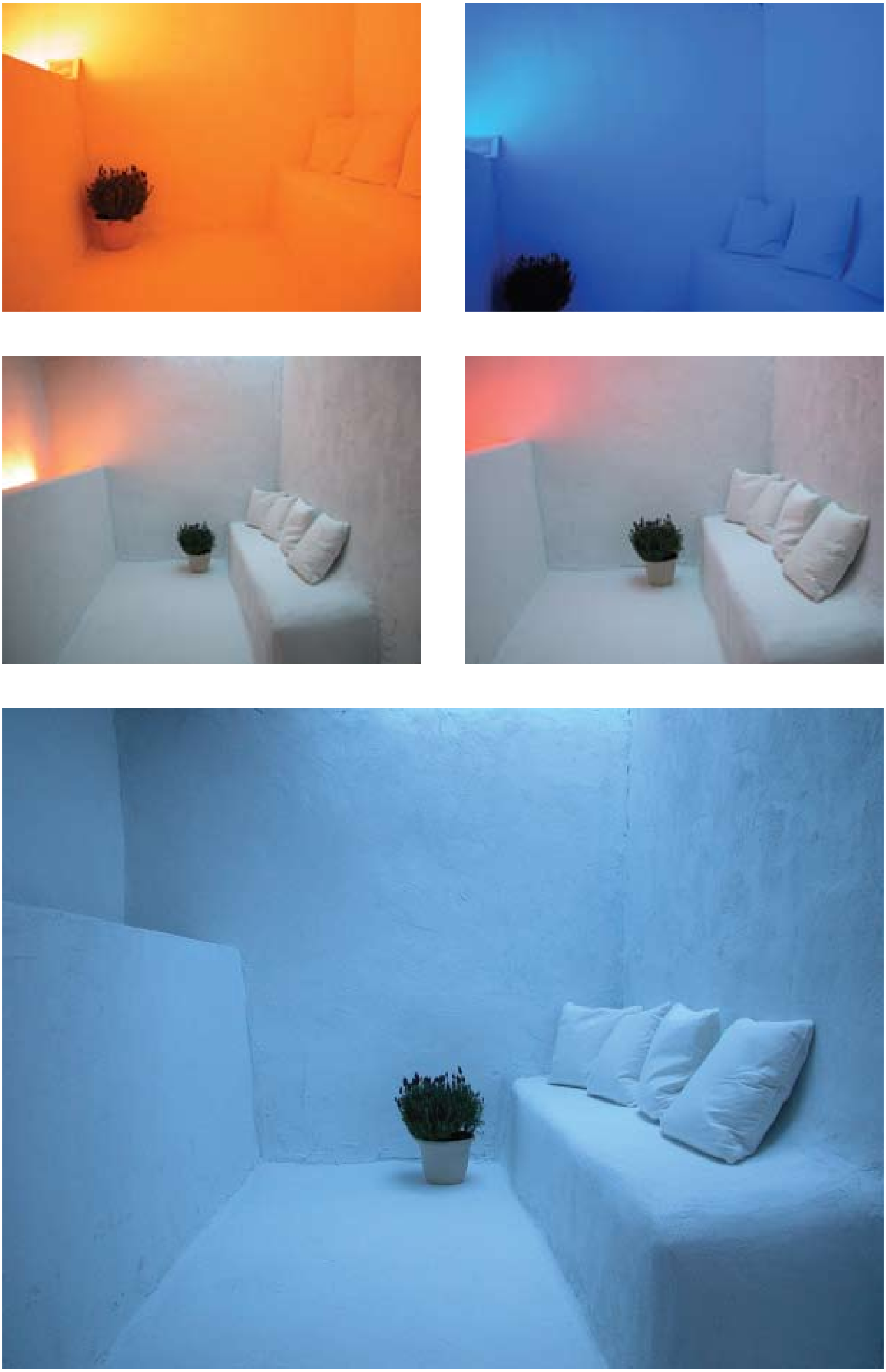
Architectural space can take advantage of an audience locally, regionally, and globally by reconceptualizing the role that the physical environment plays in shaping the viewer's experience.

Architectural space can take advantage of an audience locally, regionally, and globally by reconceptualizing the role that the physical environment plays in shaping the viewer's experience. Such an approach suggests that the physical environment can be interactively viewed both within the confines of the space and beyond its walls. New lifestyle trends present many architectural situations for unique and wholly unexplored applications that address today's dynamic, flexible, and constantly changing activities. An interactive architectural environment can not only facilitate lifestyles and behaviors, but also influence them. It is important to remember that our psychological and sociological interpretations of space are influenced by many factors beyond the spatial confines or interpreted definition of space and include lighting, acoustics, and smell. Many applications in interactive architecture are not limited to sensing and mechanical movement, and can embrace a wealth of new tectonic innovations that can facilitate interactions through flexible or foldable LCD screens, smart fabrics, thin-air projection technologies, and holographic projections. These innovations will all be integral to architectural programming in the future and will demand new ways of thinking about and designing the experience of space. While many of these technologies are not physical, they do play an important role in influencing the definition and use of space and the experience of space. In many instances, a building that adapts to our desires can shape our experience. By the very definition of dynamically responding to user desires, IA can create an enhanced spatial experience. As a building responds to our actions, we are confronted with a new level of awareness and choices. An environment can create a dialogue with inhabitants based on either satisfying an interpretation of goal states or creating a new emergent state (a number of simple entities forming more complex behaviors) based on ambiguous assumptions of desires. Key to such a dialogue, however, is that the user is engaged: asked, enticed, manipulated, directed, or coerced. To do this, the environment must operate on a simple, even intuitive, level of communication. > Fig. **14**

> Fig. **14**: Michael Fox, *i-Spa*, Interactive Design at Art Center College of Design: Ali Kaufman and Suzanne Hanson



Architects need to learn to explore, think about, and design for applications particularly suited to such new lifestyle trends, ranging from programmatic and site-context response to spatial dynamics.

Changing Lifestyle Patterns

A number of trends have signaled new insights into how consumer lifestyles may change in the future that are related to the dramatic increase of online shopping. There is an increasing computer literacy amongst the population due to the continuing rise in service industry employment. In addition, we must consider the previously mentioned changes in population numbers and continuing increases in single-person households. And lastly, trends in the workplace are indicating that some individuals at various levels in the workforce are choosing to work less and work at home in order to devote more time to personal and family interests. All of these factors reflect an enormous increase in both technologies in the home and flexibility in the workspace. Such changing patterns of human interaction with the built environment will also force architects to come up with new solutions. It is the constant back-and-forth relationship of interaction that ultimately will lead to enhanced experience, as users and their environments remain in a constantly evolving dialogue between activities and the quality of the experience of performing these activities. Architects need to learn to explore, think about, and design for applications particularly suited to such new lifestyle trends, ranging from programmatic and site-context response to spatial dynamics. There are a number of changes related to living trends that are expected to dramatically impact future patterns of energy consumption in both the home and the workspace. According to the U.S. census, one-third of all school-age children in the U.S. are, for some part of the week, latchkey kids; that is, they go home to an empty house or apartment. Children are encouraged to stay at home in rooms stocked with televisions, game consoles, and so on, and are given their own mobile phone in order for their whereabouts to be checked. All of these increase the consumption of energy in the home. Aside from the higher penetration of communications and entertainment technologies, there is a greater demand for heating and lighting in the home, and more preparation of food during the day. Homes, for instance, could be designed to efficiently handle the greater amounts of flexibility needed in terms of the number of people using them and the times that they are used.

New trends in office automation technology now allow many office workers to be telecommuters, in that their work can be performed remotely with a home PC and communication technologies. Telecommuting has given rise to a number of new behavioral, organizational, People who are cut off from the workplace environment need to discover new sources for achieving personal satisfaction. Such opportunities for **remote social interaction** are therefore not only necessary for pragmatic reasons but also serve an important humanistic role in our social fabric.

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and social issues. It is the substitution of communications capabilities for travel to a central work location. Remote work refers to work that is performed outside of the normal organizational confines of space and time. Important characteristics of jobs that can be performed at home include individual control over the habits, deliverables, concentration, and a relatively low need for communication. Individuals who work at home have been found to be both highly self-motivated and self-disciplined. There are a number of reasons for telecommuting, including economic advantages, family requirements or desires, a preference for fewer social contacts, or simply a preference for the space and location. In the past, people gave priority to the demands of the workplace over their personal, family, or community interests. Time spent at the workplace was not only a source of income, but was also a determinant of one's role in the community. The workplace provided self-esteem, value, achievement, and recognition. People who are cut off from the workplace environment need to discover new sources for achieving personal satisfaction and for making meaningful social contacts. Such opportunities for remote social interaction are therefore not only necessary for pragmatic reasons but also serve an important humanistic role in our social fabric.

While the architecture can adapt and learn from our actions and adjust itself accordingly, it also has the capacity to teach us how to live and how to work.

Human Behavior Awareness

We have already spoken of the potential for IA to shape people's experience, but we should also point out the potential for making those experiences explicit. The ability of an architectural environment to inform the users of their actions can have profound effects on their behaviors. While the architecture can adapt and learn from our actions and adjust itself accordingly, it also has the capacity to teach us how to live and how to work. Sustainable living, for example, is a term that can be used to define lifestyle behaviors related to efficient operation of a building. Many such behaviors that deal explicitly with efficient building operation, however, are not intuitive at all. Particular sustainable energy strategies such as cross ventilation (opening particular windows on opposite sides of a room to induce natural ventilation) and night flushing (introducing outside air during the coolest times of the night and early morning, prior to the next day's warm weather) can be effective only if done correctly and at the right time of day. Furthermore, these strategies may not necessarily be in line with the user needs for the space; there has to be both a learning component and a dialogue of compromise between the users and the interactive building. The feedback from a system can be extremely important in measuring the effectiveness of the system, as well as in teaching users how to successfully respond to it. Such a conversation between users and the systems can make counterintuitive and inefficient actions explicit, and perhaps change them, with regards to mediating environmental conditions. There are many rather obvious benefits: windows in the workplace improve job satisfaction, aesthetically pleasing stairwells increase their use, and good ventilation affects worker performance. We all know of the path across the lawn, forged by users walking where they wish and not using the path designed for them to get from point A to point B. With an interactive architectural environment, such behaviors can be adapted to and facilitated, or they could be denied and manipulated. > Fig. **15**

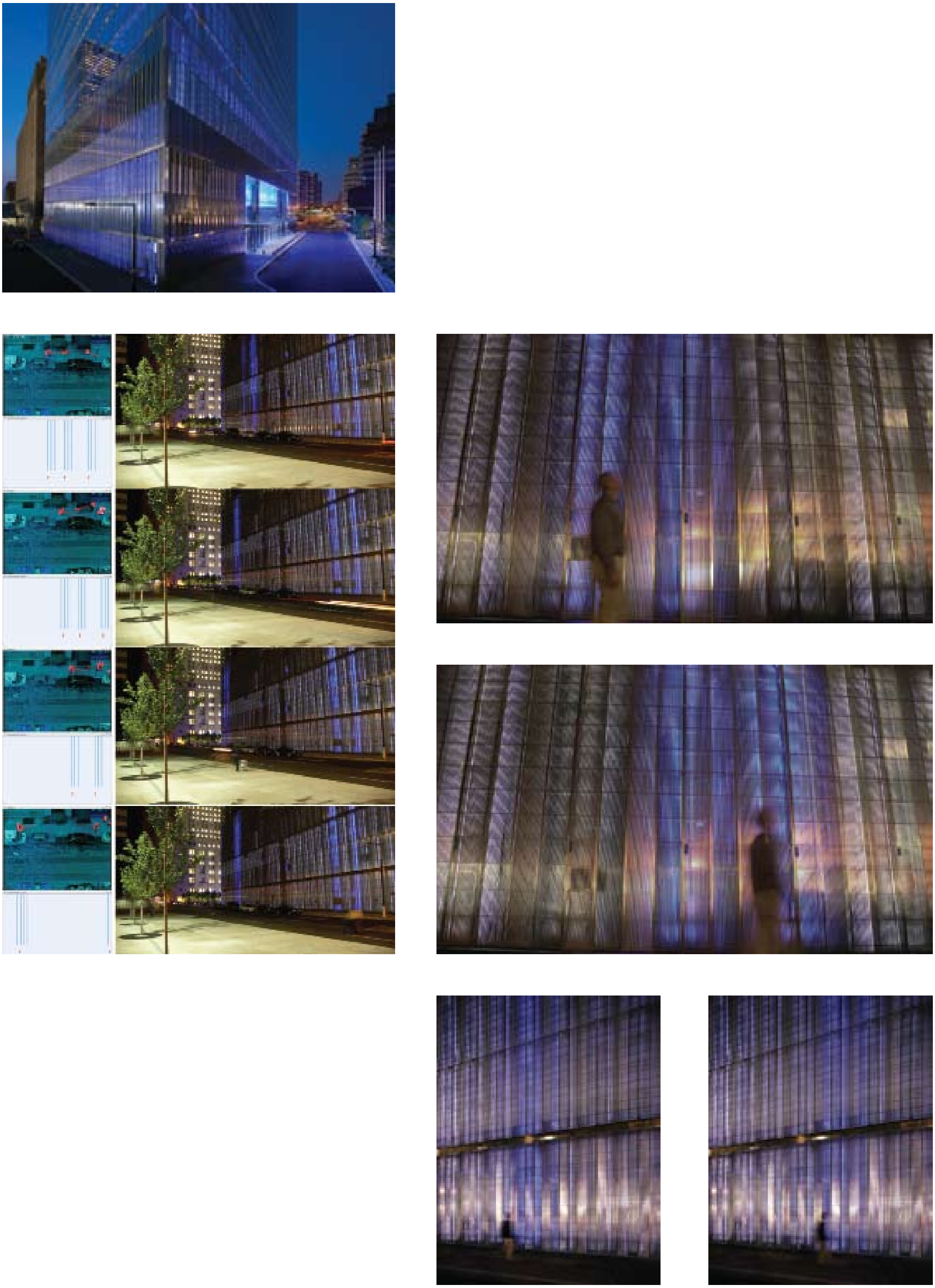
At this point, there are relatively few interactive systems that have been around long enough to be critically understood from a behavioral standpoint relative to intuition. To a certain extent, our behaviors are nothing but learned intuitions growing out of our experiences in the world. We learn early how to operate our buildings, opening doors, windows, and shades ourselves, but when the building responds to our actions, we are confronted with a new level of awareness and choices. As our buildings do more than respond and become

> Fig. **16**
> Fig. **17**
> Fig. **18**
> Fig. **19**

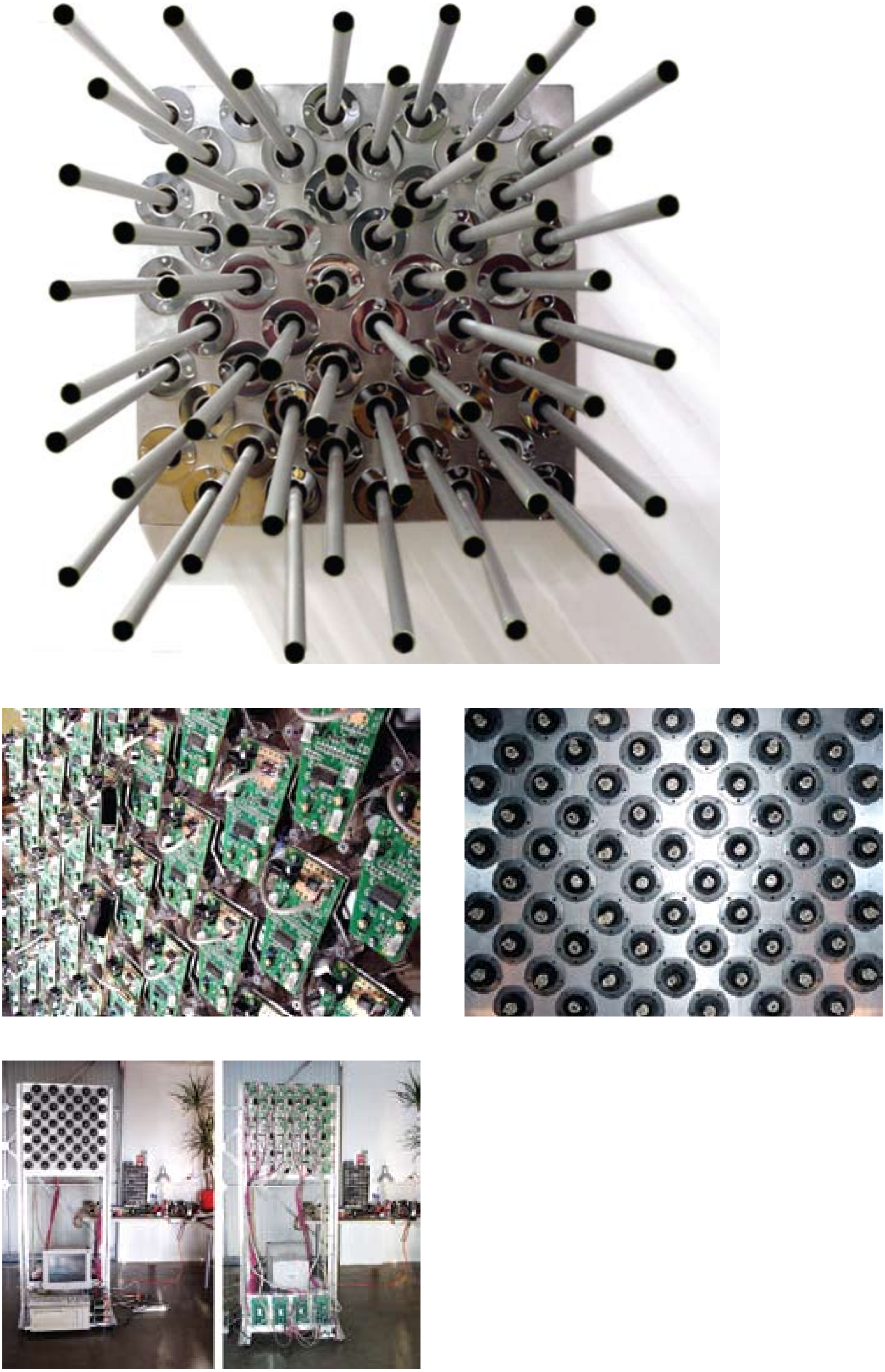
> Fig. **15**: Electroland LLC, Cameron McNall and Damon Seeley, *Enteractive*.

> Fig. 16 : Daan Roosegaarde, *4D-Pixel.*

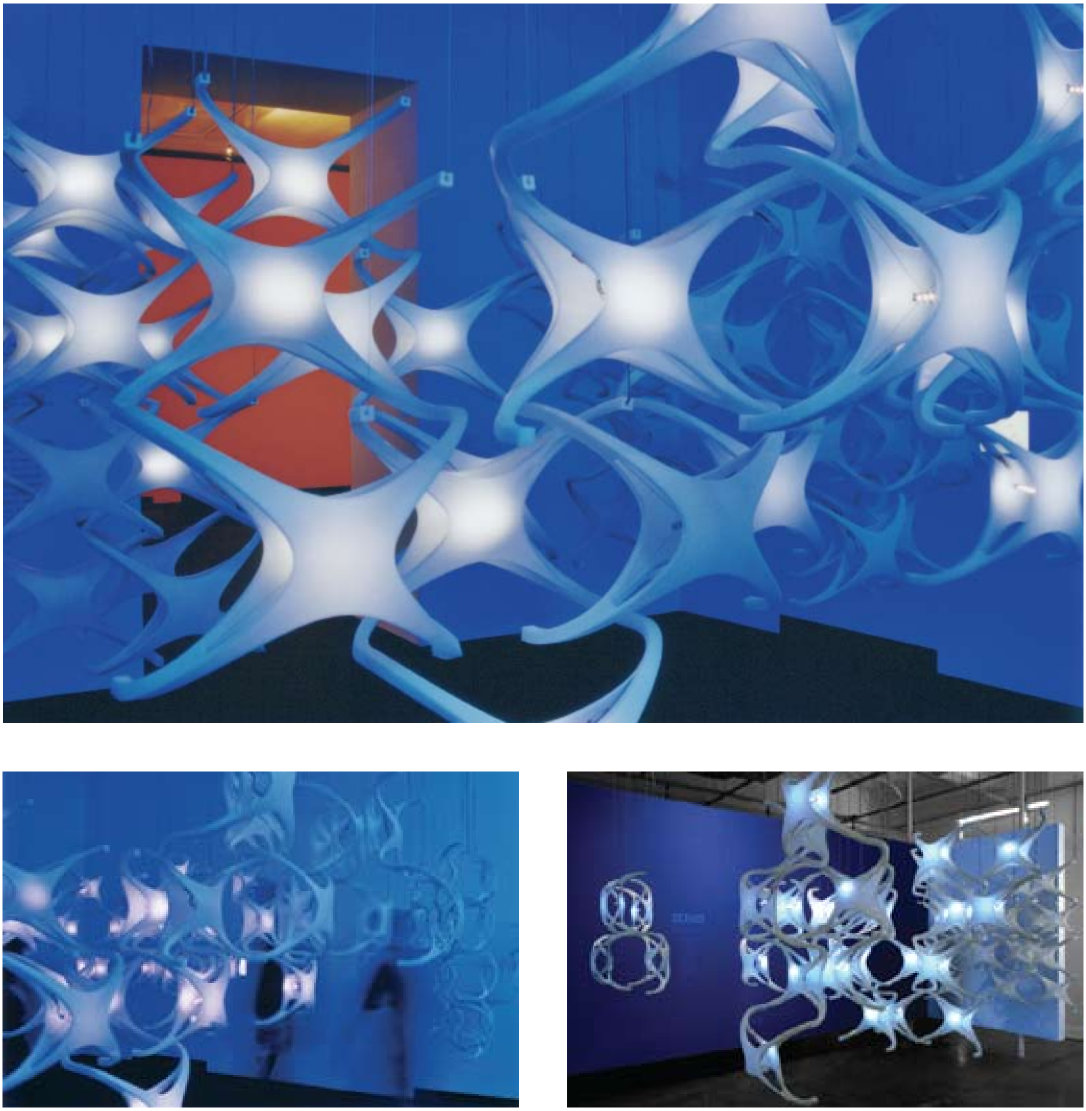
> Fig. **17**: James Carpenter Design Assoc., Kinecity, Marek Walczak, Skidmore, Owings & Merrill LLP, Cline Bettridge Bernstein Lighting Design, *7 World Trade Center: Podium Light Wall.*



> Fig. 18: Michael Fox, Axel Kilian, MIT Kinetic Design Group, *Interactive Facade.*



> Fig. **19**: Servo in collaboration with Smart Studio–Interactive Institute Stockholm, *Lattice Archipelogics.*



To a certain extent, our behaviors are nothing but learned intuitions growing out of our experiences in the world. We learn early how to operate our buildings, opening doors, windows, and shades ourselves, but when the building responds to our actions we are confronted with a new level of awareness and choices.

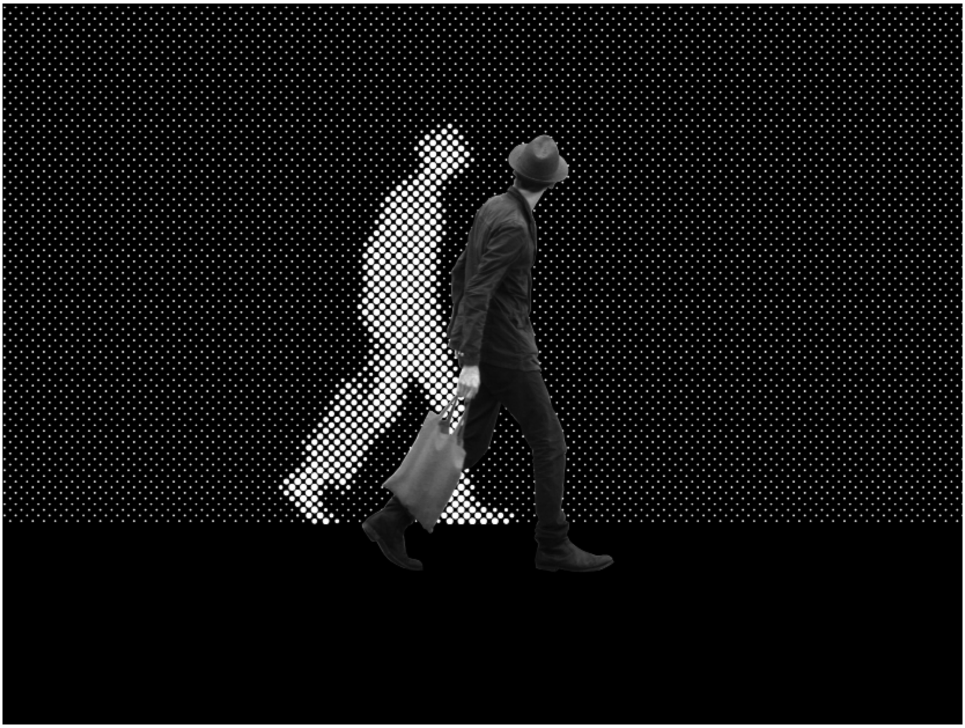
truly interactive in a sense of facilitating 'conversations,' we are in relatively unknown territory with respect to our behavioral awareness. Our buildings are furthermore not limited to one-on-one conversations, in that they can respond to, convey information about, and interact with groups of users. Such applications simultaneously convey a level of interaction between the individual and groups of individuals.

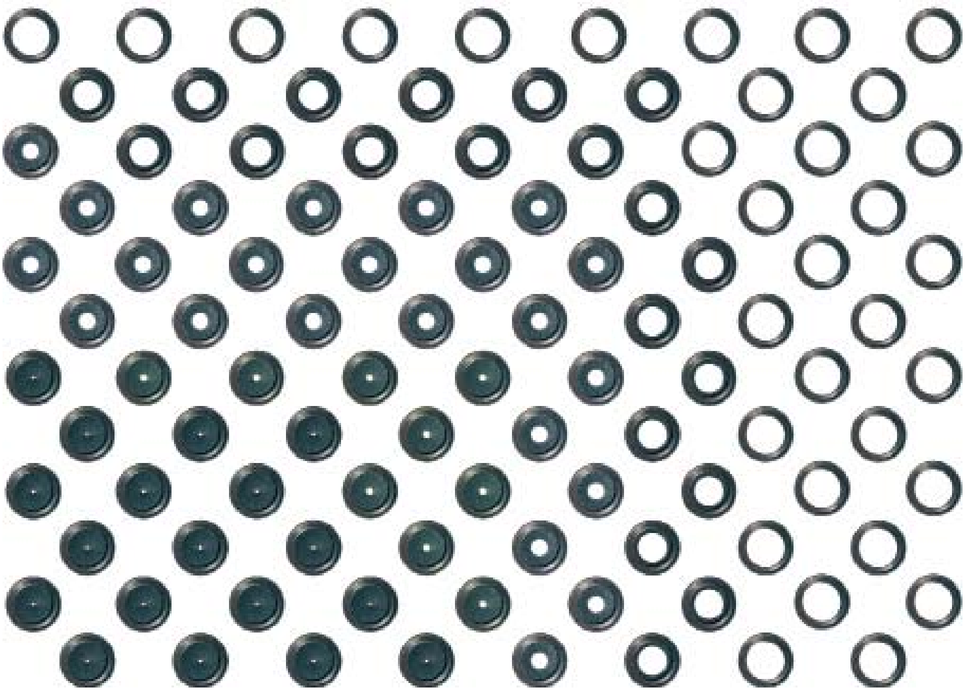
Architectural Awareness

The idea of making situational use explicit has been explored at an architectural scale in numerous recent artistic projects. Although these have mostly been limited to working with artificial lighting, the results are fascinating in their application, as they translate information about the architectural use to an abstract expression. Such projects simultaneously convey a level of interaction with the individual and groups of individuals. At the core of such projects dealing specifically with behaviors is the requirement to establish a dialogue with the users. Such a relationship requires an understanding of one's own actions and others' actions within the space, and awareness that there is some sort of dialogue with the environment itself. The environment, on the other hand, can be either an entity or a discrete organization of devices or systems, and the behavior can be a direct response or emergent. Users become participants either willingly or unwillingly, and their behaviors are translated not only to themselves and others within a particular space, but also to those on the outside looking in. > Fig. **20**

Most of the built projects exploring such issues of human behaviors to date have been > Fig. **21** artistic endeavors and have dealt with building skin and surface conditions rather than three- > Fig. **22** dimensional spatial conditions. It is important to recognize that the boundary conditions of building skin and surface should be considered differently. A building skin condition deals with both the inhabitants within the building and the external environmental conditions, be

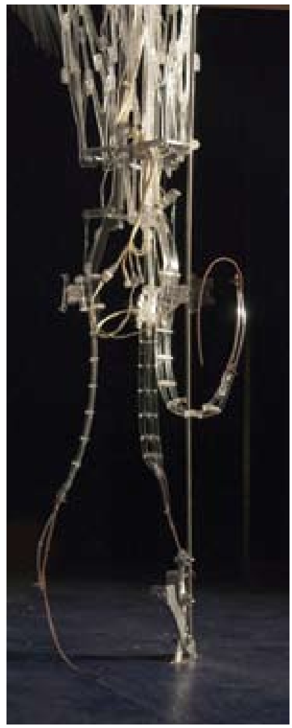
> Fig. **20**: Gunnar Green, Frédéric Eyl, *Aperture*.





> Fig. 21: Leo Fernekes & Joakim Hannerz, *Sensacell Inc.*

> Fig. **22**: Phillip Beesley, *Hylozoic Soil.*



At the core of such projects dealing specifically with behaviors is the requirement to establish a **dialogue with the users**. Such a relationship requires an understanding of one's own actions and others' actions within the space, and awareness that there is some sort of dialogue with the environment itself.

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they environmental factors or people on the other side of the skin. A surface condition, on the other hand, typically deals with the boundary between two interior spaces and the communication of the inhabitants as a mirror on one side of a wall or as a window between spaces. An interactive surface is a translator between conditions that can present specific information depending on proximity, height, weight, or any other number of criteria, and can just as easily censor what information is displayed. What is apparent is a translation and may or may not contain all of the information from the other side of the surface. Additionally, both interactive building skins and surfaces are not limited to a translation of what activities transpire on the other side, as the data input could be remote as well as local. A person in another room or another building altogether could be superimposed onto the skin either as a sole stimulant or on top of others directly sensed within the space. Such applications blur the boundaries of what a building skin or surface is and what it can do.

In simple terms, when communication is clear and the results are satisfactory, there can be a sense of accomplishment on the part of the user. Such interaction transcends traditional goals of operating a space to that of having a successful conversation with a space.

Sense of Place

An interactive architectural environment can also provide a unique sense of space heightened by the constantly changing information exchanges in small or large groups. Take, for example, two people in a large crowd trying to have a private conversation. The volume of the background noise probably would make the experience of the conversation difficult, as their conversation gets mixed up with other conversations. The overall state of the room is optimized for a large group but is not optimized to accommodate a private conversation. If architecture were able to adapt the shape of the space to accommodate a more private conversation between the two people, their experience would be enhanced. If they could understand that the environment had successfully understood their need and facilitated their desire, they would have a heightened sense of place. In simple terms, when communication is clear and the results are satisfactory, there can be a sense of accomplishment on the part of the user. Such interaction transcends traditional goals of operating a space to that of having a successful conversation with a space. > Fig. **23**

An interactive space can also work on many psychological levels, from being a soothing urban retreat from the stressful life of the city, to an exhilarating social environment for a person who is alone. An environment, for instance, that senses tension from your gait or tone of voice could adjust the space accordingly to promote relaxation and reflection through a calming environment of light and sound. When human-computer interaction becomes increasingly like human-human interaction, there is an increased willingness on the part of users to attempt communication. The goal of such interactive environments dealing with social conditions is to make them respond, interact, and adapt like human beings. A space also needs to communicate in a clear temporal manner that allows the users with whom it interacts to engage with it holistically; the users should be able to perceive a changing spatial environment as opposed to individual actions within the system. Such a method of interaction can encourage conversations that are social and not just individual. People have always been expected, more or less, to adapt to the spaces provided them. If a space could adapt to our desires, however, it would also shape our experiences, and if our experiences are shaped through interactive environments, we have a new design set to which we can respond.

> Fig. 23: Michael Fox and Juintow Lin, with NONdesigns and Brand Name Label, Exhibited at Materials & Applications Gallery, Silver Lake, California, *Bubbles*.

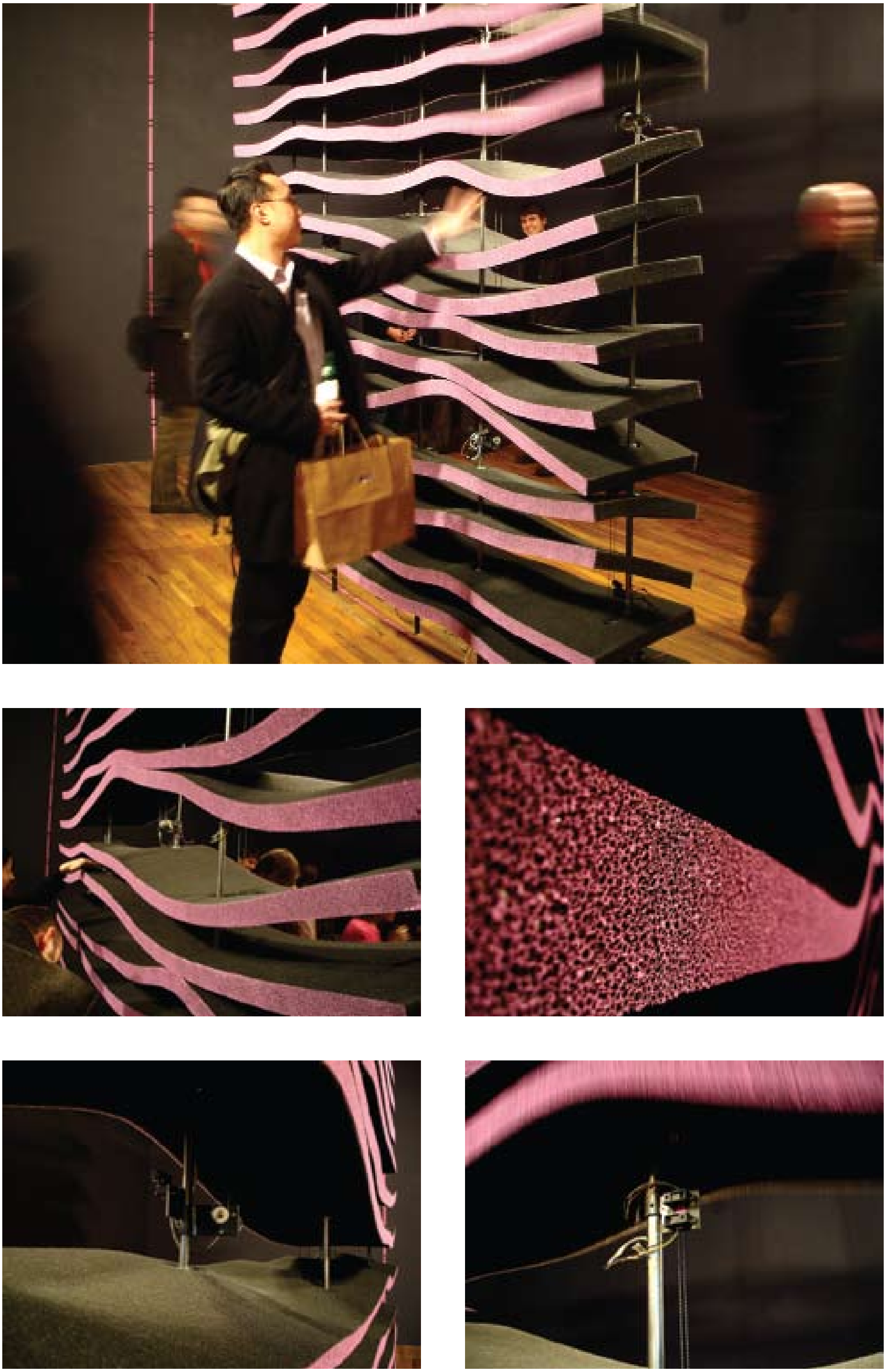
Architecture can play a more **active role** in suggesting new ways for its inhabitants to use environments based on real-time information exchanges. The experience can change depending on how a group of users interacts, whereby the rules are learned or the rules are completely dynamic and evolving.

Control of Space

The ability to control and adjust a space can be reciprocal. Clear communication between users and the environment fosters emotional attachment, which in turn enhances the spatial experience. As users have the ability to manipulate space, they also have the ability to create new types of connections with each other. If, for instance, a group of individuals was locked within a space and had to learn how to operate a door to exit the space, there would be numerous attempts to try different strategies to open the door. If those strategies that were successful were rewarded and clues were provided to the group in general by the system as to how close they were in providing the right means for opening the door, then there would be a collaborative effort in solving the problem and a communal sense of success when the door was finally opened. Doors as we know them have an intuitive sense of operation; there is a handle that latches and hinges that allow it to rotate along the z-axis and open up. If a person had never experienced such a contraption, the means of operation might not be so straightforward. The point is that, as interactive architectural applications with novel potential for change are developed, either the means of conveying potential, or the means of communication, must be extremely explicit for the system to succeed. > Fig. **24**

If a user can adjust the physical geometry, then whole new possibilities arise in how the environment can be used in real time. The experience lies in understanding the potential of space, or parts that comprise it, over a certain amount of time. Architecture can play a more active role in suggesting new ways for its inhabitants to use environments based on real-time information exchanges. The experience can change depending on how a group of users interacts, whereby the rules are learned or the rules are completely dynamic and evolving.

> Fig. **24**: nArchitects, *Party Wall.*



When architectural space has a true **communicative capability**, it can foster a heightened sense of attachment.

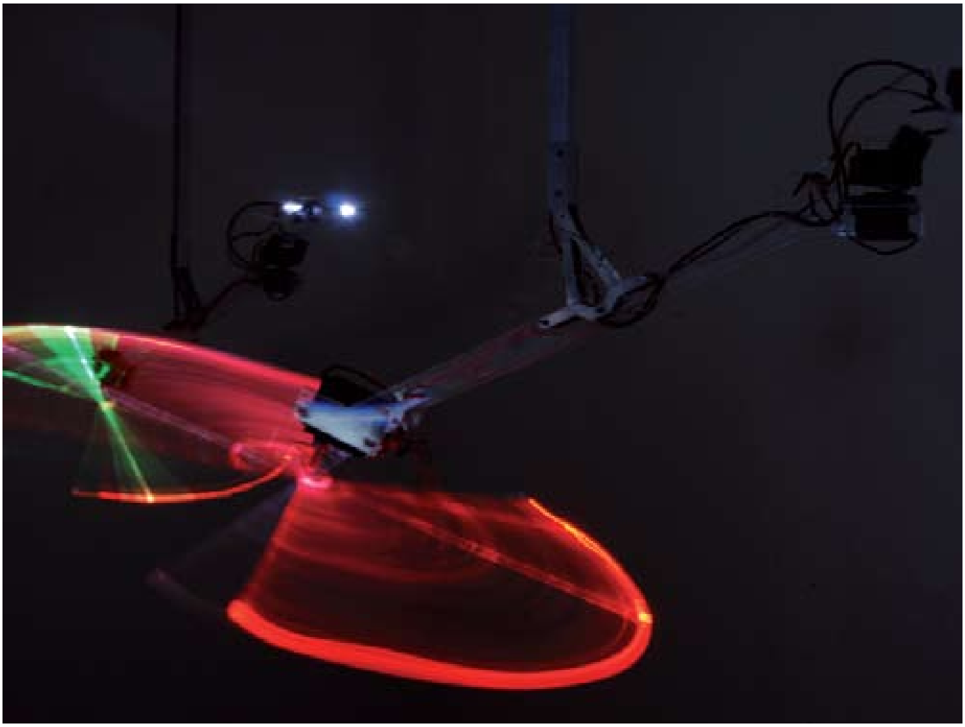
Attachment to Space

Interactive architecture, in particular that which built upon a sympathetic understanding of biological systems, may present a break from the ways in which we have constructed our built environment in the recent past. When architectural space has a true communicative capability, it can foster a heightened sense of attachment. As Salingaros points out: "Our society tries to understand its own structure, and builds its physical extensions on the earth's surface, guided by the blank slate hypothesis."[27] How the mind reacts to form and environment has led to many mistakes in the past, as Pinker points out: "City planners believed that people's taste for green space, for ornament, for people-watching, for cozy places for intimate social gatherings, were just social constructions. They were archaic historical artifacts that were getting in the way of the orderly design of cities, and should be ignored by planners designing optimal cities according to so-called scientific principles."[28] It is important to recognize that people truly desire space, not style, and to understand the role that interactive architectural applications can play in fulfilling such desires. "The overemphasis on design is a problem because it tries to capture visually, in one go, what is a changing set of experiences, by season, day of the week, time of day."[29] We do not inhabit architectural space simply for shelter; we do so because we need the experience of space. > Fig. **25**

> Fig. **26** As previously mentioned, there are many factors behind this need for spatial experience, ranging from the desire for solace or privacy, to invigoration or social interaction. Yet there is also a point where we gain a special attachment to space based on our experiences with that space. The reasons for how such attachments are established are ambiguous and varied, but they are definitely tied to an idiosyncratic experience of a particular space. Be it a park bench, a chair on a front porch, a living room couch, or a chair behind a desk, we all have a special space that has memories tied to experience. When the space becomes interactive, when it can understand what it is that we appreciate about it, and when that space can sustain, replicate, or even enhance the aspects that make it special on a personal level, then this process can provide a true attachment to space. For example, imagine a space where you work at a computer with a view of trees and the ocean beyond. Imagine that this space understands that you appreciate this view, but when the sun reaches a certain angle at a particular time of day, it is impossible for you to work at the computer. Imagine that the

> Fig. **25**: Paul F. M. J. Verschure, *Ada—Intelligent Room*.

> Fig. **26**: Ruairi Glynn, *Performative Ecologies.*



The sense of **sound** is much **underrepresented** in discussions of architectural experience and is very often only dealt with from a design standpoint, relative to the negative aspects.

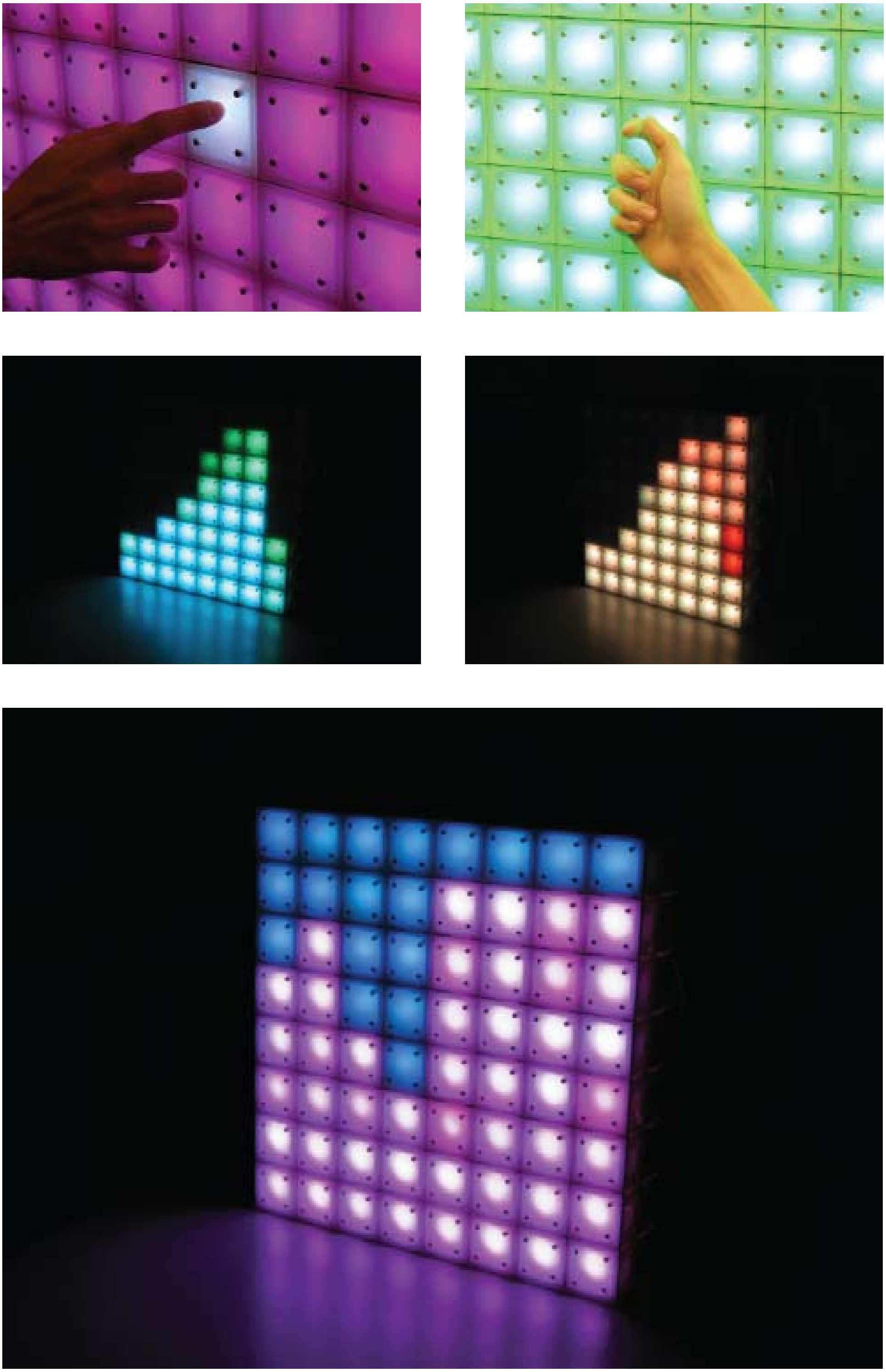
space understands that you enjoy listening to the sounds from the ocean except when you are on the phone. When the space understands and mediates the multitude of your desires and—often conflicting—needs, then you begin to understand a space by means of anthropomorphic metaphors such as supporting and understanding. You have an enhanced attachment to such a space.

Sense of Sound

While most of the applications up to this point have dealt with the spatial aspects of environments, particularly with respect to visual cognition, there are other potentially profound experiences that are defined by other senses. The sense of sound is much underrepresented in discussions of architectural experience and is very often only dealt with from a design standpoint, relative to the negative aspects. If a west-facing deck has a dramatic view that deserves prioritized orientation but also has noise from a freeway, noise becomes a design issue. In the past, such issues of noise pollution have been dealt with through an approach of isolation, by blocking the negative acoustics in the same manner one might block unwanted direct sunlight. Whereby the negative aspects of acoustics tend to rely on empirical lab measurements and acceptable thresholds, research in noise pollution is increasingly approaching such problems holistically by looking at people's attitudes to entire landscapes of noise rather than individual aspects, and how such sounds can be manipulated to be more acceptable. The term *soundscape*, coined by the composer R. Murray Schafer, can be defined here as sound(s) that either forms or arises from an immersive environment; such sounds can be either natural or artificial. Soundscapes are often generally defined as "place-inspired" sounds. Sound is both an individual and a connective sense, which is emotional and direct in ways that sight alone can never quite be.

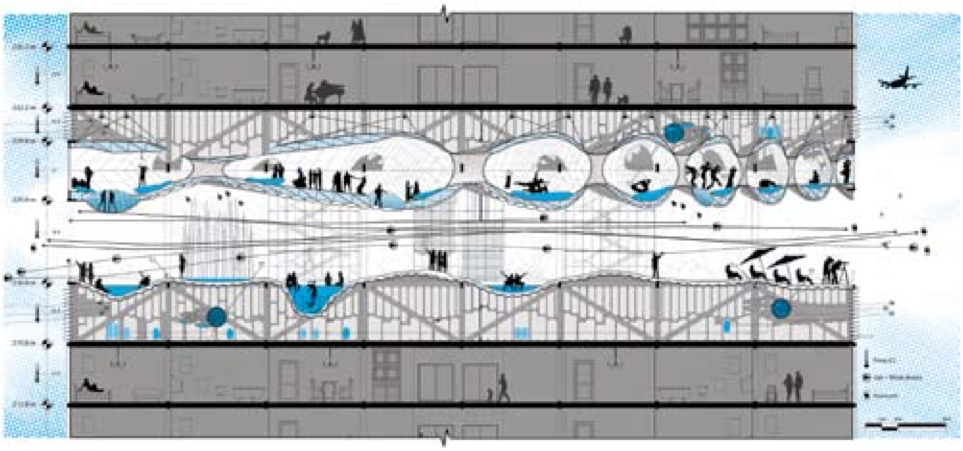
> Fig. **27**
> Fig. **28**
> Fig. **29**

> Fig. **27**: Catherine Hu, *Music Wall.*



> Fig. **28**: Christian Moeller, *Audio Grove*.

> Fig. **29**: Jason K. Johnson + Nataly Gattegno (Future Cities Lab) with sound artist Troy Rogers and assistants Carrie Norman, Thomas Kelley, Beth Haber, Karey Helms, and members of the Robotic Ecologies Lab. CNC Fabrication collaborators: Tektonics Design Group in Richmond, Virginia. Installation commissioned by the Extension Gallery for Architecture in Chicago, Illinois, *Vivisys Prototype* (a module of the *Super-Galaxy* project).



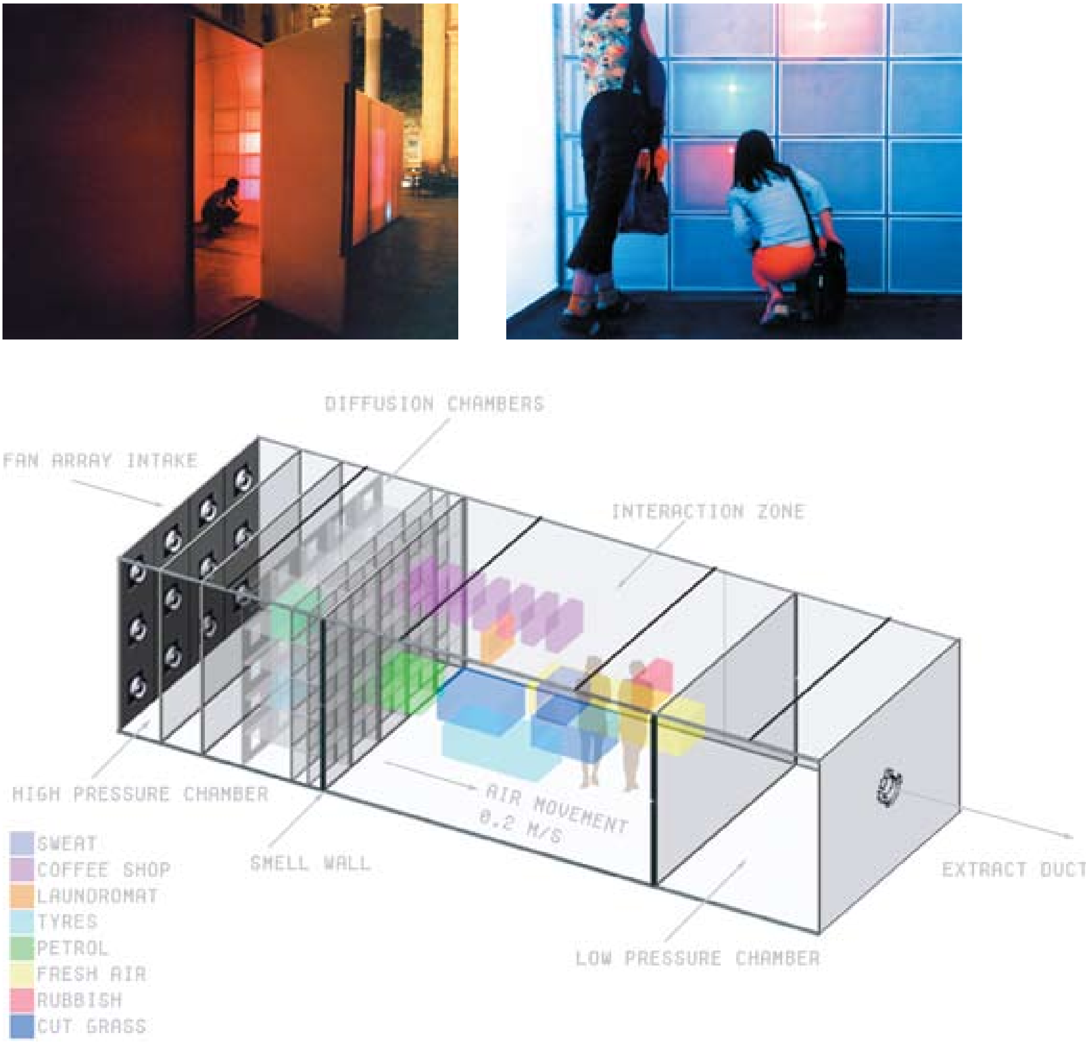
Through interactive architectural applications, sound could be understood and manipulated from a positive, rather than negative, standpoint. Instead of sound management taking on the form of acoustic baffling, specific positive attributes could be amplified while negative aspects could be suppressed. Acoustic translation could potentially turn negatively associated sounds into positively associated sounds while allowing for a connected sense of the space itself. Imagine such a system in an office environment that translated typical office chatter and white noise directly to the sounds of birds or ocean waves; this could allow an individual to remain cognizant of the activity within the space through positive rather than negative connotations.

Sense of Smell

In the past, such issues of smell in architecture have been dealt with very similarly to those of sound: through an approach of isolation. Typically the management of smells has been focused on negative rather than positive associations. Odor, a term which refers to unpleasant smells, is considered an important environmental pollution issue for the simple reason that it is often an indicator of poor air quality. Order dispersion (molecules being distributed from the odor sources into the environment) is also extremely important in this discussion, for without any dispersion process, odor production will not result in complaints by the people in the surrounding area. Often this can be a problem, as a lack of human complaints will not result in any investigation or rectification of poor air quality. Scientifically speaking, "Humans perceive odors by chemical stimulation of the chemoreceptors in the olfactory epithelium located in the nose. Odorants are the chemicals that stimulate the olfactory sense."[30] It is easy to imagine that if air movement can be facilitated by an interactive architectural system, odor management can be controlled as well. > Fig. **30**

Smells can have extremely positive associations, too. Smells can evoke strong emotional reactions, as many of our olfactory likes and dislikes are based on emotional associations. Our olfactory receptors are directly connected to the limbic system, which is the part of the brain commonly associated with emotions. A number of projects are beginning to investigate applications that take advantage of this emotional aspect of smells. The

> Fig. **30**: Usman Haque and Josephine Pletts (with Dr. Luca Turin), *Scents of Space.*



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Scentsory concept phone by Nokia can detect, transmit, and emit smells from the caller's environment via sensors that translate odors into information. This process also works in reverse, as you send the info to another Scentsory device and it turns data into odor. The nose of the phone would sample the odor of the caller's environment and transmit this to the recipient electronically.[31] While this is an unrealized concept phone, it does offer fascinating potential for the control and redistribution of olfactory sensations. The detection and re-creation of smells is still very hard to achieve technically, and yet the potential for explorations in architecture is profound considering the aspects of emotional association. The difficulties lie in both the control (localization) and re-creation of smells. Aside from the obvious emotional aspects of personal associations, environments augmented with olfactory enhancement could be very beneficial for those suffering memory loss illnesses.

Installations and other artistic endeavors also free the designer from many of the constraints associated with constructing architecture, such as building codes or life safety considerations.

Artistic Initiatives

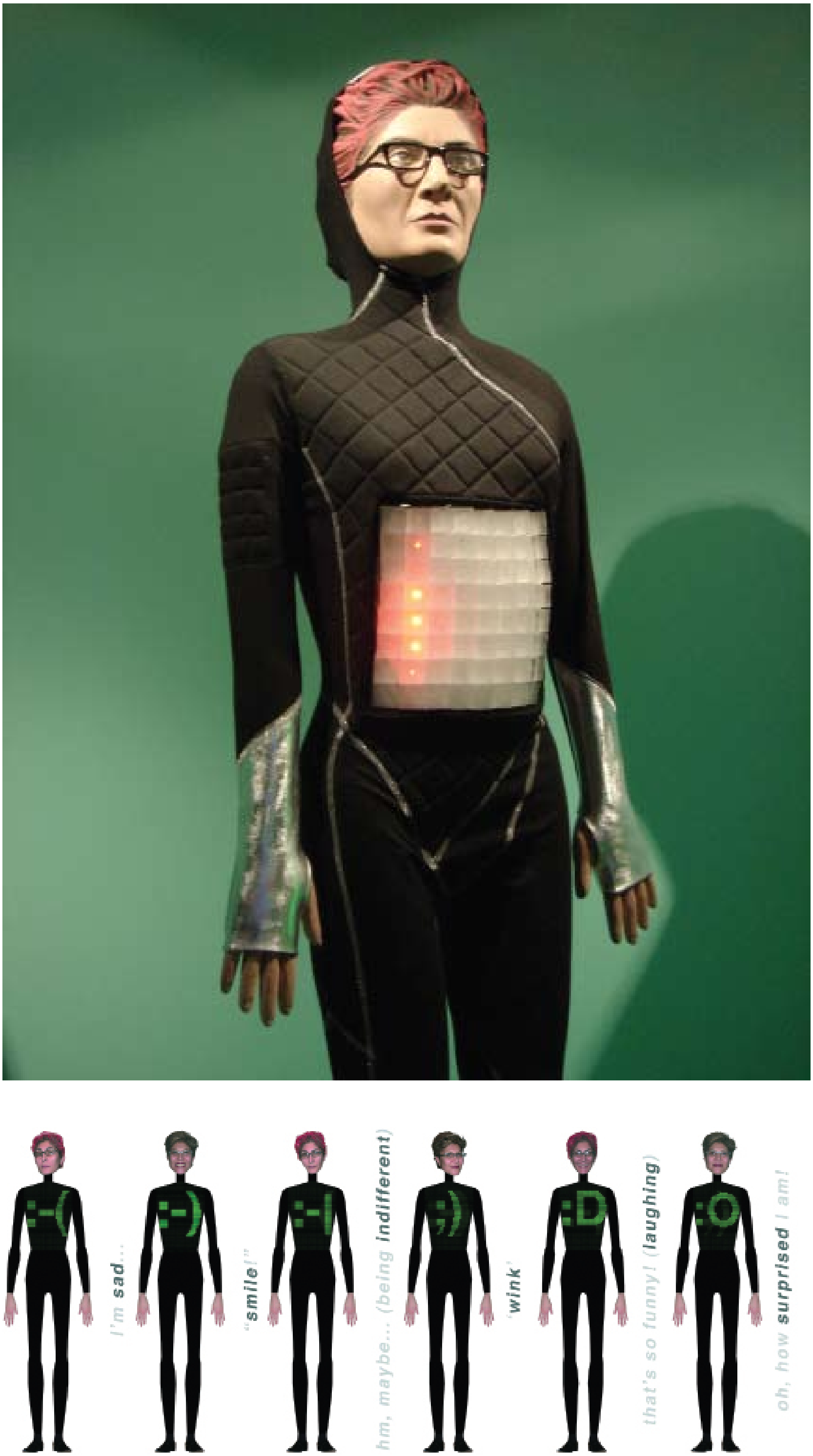
There are a number of differences between designing interactive architecture and interactive artistic explorations. Artistic explorations in interactivity have more of a possibility for inclusive public use and exposure. Installations and other artistic endeavors also free the designer from many of the constraints associated with constructing architecture, such as building codes or life safety considerations. Artistic explorations can be constructed for less money than architecture, allowing a broader group the ability to experiment, and have considerable less liability, which allows for the possibility of more playfulness from an application standpoint. Interactive spaces can also be designed in a way that allows them to easily travel, which in turn allows a much larger audience to be exposed to the experience. Lastly, artistic explorations are not constrained to permanency. This lack of permanence not only allows for interactive systems to exist in nonstandard locations, but it also allows for looseness in user experience, whereby users may be involved who would not ordinarily participate in an architectural setting. There are a number of significant annual conferences and exhibitions on interactive art that foster the latest explorations and innovations. Artistic endeavors in interaction design are also inherently interdisciplinary. Means of obtaining input, articulating output, manufacturing and fabrication, and social, psychological, cultural, and even political issues are all areas that interactive artists must engage.

> Fig. **31**
> Fig. **32**
> Fig. **33**

Developing interaction design on the fringes of the context of architecture also provides designers a platform with which to focus on specifics, and thoroughly isolate and test ideas. Artistic explorations open up the door to take a look at human emotion and human impulse. Imagine how different cultures would react to different gestural interactivity or operational procedures. Creative inquiry allows for an opportunity to reexamine ourselves and what space means to us. Imaginative explorations allow interactivity to become experiential, as people have the ability to interact with the installation or just watch others. It allows for continuous testing and changing of the perimeters in the system. It can promote unexpected behavior on both the side of the participant and the system. It can be more improvisational as well. All of these things further the entire state of interactive architecture as a whole. In general, dissemination of ideas in interaction design helps to progress the field of interactive architecture through making possibilities known.

> Fig. **31**: Usman Haque, *Moody Mushroom Floor.*

> Fig. **32**: Hariri + Hariri and James Clar, *Digital Dress/Flexigrid.*



> Fig. **33**: Daan Roosegaarde, *Dune 4.0.*

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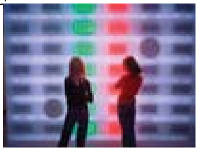

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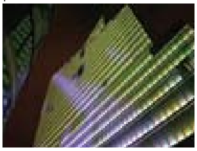

Designing Interactive Systems

As previously stated throughout this book, interactive architecture is about creating new types of interactive relationships between people and the built environment. Interactive architecture is different from many other types of interactive design, such as art, digital media, and sculpture, because it emphasizes interactivity in the context of space. As technologies and fabrication techniques develop, it is increasingly apparent that IA systems can greatly benefit from insights gained from disciplines outside of the field of architecture. A concerted effort is needed on the part of the architectural community, to step back and examine the overall landscape and future trends. This book provides a context for this emerging area of design by which to situate future projects inside—or, better yet, on the edge of—the current IA "landscape." In this chapter, we discuss some of the new design tools necessitated by IA and the associative design heuristics. A general pedagogical approach is also put forth as a strategy for making the design of IA accessible for architects, and we examine the fertile ground of academic initiatives in this area. Lastly, we examine the roles of the users, clients, and corporations in fostering built work in IA and the economic feasibility of such endeavors.

Architects are well equipped when conceptualizing applications in IA, because their background is in visualizing space and understanding both user and environmental demands. For architects to take an active role in the development of IA, there is also great benefit in having a contextual understanding of the history and driving forces in IA that for the most part reside outside the discipline of architecture. Another advantage is the fact that architects have experience with using building materials in structural ways at the scale of a building and therefore understand how these new types of interactive systems could be applied

Only when designers confront interaction scenarios at an architectural scale and the consequent issues of privacy, ethics, convenience and apprehension will they truly take an active role in the larger dialogue of how the associative technologies will develop.

to mechanical systems, structural systems, and general building code issues from a standpoint of adaptable optimization. Finally, architects also have a fundamental understanding of how important the relationship between desired activity and the built environment is, and are practiced at predicting how such relationships can be facilitated.

Adam Greenfield coined the term *everyware* to describe information processing that has been removed from the context of the personal computer and distributed everywhere in the built environment.[1] The sensing, processing, and output have been taken out of the computer and are now instead embedded in the objects and forms of everyday life. How such systems in our everyday buildings affect our behavior are the issues that architects will be forced to confront in the near future. Only when designers confront interaction scenarios at an architectural scale and the consequent issues of privacy, ethics, convenience, and apprehension will they truly take an active role in the larger dialogue of how the associative technologies will develop. Aside from such issues related to human behaviors, the issue of sustainability is paramount to any discussion of architectural design; the potentially profound implications of interactive design related to this area have barely begun to be explored. The applications that can be developed through combining interactive design and energy-efficient design are those that architects are beginning to see as an ethical mandate.

Overall, the design of interactive systems needs to start with rethinking our approach to designing architecture by including interactive capabilities at the onset. The role of the architect, or more importantly the need to have architects, does not diminish when thinking about creating interactive environments; instead, it becomes increasingly important to have such individuals with an understanding of the human issues that drive the creation of space. Architects need not become specialists in this area but should clearly understand the potentials of how this new area of design could impact and/or enhance the projects they are designing. As these new systems are designed, it is important also to consider the capability of such systems to yield real-world benefits. Actual construction and operation will allow architects to develop a realistic consideration of human and environmental conditions, and to overcome simplified assumptions about the costs of manufacturing and operations. Architects thus must be equally involved with both the pragmatic and the humanistic considerations when engaging in IA design considerations.

It is important that new concepts and ideas are tested in a physical tangible form and at a real-world, human scale, as it is these built experiments that will give us the most insight

Architects need not become specialists in this area but should clearly understand the potentials of how this new area of design could **impact and/or enhance the projects** they are designing.

into the capabilities and deficiencies. Much of the built precedent has already proven to yield valuable future possibilities. The projects that seem to yield the most benefit to the profession are those that actually experimented with fabricating tangible objects and spaces at full-scale and within the public domain. It is also extremely important that architects and designers, while understanding and designing these new interactive systems, also continue to remain alert to the new tools, fabrication methods, materials, and peripheral technologies that are being developed in tandem with architecture.

Novel Tools and Heuristics

A number of new types of tools and methods for experimentation are greatly affecting the ways that we build and test prototypes in this field. Manufacturing tools, such as computer numerical control (CNC), laser cutting, vacuum forming, and three-dimensional printing, are also contributing to accelerating the prototyping process by making it possible to fabricate parts more cheaply, precisely, and quickly. These tools are becoming increasingly commonplace and rapidly more sophisticated. Such tools have an advantage over previous manual manufacturing technologies, as they allow designers the ability to build three-dimensional models in software in "real size," and to fabricate parts directly from these models. This methodology blurs the lines between creating digital simulation experiments and creating real objects from simulation data. New types of testing methods are also aiding builders in providing real-time

The use of **tools with real-time feedback** for prototyping behaviors can greatly influence the overall process of design and can have a profound effect upon the final end product.

feedback while performing experiments on prototypes. The use of tools with real-time feedback for prototyping behaviors can greatly influence the overall process of design and can have a profound effect upon the final end product. The design process is also greatly affected by new computational tools in terms of both simulation and generative design. All of these technologies and methodologies also affect how we construct, test, and learn.

In the past fifteen years, a number of digital manufacturing tools used in the airline, automotive, jewelry, mechanical, and various other types of industries have begun to be used by architects and designers to produce and rapidly prototype parts. A number of architecture and design schools have recently adopted tools for digital fabrication and developed curricula around them as a means of discovering their potential in the field of architecture. Computer numerical controlled machines, for instance, have radically transformed the manufacturing industry in recent years. CNC refers to a computer controller that drives a machine tool. Its importance relative to interactive system design, however, lies more in the design process than in the fabrication process. Rapid prototyping and the ability to re-create items with extreme precision enables CNC manufacturing to have a profound influence on the design of complex three-dimensional parts and parts that will be set in motion. Rapid prototyping is also showing great promise as a different type of automated fabrication that works by the principle of addition rather than subtraction. The technology transfer of many such tools to architecture is discussed further in "New Horizons." Such manufacturing tools and processes offer a number of great benefits for rapidly creating inexpensive prototypes, but in testing such IA prototypes, it becomes increasingly important to determine the goal of the tests before using specific technology to manufacture parts. For example, when understanding how gestures can be sensed and how it potentially could relate to adaptive furniture in architecture, it is important to consider an overall range of tests rather than a specific test. When testing prototypes that relate to dynamic environments, it is important to perform multiple tests that look at an array of activities or input sets rather than specific moments or tests. The results of a specific test often can be misleading without the context of other tests that validate or support these results in a collective whole. It is important to point out that such tools require well-trained, specialized personnel to operate them. Bryan Lawson points out that "the experience and skills required of a designer to work with such tools may well be quite different to those needed for a traditional design process."[2] Already we see an area of specialty developing in the

The **integration of computational tools**, such a 3D modeling software for real-time simulation and actual physical testing into the process of designing also allows designers to confront and anticipate many of the issues that occur when building at full scale.

architectural profession related to CNC machinery in academia and by manufacturers who have forged relationships with architects to create very specific parts.

The integration of computational tools, such as 3-D modeling software for real-time simulation, and actual physical testing into the process of designing also allows designers to confront and anticipate many of the issues that occur when building at full-scale. For example, building a simple, programmable kinetic prototype to test an idea about how a structure could move to accommodate a specific scenario can be invaluable in gaining an understanding of specific mechanical problems. Such real-time tests give designers the most insight, as they allow real-world factors to be applied to ideas previously developed in computer models. We are discovering many other ways that computation can be useful in the design process. Generative design looks at the means by which computation can be used to generate design, of which genetic algorithms are the most frequently used within the context of architecture. *Shape grammars* are a specific class of computational production systems that generate geometric shapes. They are fascinating in that they present a basis for visual computation for design through shapes. They were one of the earliest algorithmic systems for creating and understanding designs directly through computations with shapes, rather than indirectly through computations with text or symbols.

This brings up an important point, in that the use of such new tools in the profession actually repositions the role of the designer. Pask states that "the role of the architect here, I think, is not so much to design a building or city as to catalyze them: to act that they may evolve."[3] In a sense, generative simulations replace design, since designers can use this software to breed new forms rather than specifically design them. Interestingly, in the same manner that traditional design skills did not translate well to a CAD environment, the skill set of an experienced designer today will have to transition to evolutionary design methodologies. At a certain point, the designer must play a role in making design decisions. Claude Lévi-Strauss points out, a bit more abstractly, that we work inventively with what is already available in our minds in order to solve problems. The point here is that we devise concepts and make comparisons because they satisfy cognitive constraints. Furthermore, Lévi-Strauss claims, human beings never create absolutely; "the best we can do is choose certain combinations from a repertoire of ideas which we then reconstitute."[4] Such a statement clearly will be challenged by defenders of creative thought. Although there may be a limited number of cognitive symbols, the amount of invention and creation that can be

When the tools evolve with the design, the heuristics are facilitated by the tools, and not necessarily limited by their parameters. The design processes associated with interactive systems design are constantly evolving and are fostered by the consequent development of new tools.

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generated from them is, as a practical matter, unlimited. Furthermore, structure is not necessarily static by definition. Such argumentation follows that our reality is created by these symbolic forms; that such systems constitute, rather than reflect, reality. Structure can be syntactically specific to realms of the arts in a constructive manner, yet retain idiosyncrasies through semantic interpretation. The great utility of understanding such symbolic cognitive structure is that it can help to answer some of the toughest questions within the design process, specifically, the ways in which we judge right from wrong, or determine that which is most right. Judgments that are right are those that seem to capture significant aspects of our own experiences, perceptions, attitudes, and intuitions. Einstein once claimed that there is no logical path (to arriving at universal laws), only intuition, resting on a sympathetic understanding of experience. The representational process, which allows designers to make critical decisions in the world of evolutionary design, is predicated upon the existence of an idiosyncratically designed internal library of diagram-like representations, structured in the ways in which we perceive and store information from the experienced natural world around us. If architects are to play a role in directing the development of the technology that affects interactive architecture, then they ought to ask what is architectural about computation, not the inverse.

The importance here is in architects understanding the roles of idiosyncratic decision making and tool making within the process: of tools evolving with the design. When designing with a tool or many tools, the heuristics of the process are directed through the affordances and limitations of the tools. When the tools evolve with the design, the heuristics are facilitated by the tools and not necessarily limited by their parameters. The design processes associated with interactive systems design are constantly evolving and are fostered by the consequent development of new tools. When design tools are understood and used as flexible entities (so that when a problem occurs or a mental limitation is encountered, a new tool is developed to transcend that limitation or solve the problem), the construction and application of the new tools then become substantial and undeniable heuristics.

The challenge in developing IA lies in the highly technology-intensive nature of the subject matter, involving knowledge and skills that cross boundaries into engineering, computer, and behavioral sciences. There are a number of difficulties designers might experience.

A Pedagogical Approach

It is important to continue developing new courses, events, and materials on this topic for both practitioners and students. In addition to taking classes on simple mechanics and computation, students should be able to choose courses related to interaction design that will help them develop the skills necessary to explore, think about, and design interactive architecture. Since the primary focus of these classes should be on how interactivity can benefit the relationship between user activity and space, these courses should be available to a wide audience. The beneficial effects from such courses could extend far beyond the walls of academic architecture and could also easily be applied to many different disciplines, including digital media, art, engineering, psychology, and interface design.

The emerging field of IA has gained prominence in recent years. The increasing presence of interactivity in our built environment calls for architects and designers to integrate interactive and adaptive systems into architecture. The majority of architecture and environmental design students, however, have not been exposed to this field. The challenge in developing IA lies in the highly technology-intensive nature of the subject matter, involving knowledge and skills that cross boundaries into engineering, computer, and behavioral sciences. There are a number of difficulties designers might experience. These problems are best tackled by removing the psychological barrier designers tend to have against computing and engineering.

As a pedagogical approach, this can be achieved by having designers work on a series of small, explorative, hands-on model-making exercises that are incremental in nature, and gradually incorporate engineering and computing components. One such approach based

While gaining (elementary) competence using an interdisciplinary approach, the ultimate goal is for students to overcome psychological barriers and have the confidence to communicate with engineers and programmers about their design intentions in an effective manner.

on discrete interdisciplinary learning is described below. Initially, kinetic function can be presented as a technological design strategy for building types and objects that are both efficient in form and inherently flexible with respect to various contexts and a diversity of purposes. The point is to initially understand ways to create spaces and objects that can physically reconfigure themselves to meet changing needs. Basic engineering concepts for mechanical structures can then also be introduced. Simultaneously, students can explore various mechanical motions and joints from found objects and structures that intrigue them, and then select one structure in order to examine closely its underlying mechanics. They can then rebuild and remodel the mechanical structure to replicate and expand its basic kinetic capabilities. Next, students should be introduced to basic concepts in electronics, as well as the use of sensors and motors. While learning to work with a microcontroller, students should think about applying the means of actuation to their mechanical joint explorations, as well as using sensors to trigger the motion. At this point, the concept of behaviors can be introduced, and students can both design and rationalize the intended behaviors of their mechanical structure, and apply these interactive behaviors toward an architectural application. In this way, the students' initial model explorations gradually grow in complexity, integrating automatic functions at first, and later, more complex autonomous behaviors, and, finally, architectural applicability and conceptual insight.

In such an approach geared to architects, most of the topics on electronics, computation, and mechanics are covered only in a very basic, introductory manner. The strategy is inverted from typical architectural design strategies in that rather than starting from a macro level—finding a problem, then performing research, then designing—the students start at the micro level, first designing the mechanical structures, then "growing" the system by adding sensors and motors, moving on to designing the behavior of this system, and finally developing the application of the system in a larger context of use. The objective behind this pedagogical approach is to allow students to focus on the core of the responsive system itself, that is, the fundamental means of adaptation, and how to imbue it with interactivity. This approach minimizes the daunting psychological effects students might experience if, from the onset, they were told that they would have to develop an intelligent structure or building that can physically demonstrate interactive behaviors. Such a hands-on demystification process has been proven to be very effective for crossing interdisciplinary boundaries.[5]

One of the most important qualities needed to design IA is an **enthusiasm to experiment** with new technologies that is driven by innovation rather than market profitability.

The approach lies in having the students learn the skills to demonstrate, as opposed to simulate, their design ideas and intentions in interactive architecture. While gaining elementary competence using an interdisciplinary approach, the ultimate goal is for students to overcome psychological barriers and have the confidence to communicate with engineers and programmers about their design intentions in an effective manner. Such confidence can impact architects' engagement in directing the development of interdisciplinary design. Designers need to have at least a basic knowledge of both engineering (in terms of mechanics and fabrication) and computational substructures in order to develop the necessary skills, and the conceptual and intellectual framework for designing. While this is just one particular pedagogical approach, what is important is that a degree of demystification is required for tackling the complexity and interdisciplinary specialization of the subject matter.

Academic Initiatives

Academic projects dealing with IA are pioneering for a number of reasons. There are several advantages to designing and testing interactive architecture in the context of academia, including the extreme enthusiasm and high energy levels that students bring to these processes. Careers in academia are defined by the merits of peer-reviewed innovation. In addition, particular topics can be studied in more detail as multiple students working together simultaneously can create a collective knowledge about a topic while also exploring interesting individual experiments. Along with all of the advantages of designing interactive projects in the context of academia, there are also a number of important disadvantages to call out. These disadvantages include lack of funding and the consequent limited scale and scope of projects, underdeveloped skill sets of students, and time constraints. One of the most

Through discretely gaining elementary interdisciplinary confidence, students are able to have the confidence to communicate with engineers, programmers and other specialists their design intentions in an effective manner.

important qualities needed to design IA is an enthusiasm to experiment with new technologies that is driven by innovation rather than market profitability. With architectural designers approaching such a multidisciplinary subject as IA, it is important to be optimistic when approaching specific tasks that include programming, kinetic engineering, or robotics. It is often discouraging and difficult to begin if the designer has no background in developing these types of necessary systems. > Fig. **1**

As opposed to research-based projects, with student work there is a degree of freedom to step outside some of the conventional pressures that can limit creativity in IA. As students take advantage of the freedom to experiment, fail, and learn from such endeavors, the dissemination is a recipe for rapid advancement. Another reason that student projects are so valuable is that a large group of students is capable of adding an incredible amount of collective knowledge and energy toward a particular topic. Typically, students come from a wide variety of backgrounds, and this provides the potential to vastly expand the skill set and overall mindset of the collective whole. For example, in collective brainstorming these different voices enhance discussion for how to tie a larger vision together. The sheer number of students can also be a great advantage, because it allows for a number of diverse projects to take place within the envelope of a specific area of research. In most cases it is the knowledge gained collectively through all of the projects that allows for the full breadth of study of a particular subject. > Fig. **2**

An optimistic side to the lack of funding (in particular with individual student initiatives) lies in the fact that students are more likely to focus on developing, prototyping, and testing the most crucial aspects of a design. Communicating design intent in IA often requires methods of demonstration rather than simulation. The necessary physical modeling of adaptive behaviors is often limited, by time and financial resources, to a scale that excludes full-scale prototyping. In most cases, only one or two tests are usually performed, and outside observers usually need to "fill in the blanks" as to how these systems could be applied at a full-sized architectural scale. While the uninhibited perspective that students have in approaching scaled prototyping is extremely beneficial, it typically means that students need to rely heavily on either the professors' or other specialists' knowledge and technical ability during the fabrication process. > Fig. **3**

The multidisciplinary nature of IA can be very advantageous, as architectural designers very naturally break the rules when considering outside disciplines during design

> Fig. 1: Michael Fox with students at Art Center College of Design: Chris Alvarado, Scott Franklin, Nathan Lewis, Donna Salazar, Bao Vo, Vlademir Martinez: *i-dining*, exhibited at the JACC, Los Angeles, California.

> Fig. **2**: Michael Fox with students at Sci-Arc, *i-zoo*.

> Fig. **3**: Michael Fox with students at Art Center College of Design: *i-spa*.

Students of architecture should take courses in mechanics, computation, biology, etc., in order to accumulate a superficial knowledge base in these domains.

development. This in turn has facilitated the crossing of boundaries and subsequent acquisition of hands-on knowledge in various domains. Through discretely gaining elementary interdisciplinary confidence, students are able to have the confidence to communicate their design intentions with engineers, programmers, and other specialists in an effective manner.[6] Building is a complex endeavor, and it is not possible to design a building without consulting many specialists, including architects, engineers, construction managers, lighting consultants, mechanical engineers, acoustical experts, financial advisors, legal experts, and others.[7] But collaboration is difficult, because each specialist comes from a different educational foundation, and has goals and criteria and methods that are different from others.[8] IA, 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.[9] A student of architecture should take courses in mechanics, computation, biology, etc., 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 a team. Architecture will integrate new roles of engineering and specialized consultancy, defining and designing the next generation of IA.

The value of such **real-world understandings** is a huge asset to the field at large. Such projects, which are essentially usable prototypes, are great for testing specific ideas, but the real test is to see how the environments perform with users that inhabit or interact with them every day.

Client and User Initiatives

Projects that are built for specific users or clients also offer a number of advantages and disadvantages to the overall development of the field of architecture. One of the greatest advantages to these types of projects is that they have the ability to be realized at full-scale. Most projects in this category are built at a moderate scale, typically confined to the size of a room, a series of rooms, or a small house.

Since client-driven projects are built at full-scale, they offer a valuable means to understanding many real-world issues. These projects, for the most part, are built for either an individual or a small group of individuals, such as a family. At this scale, designers are able to test and fabricate manageable projects that provide invaluable new insights for what is possible at other scales. Further, the behaviors of both the architecture and the users can be explicitly understood (through user occupancy evaluation and documentation) via the exploitation of the environment up to its limitations. The value of such real-world understandings is a huge asset to the field at large. Such projects, which are essentially usable prototypes, are great for testing specific ideas, but the real test is to see how the environments perform with users that inhabit or interact with them every day.

Another advantage to building client projects is that these projects necessitate innovation within the bounds of fiscal responsibility. Applying workable budgets to these projects necessitates exploring interaction while developing an understanding of appropriate technology transfer. Although technology transfer can be very valuable, the specificity of client-based initiatives makes it increasingly necessary to build customized components and software as needed for specific uses. It also means that these parts and processes can, and should, be designed in such a way that they can be reused or resold for future projects or to the IA community at large.

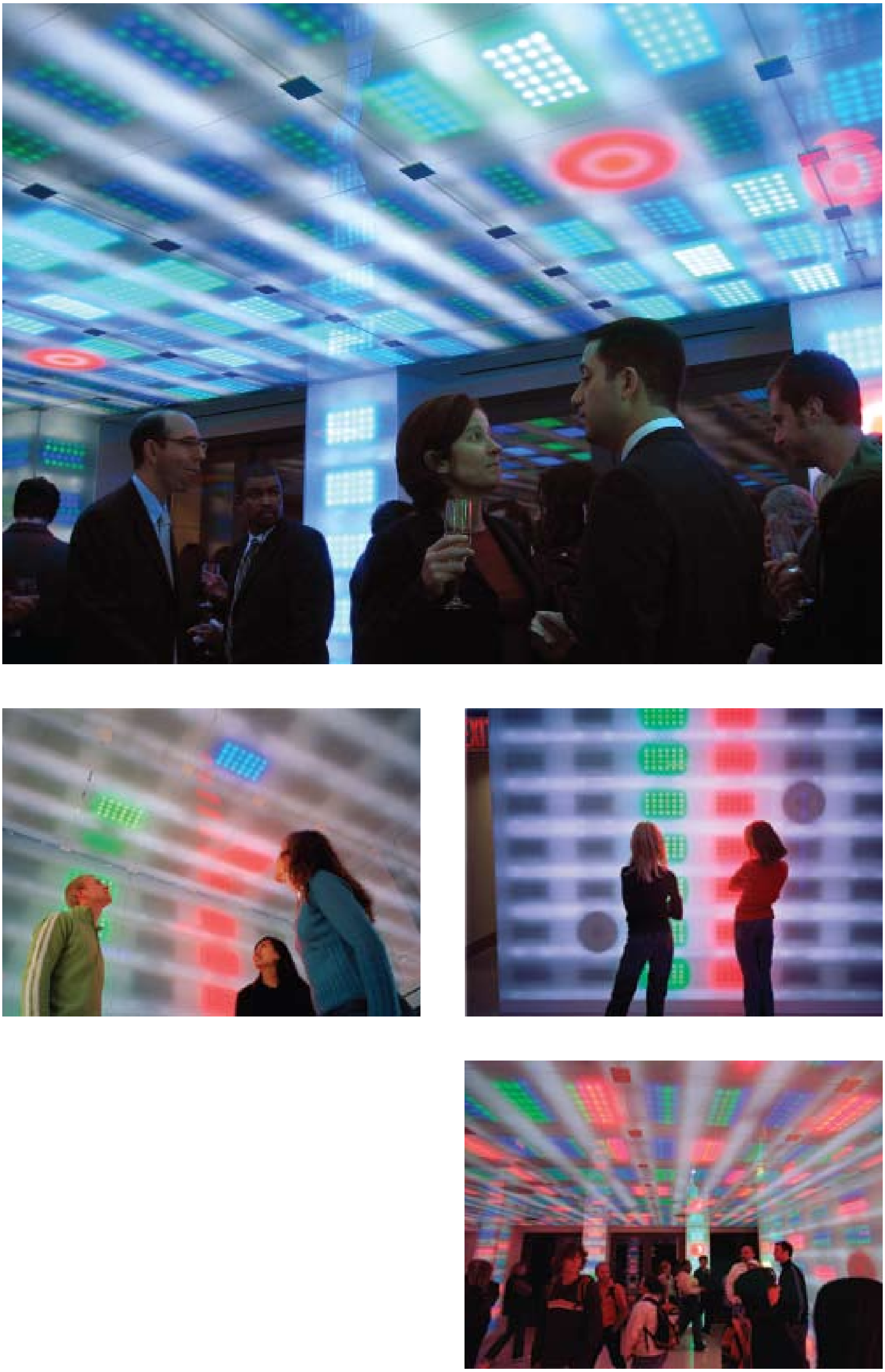
A disadvantage of very specific client-driven initiatives is that in many cases the interactivity is largely focused on satisfying the idiosyncratic desires and needs of a specific client. This does not mean that these systems should necessarily be designed to only accommodate the desires of one particular group—in fact, the point of these systems could be to learn how to interact with individuals through varied interactions learned over time—but it does mean that one voice is the driving force behind a particular project. In many cases, to satisfy client goals, projects become very specialized, and it becomes increasingly difficult to reuse components of these projects for other projects that necessitate generalized adaptive behaviors.

Corporate Initiatives

Corporate projects are usually realized at a larger scale than many other types of IA projects. A number of advantages and disadvantages can be associated with projects of this type. They tend to be designed with a broad audience in mind and are typically built for multiple users. These projects tend to exist within a large public context or urban scale which also boosts the amount of exposure that they receive, typically much higher than other types of IA projects. > Fig. **4**

Corporate projects, because their intended audiences consist of a large number of users, typically exist in large corporate settings, stores, or densely populated urban contexts. Such projects are developed with the intention that they will be used by multiple users at once. This type of interactivity tends to bring people together and collectively engage the

> Fig. **4**: Electroland LLC, Cameron McNall and Damon Seeley, *Target Breezeway.*



Corporate projects, because their intended audiences consist of a large number of users, typically exist in **large corporate settings, stores, or densely populated urban** contexts. Such projects are developed with the intention that they will be used by multiple users at once.

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general public. This collective exposure is valuable for IA, because it helps usher ideas of interactivity into a much larger audience typically accustomed to interactivity on an individual basis in product design and digital media. > Fig. **5**

The budget for this type of interactive projects also tends to be much larger. This usually translates to the potential for more experimentation early on and the development of refined prototypes used to sell the initial ideas to corporations to get more funding. This type of project, if done well, also offers the potential to develop long-lasting working relationships with large corporations that can lead to embedding ideas of interactivity into the branding and general architectural aesthetic of public-facing products and environments. Such client relationships also contribute to unprecedented levels of exposure for interactive concepts. This heightened exposure can be extremely advantageous to new designers, as it will lead to new opportunities for building upon the precedent of success. In the end, architects will inevitably have to convince paying clients that the benefits of doing something novel outweigh the security of doing something with built precedents.

A marked disadvantage of corporate initiatives in IA has to do with their lack of specificity at the individual level. As such projects are designed at a much larger, urban scale, they often employ interactions or general interactivity based on very nonspecific data and focus on making the collective group more aware that people are affecting these environments rather than interacting with people directly. The advantages of corporate initiatives, however, far outweigh the disadvantages, and lie in innovative exposure associated with corporate branding. Branding in the classic sense is about creating unique identities for products and services, and aims to distinguish their offerings from competitors. Corporate branding employs the same methodology. While corporate branding is a complex undertaking that entails many activities, the role that architecture plays in branding is often overlooked. Recently a number of corporations have employed interactive strategies for building and maintaining strong perceptions in the minds of customers. When the architecture itself becomes communicative and when it has an identity associated with a corporation, it can facilitate a whole new level of accessibility and personal attachment to a particular brand.

> Fig. **5**: LAb[au]: laboratory for architecture and urbanism, Philippe Samyn & Partners, M & J. M. Jaspers, J. Eyers & Partners, Barbara Hediger, *Touch*, interactive urban installation.

Every year IA becomes increasingly **feasible** from an **economic standpoint**. Recently a number of different factors and demands have drastically accelerated the feasibility of prototyping, as well as full-scale implementation.

Economic Feasibility

Every year IA becomes increasingly feasible from an economic standpoint. Recently a number of different factors and demands have drastically accelerated the ease of prototyping, as well as full-scale implementation. Much of this feasibility stems from different processes, technologies, and mindsets that have been expanded upon in the previous three sections. Other interactive fields paralleling architecture, such as home automation, have also greatly contributed by raising the demand for technology used in IA projects. This increased demand has aided in the hardware and software becoming cheaper, more powerful, and more available.

In the past architects and designers who wanted to experiment with IA were greatly limited in the possibilities for testing, because the hardware, software, and manufacturing logistics were cost-prohibitive. This meant that the amount of testing and experimentation was very limited and that most tests needed to take place through software simulations rather than in the physical world. Many great resources currently exist for students and practitioners to quickly gain the insight necessary to begin building simple, cheap prototypes. For example, Tom Igoe and Dan Sullivan wrote a fantastic book called *Physical Computing* that is a valuable resource for the uninitiated to build interactive systems.[10] Other great resources include "Low Tech Sensors and Actuators" by Usman Haque[11] and resource pages on a number of interactive architecture blogs such as Ruairi Glynn's Interactivearchitecture.org.[12] All of these resources demonstrate accessible means of using existing technologies and products, and strategies for reusing them in interactive prototypes.

Usman Haque's article "Low Tech Sensors and Actuators" is particularly interesting, because it gives a synopsis of the finding from a university class where the goal of the project

In the past architects and designers who wanted to experiment with IA were greatly limited in the possibilities for testing, because the hardware, software, and manufacturing logistics were cost-prohibitive.

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was to reuse parts of existing toys and technologies found in other fields for interactive projects. He states that "new media artists and architects don't necessarily need the precision and accuracy that scientists usually do in order to explore the poetries of interaction. They therefore often do not require such sophisticated equipment in order to develop truly interesting interactive projects. They work well with the making-the-best-of-what-we-have approach."[13] In this article he also goes on to further describe how off-the-shelf children's toys can be used in different ways to build prototypes; a few examples of this include reworking kids' walkie-talkies to set up a simple wireless network, reusing toy motors for kinetic mechanics, and using remote control devices to control prototypes.

Another way that building prototypes are becoming more economically feasible has to do with advancements being made in the technology and software associated with the manufacturing and use of microprocessors. Currently a number of different types of software for multiple operating systems are available to use to program microprocessors. A number of new companies have also emerged to compete with older microprocessor companies by building more simple microprocessors in modular arrangements that allow consumers with very little knowledge of coding to easily program interactivity. As users become more knowledgeable about programming microprocessors, it becomes increasingly feasible to use even cheaper stamp processors, such as a Peripheral Interface Controller (PIC), which makes it extremely inexpensive to rapidly prototype interactive systems. Lastly, new do-it-yourself (DIY) resources on the Internet are constantly sprouting up that relate to new types of technology that can be used, with a little imagination, to build interactive prototypes. The increase in the availability of video on the Internet is not only making it easier to find content but also making it possible to view very thorough guides on how to use existing technologies from other peripheral fields for architecture projects. New DIY technologies are constantly being developed and should be considered when designing and building inexpensive prototypes.

In the future a range of emerging technological trends will greatly contribute to the future of IA. The following chapter is aimed at exploring and understanding these new trends as they relate to IA as well as many other emerging technologies that are still being developed or will be developed soon.

1 Adam Greenfield, *Everyware: The Dawning Age of Ubiquitous Computing* (Berkeley, CA: New Riders, 2006).
2 Bryan Lawson, *How Designers Think: The Design Process Demystified* (London: Architectural Press, 2005).
3 Gordon Pask, introduction to *An Evolutionary Architecture,* by John Hamilton Frazer (London: Architectural Association Publications, 1995).
4 Claude Lévi-Strauss, *The Savage Mind* (Chicago: University of Chicago Press, 1966).
5 Michael Fox and Catherine Hu, "Starting from the Micro: A Pedagogical Approach to Designing Interactive Architecture," in *Proceedings to CAADRIA*, Bangkok, 2006.
6 Ibid.
7 Dana Cuff, *Architecture: The Story of a Practice* (Cambridge, MA: MIT Press, 1991).
8 Yehuda E. Kalay, "The Future of CAAD: From Computer-Aided Design to Computer-Aided Collaboration," in *Computers in Building: Proceedings of the CAADfutures'99 Conference*, ed. Godfried Augenbroe and Charles Eastman (Boston: Kluwer Academic, 1999), 65–79.
9 Ibid.
10 Tom Igoe and Dan O'Sullivan, *Physical Computing* (Boston: Thomson, 2004).
11 Usman Haque, http://www.haque.co.uk/lowtech.php.
12 Interactive Architecture, http://www.interactivearchitecture.org.
13 Usman Haque, http://www.haque.co.uk/lowtech.php.

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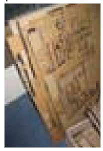
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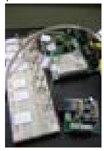
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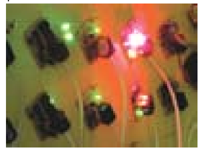
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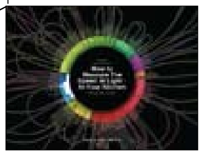
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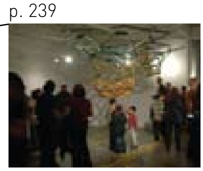
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Developments in interactive architecture are progressing at such a rapid pace that the best we can do is try to predict future influences based on what is unfolding around us today. A number of areas that will significantly influence the field are outlined in the sections that follow. These include technology transfer in interface design, materials, autonomous robotics, biomimetics, and evolutionary systems. Clearly, technology transfer from developments in other fields will continue to impact and evolve with IA. Designing IA is not inventing, but appreciating and marshaling the technology that exists, and extrapolating it to suit an architectural vision. Recent developments in the area of interface design will eventually play out in interactive architectural environments. Interface design is heavily tied to sensor innovation and manufacturing, which has signaled the availability of previously unimaginable means for gathering data and information and nontangible forms of interaction such as gesture and brainwave recognition. The notion of kinetics is currently being radically redefined through robotics as well. Current trends in the design of autonomous robotic systems are setting precedents for how intelligent objects can work together to accomplish changing goals. In architectural terms, such advancements in robotics are viewed as a transitional area where scale is heavily influenced by developments in material science and biomimetics. The future of IA will most certainly involve reexamining and adjusting the scale of the materials that are used in architecture. As physical robotic parts scale down, it will become increasingly necessary to integrate the intelligence of the objects into the physical form itself. Designers in the future will need to simultaneously develop the movement, method of connection, geometry, and embedded intelligence of these smart objects. What we are beginning to see is an end of mechanics as we know it, whereby scale will once again play a critical role.

Historically speaking, the utilization of novel materials has altered the course of architecture. Today we have a compressed technology transfer of modes of production and design methodologies tied to form-making that bring innovations in materials to architectural reality faster than ever. Furthermore, the organic paradigm of kinetic adaptation, mentioned previously in "Physical Change," has fostered a profound set of advancements in both robotics and new materials, whereby the adaptation becomes much more holistic and operates on a very small internal scale. The organic paradigm is being spurred on by the wealth of explorations in biomimetics, which refers here to the architectural application (as opposed to the acquisition) of developments in robotics

Driven by the application of embedded computation into architecture, we will perhaps soon see the age of "live-by-wire" and "work-by-wire" technologies.

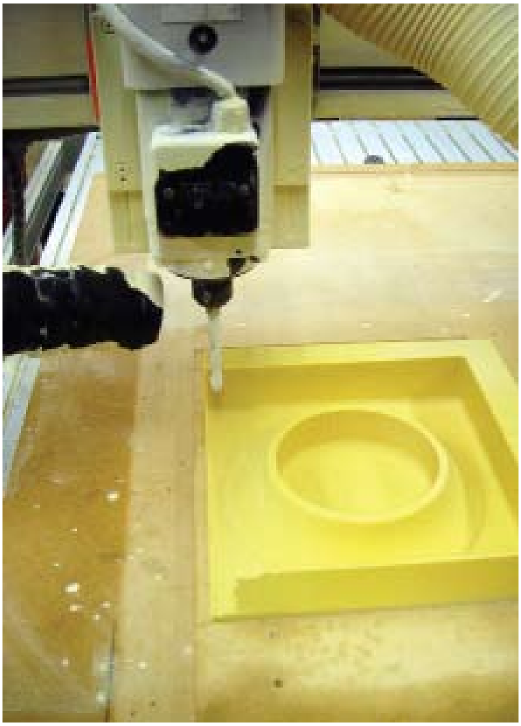
and materials. Biomimetics lies at the intersection of design, biology, and computation, as a science that studies systems, processes and models in nature, and then imitates them to solve human problems. Evolutionary systems describe the processes of a biologically inspired architecture that operates like an organism, directly analogous with the underlying design process of nature. The important thing here is that evolutionary systems reposition the role of the designer. As Pask states in his foreword to the book *An Evolutionary Architecture*: "The role of the architect here, I think, is not so much to design a building or city as to catalyze them: to act that they may evolve."[1] Architects should be informed of developments in biomimetics to understand what is possible and to extrapolate from these ideas and technologies in the creation of a vision to direct the future of their profession.

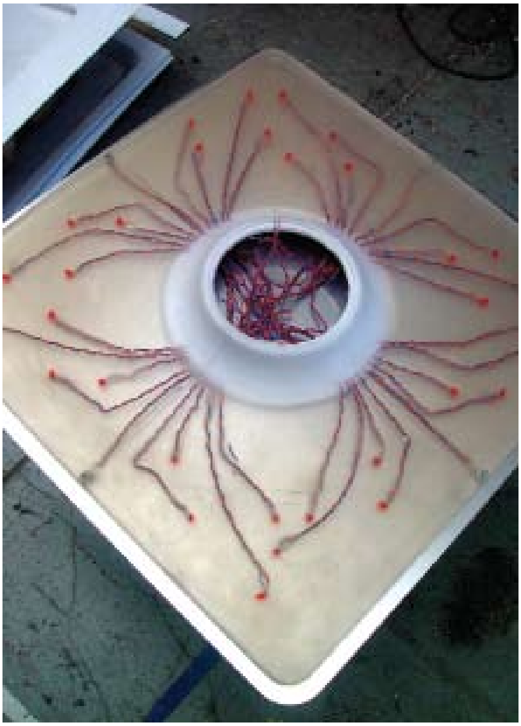
Technology Transfer and Design

The future of IA can best be predicted through examining the use of new technologies in other fields. Such transfer is particularly clear with respect to innovations in aerospace design, automotive design, and digital media. Driven by the application of embedded computation into architecture, we will perhaps soon see the age of "live-by-wire" and "work-by-wire" technologies as discussed in the introduction. Technological advancements in manufacturing and fabrication will also continue to expand the parameters of what is possible in the field of IA, and influence the scale by which we understand and construct our world, resulting in a reinterpretation of the mechanical paradigm of adaptation. > Fig. **1**

In the recent past, the widespread integration of computers into this manufacturing process has brought about new methods in the ways that objects and space can be

> Fig. 1: Michael Fox and students, various CAD-CAM processes.





Engineers invented CNC to increase design and manufacturing process performance, and architects adopted it for its usefulness in creating presentation models. Ironically, it was not for a number of years that architects began to understand how these processes could be useful in the design process.

produced. Automated processing techniques afford unprecedented stability and precision. They can afford dramatic time savings with the ability to produce materials and parts around the clock, and they can improve both the precision and quality of materials and parts.[2] The addition of computation to fabrication machinery has allowed for many manufacturing techniques to become automated. CNC, as mentioned in the previous chapter, is a process by which a powered mechanical device is used to fabricate components by the selective removal of material. These software-driven machines introduced in the early 1950s have dramatically changed the manufacturing industry, making curves as easy to cut as straight lines and complex three-dimensional structures relatively easy to produce. Engineers invented CNC to increase design and manufacturing process performance, and architects adopted it for its usefulness in creating presentation models; it was considered inappropriate for early stages of design. Ironically, it was not for a number of years that architects began to understand how these processes could be useful in the design process.

Rapid prototyping or three-dimensional printing is a different type of automated fabrication that works by the principle of addition rather than subtraction. The first machines became available in the late 1980s out of the manufacturing industries and were quickly adopted by architecture as a means of producing very precise one-off parts and models. There are a large number of such machines available today that are differentiated by the ways in which the layers of material are built up to create the parts. The layers may be of liquid, powder, or sheet material, and a model is built up from a series of cross sections. In the last five years, this machinery has become larger, more affordable, and more readily available. Research in rapid prototyping software focuses on advancements in file translation from a solid model to machine tool paths as a repetitive series of functions.[3] It is now possible to find many of these machines on a smaller scale in universities around the country. This testing has lead to many new innovative uses of materials and even new technologies in digital fabrication.

Larry Sass and the Digital Design and Fabrication Group at MIT are grappling with the problem of realizing such noneuclidean form-making at an architectural scale. Currently there are few clear methods that illustrate how designers can effectively build free-form shapes for design projects as scaled models. "Architects, Sass notes, "when they adopt such technology, would benefit from a variety of size models that can be manufactured

Already we see an area of specialty developing in the architectural profession related to CNC machinery in academia and manufacturers who have forged relationships with architects to create very specific parts.

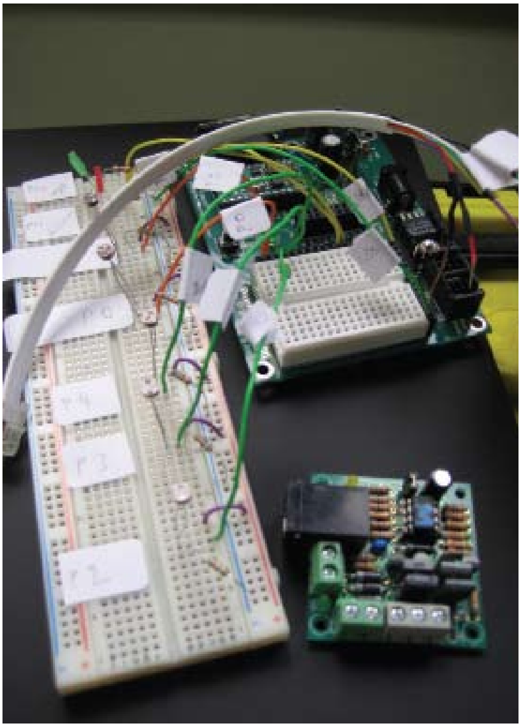
from the same machine with software functions that subdivide a model into parts with attachments."[4] It is important to point out that such automatic equipment requires well-trained personnel. Already we see an area of specialty developing in the architectural profession related to CNC machinery in academia and manufacturers who have forged relationships with architects to create very specific parts. > Fig. **2**

The software that runs on these machines is also developing at a rapid pace. Software is becoming more affordable and more prevalent. Recently we have seen an explosion in architects exploring a complementary means of conceptualizing designs and generating the geometric data necessary for three-dimensional printing through scripting code for design generation.[5] Parametric software, which was developed for the aerospace industry, allows for the design of objects that have the ability to vary their form, location, and function. It is possible to design variation in the parts that make up complicated systems while managing the specific goals of the system. Many programs also offer scripting parameters, further allowing for the system to be controlled by its creator. Because this software also has the ability to communicate directly with the actual machinery that is producing the object, it is quite literally possible to manufacture an object using the exact same file you are developing in the computer. Through adopting technology formerly associated with efficient mass production, it is becoming possible to rapidly prototype custom architectural parts. This is liberating because when you manufacture objects using CNC or rapid prototyping methods, you can measure the cost based on the volume of material and the time it takes to manufacture the part. An endless variety of precise geometries can be manufactured in the same amount of time using the same amount of material. > Fig. **3**

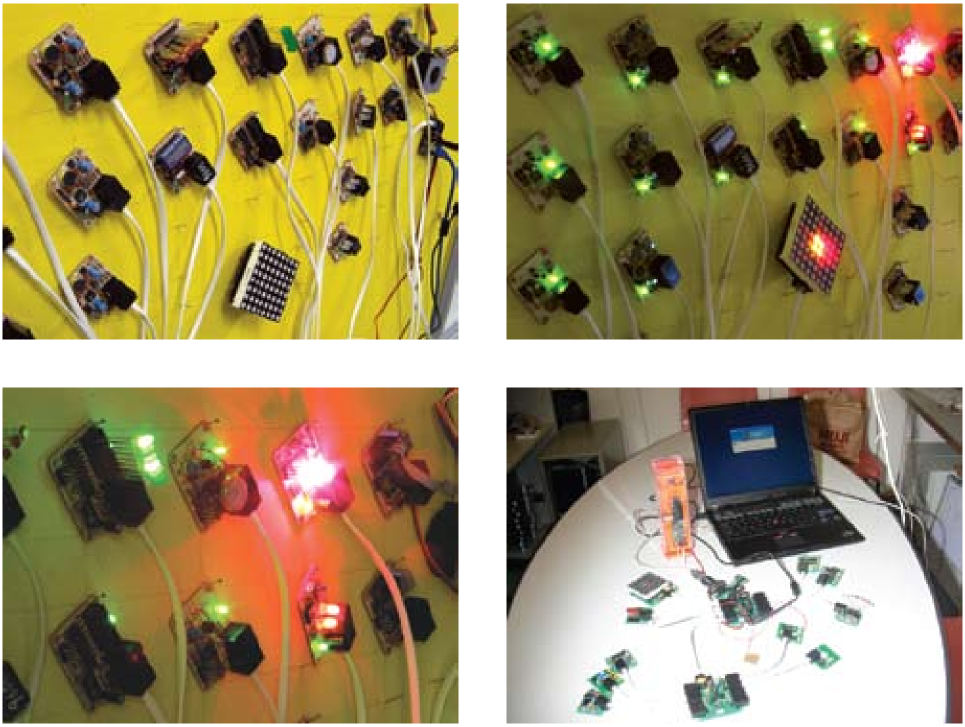
From a hardware standpoint, the actual parts are becoming much smaller and more sophisticated, and the tools used to manufacture these parts have become increasingly affordable. Toshiko Mori states that "we are now in an age where light, chemistry, and especially nanotechnology form the basis of manufacturing."[6] Developments in manufacturing and fabrication processes have significantly influenced the areas of robotics and materials, both discussed in further detail as paramount to developments in IA in the sections that follow. The influence of scale in these areas and their consequent technology transfer has signaled a transition from a mechanical paradigm to a biological paradigm and the inherent evolutionary processes with respect to physical adaptation, discussed in the last sections. > Fig. **4**

> Fig. **2**: Michael Fox and students, various processes used in interactive design.

> Fig. **3**: Parallax Basic Stamp Microcontroller attached to infrared sensors



> Fig. **4**: Yasu Santo, Kinsun Tung, *Interaction Kits.*



Currently a change is taking place in interactive media whereby increased emphasis is being placed on designing and creating interfaces, experiences, and software that are customizable, reprogrammable, and adaptable.

From a software standpoint, IA has seen a recent influx of technology transfer from digital media, in particular, advancements in interface design, which will be discussed in greater detail in the next section. The vast quantity of information that is being used is requiring us to rethink some of the historical standards for data organization and user experience, and place more emphasis on creating seamless interactive spatial user interfaces.

Interface Design

Currently a change is taking place in interactive media whereby increased emphasis is being placed on designing and creating interfaces, experiences, and software that are customizable, reprogrammable, and adaptable. Emphasis is being placed on designing systems that use real-time information in true two-way dynamic conversations with users. The complexity of these new interfaces is rapidly growing as our digital footprint expands and the quantity (and quality) of information grows. New software has been created that acts as a translator to move information between multiple media types. For example, software can actively seek out dynamic (live) content on the web and transmit this content to another type of program that manages an interactive process. New technologies, specifically tied to touch-based, gesture-based, and cognitive control, are beginning to see increased use in mobile devices, online interfaces, video game consoles, and environmental displays. New relationships are emerging between interfaces and users as we see the increased integration of user control and information through a new digital-physical space. Users are beginning to be able to directly manipulate and interact with complex data and media through gesture and touch. These technologies coupled with revised design standards, navigation models, and user experience guidelines are creating unprecedented possibilities for the way we can interact with information.

A similar change is also beginning to take place in the built environment as we study and learn from interactive media precedents and begin to use the technologies that they employ toward controlling environments. Adam Greenfield's vision of ubiquitous computation is taking root in architecture, and we are beginning to see an increased desire to create

This **heightened level of realism** in interface design and an emphasis on organizing information in a **more spatial manner** can also be seen in a number of different interfaces that have recently been developed to mimic and enhance formerly physical activities.

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more responsive and interactive environments.[7] The growing emphasis on using space to organize information in current interface design will begin to evolve into interfaces that are more integrated with their immediate surroundings. We are beginning to see possibilities developed for how people can control their environments through integrated touch-and gesture-based languages with software and hardware that were developed for media projects. Some of the current themes continue to be based on a desire to create user-friendly, customizable, and immersive interactive experiences for users. Real-time customization is currently being applied to a number of interactive media projects and creates a unique experience, as it allows users to dynamically manipulate the organization of information without needing to refresh a specific page, giving users an uninterrupted experience. This does not mean stepping away from creating useful task-based experiences but instead means layering a new set of criteria on top of what we have historically thought of as good design, good usability, and good user experience. Current precedents in interface design are very useful in understanding how relationships are being developed between information in interfaces and users controlling or interacting with these interfaces. > Fig. **5**

Technologies specifically relating to language and software are allowing for the creation of new ways of visualizing real-time data. For example, in the recent past, websites such as Digg Labs have developed popular interfaces aimed at quickly understanding the breadth and popularity of various types of content across the Internet by providing a means to visualize real-time popularity indexes via a number of different graphical organizational methods.[8] As more layers of information are applied to these visualizations, they become more three-dimensional.

Methods for visualizing more tangible concepts in real-time are also taking root. These interfaces are beginning to reinterpret traditional means of controlling space, specifically systems in space, in real life, and through an interface. For instance, Greener Grass has designed a real-time energy-use monitoring system for touch-based devices called "Current State," with which users can directly manipulate the power consumption of all the devices in their environment. This interface currently runs on an Apple iPhone and allows users to spatially visualize information related to energy use in a manner similar to how they would do so in physical space: through controls and diagrams in the interface that mimic the real-life controls, a user needs to touch the phone physically as one would with the real physical objects, rather than navigating with a mouse and keyboard.

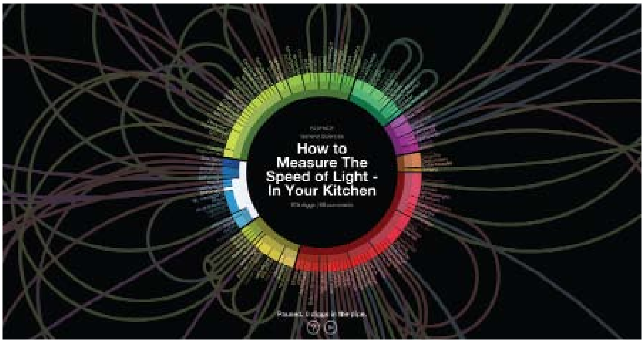
Technologies that allow users **new means to control and interact** with digital information can be broken down into three general categories: touch and multitouch, gesture, and cognitive control.

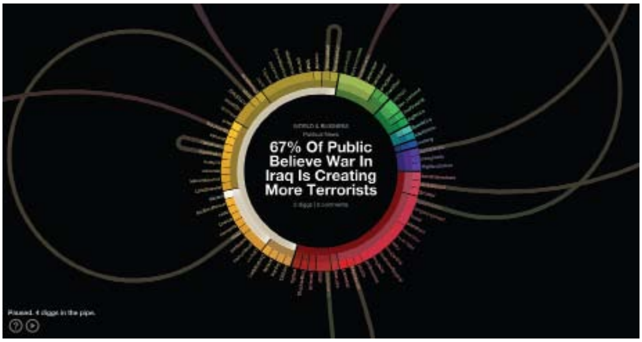
This heightened level of realism in interface design and an emphasis on organizing information in a more spatial manner can also be seen in a number of different interfaces that have recently been developed to mimic and enhance formerly physical activities. Photosynth software, for instance, developed by Microsoft Live Labs, allows a user to stitch images together into a three-dimensional environment using visual graphical data and image metadata.[9]

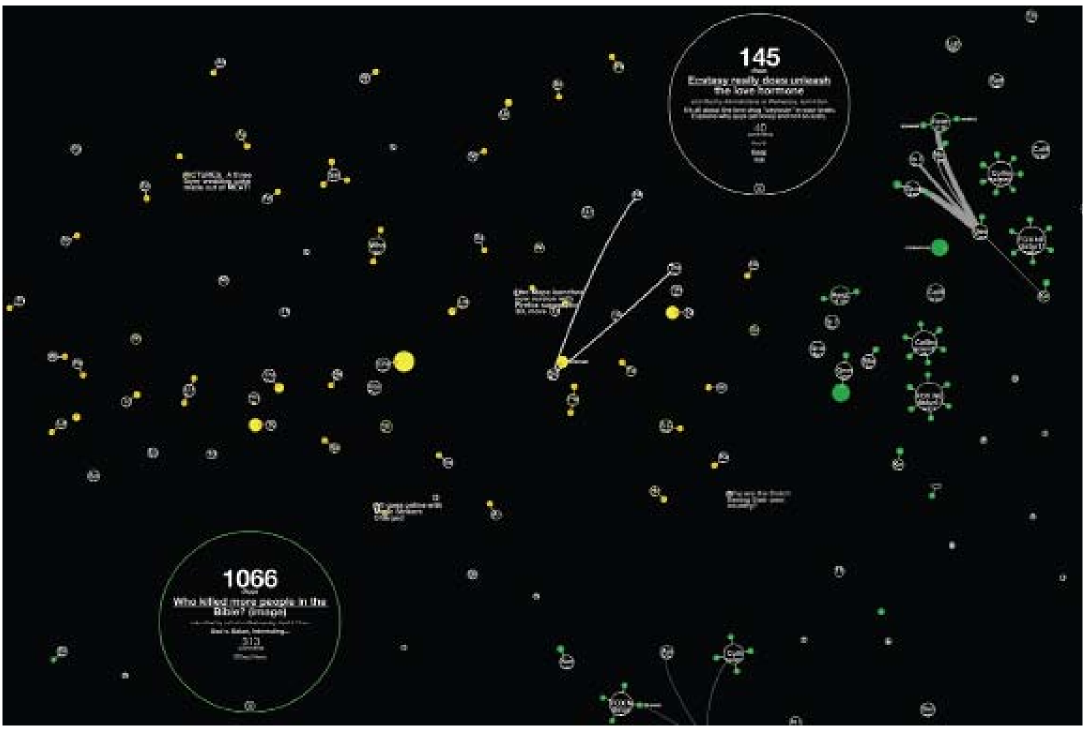
Much of the software being developed in interface design is centered on managing vast amounts of information. There has been much discussion of the issue of information overload, often focusing on negative aspects, when users are presented with the notion that everything in their physical environment will be dependent upon information acquisition. This conversation about information management transcends the discussion of "fear of technology" versus "empowerment through technology" of interactivity that was presented in the Introduction. If people are to accept that interactive technologies are empowering with respect to architecture, they will have to reconcile this with the information acquisition that is required. John Maeda, one of the most influential digital designers of the twenty-first century, recently articulated the need for simplicity with respect to information overload in his book *The Laws of Simplicity*. His first law states: "The simplest way to achieve simplicity is through thoughtful reduction"; the tenth rule is: "Simplicity is about subtracting the obvious and adding the meaningful."[10]

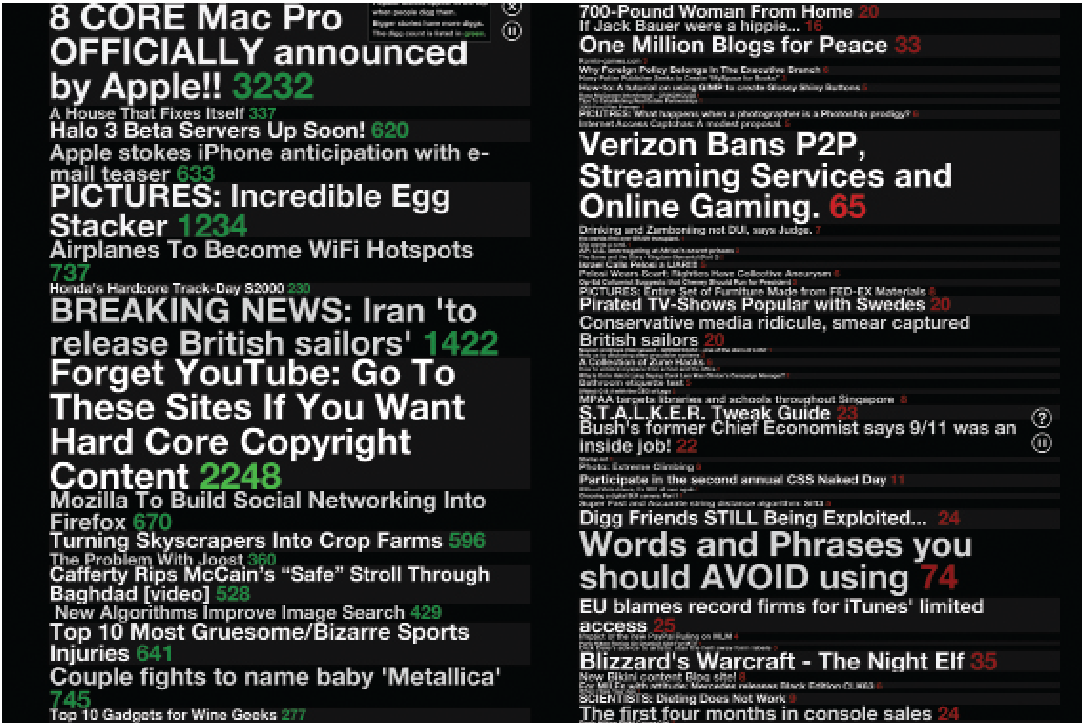
Technologies that allow users new means to control and interact with digital information can be broken down into three general categories: touch and multitouch, gesture, and cognitive control. To date, there are many touch and multitouch interfaces, gesture interfaces are still in their infancy with regard to architectural applications, and direct cognitive controls reside on the developmental horizon but show fascinating promise. A number of projects in interface design have begun to articulate a true spatial integration, such as the Microsoft Surface table with a number of software applications that mimic and enhance real-time physical activities, whereby physical activities with the table allow users to interact with real-time data. The space inside the interface and the gesture space used to control it are becoming more integrated with heightened interactivity. For example, users can order food and drinks through an interface; they pay by placing a credit card on the table and dragging their ordered items onto the card. Such applications put emphasis on spatially organizing information in a way that mimics tangible objects and

> Fig. **4**: Stamen Design, Digg.com, *Digg Labs.*





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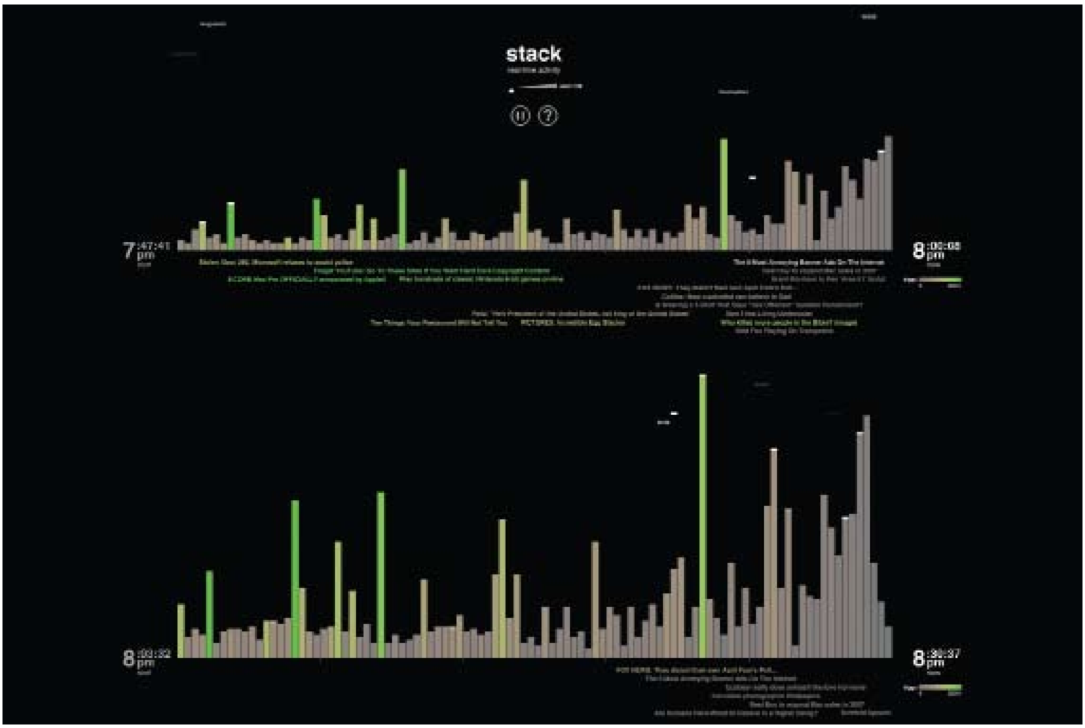
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Advancements in multitouch hardware technology are significant to architecture, because in many cases the **gestures used to control an interface** are the most similar to gestures that would be used to **replicate these activities in real space** with tangible objects.

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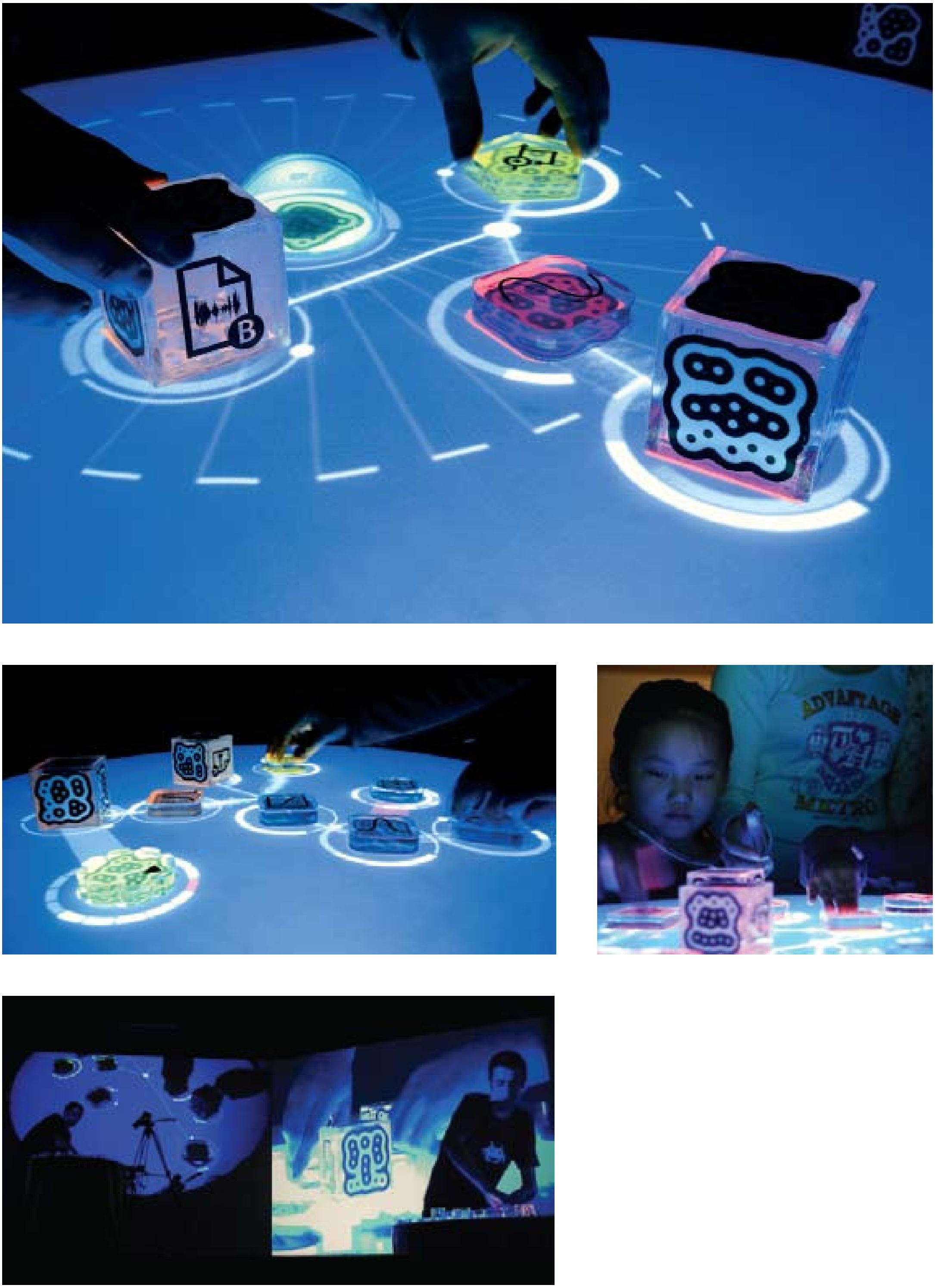
familiar scenarios. The music application shows cover art for music CDs in their original size. Users can interact with on-screen graphics, and can share and play music through the table. Users also have the ability to place an MP3 player onto the table and wirelessly transfer and purchase music by dragging songs onto their players. The music application organizes albums in a way that mimics a real-life scenario, as the albums are spread across a surface in even rows. Using gesture, users can turn albums over to view album contents and information similar to the way they would in physical space. Other multi-touch systems, such as the Reactable, allow users the ability to create music in real time through a sophisticated set of tangible objects that allow users to visualize music and make dynamic changes. > Fig. **6**

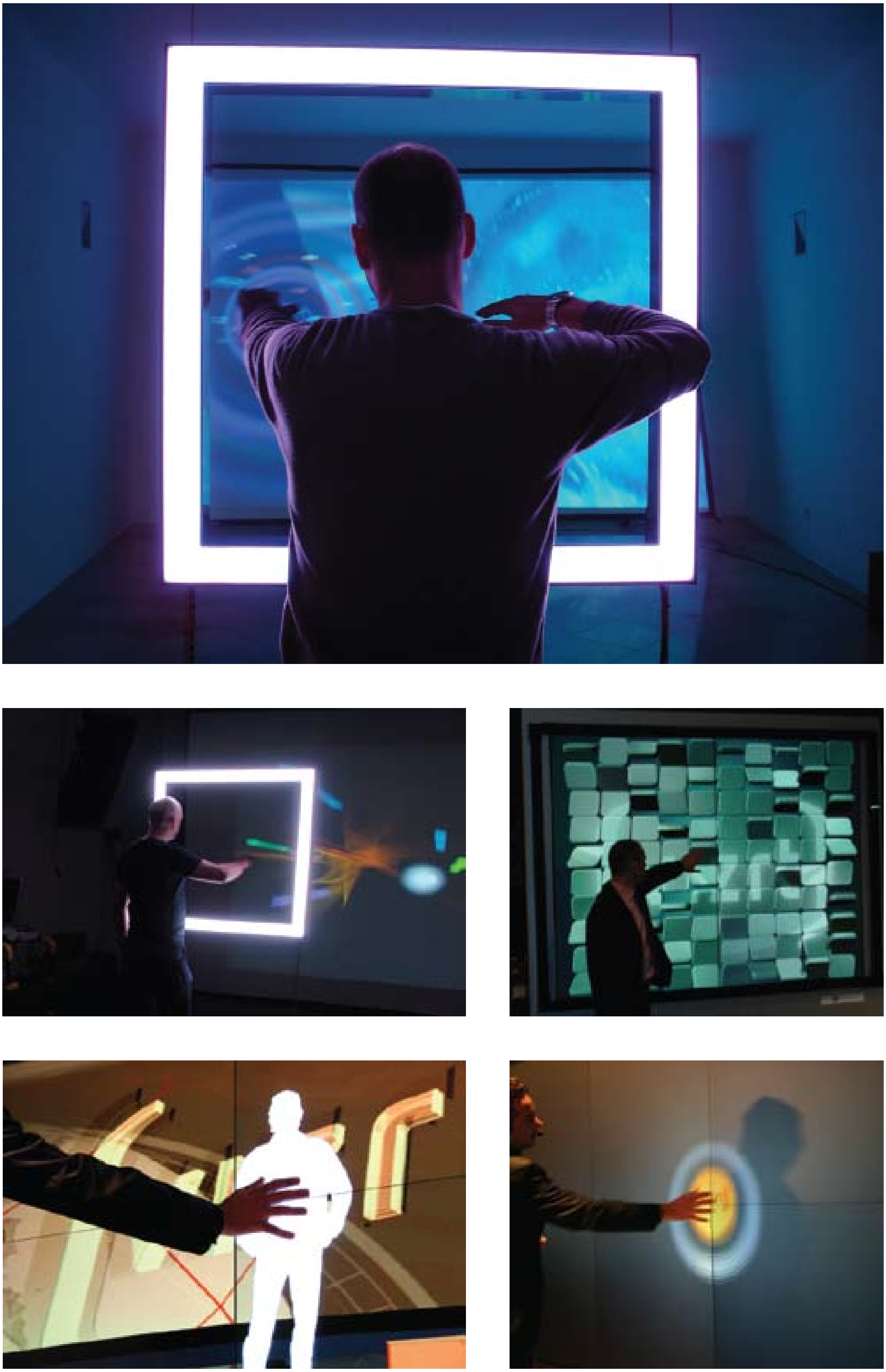
In the future it will be possible to embed architecture with interfaces to allow users to interact with space and objects via gestural language that is currently being developed for each of these systems. Advancements in multitouch hardware technology are significant to architecture, because in many cases the gestures used to control an interface are the most similar to gestures that would be used to replicate these activities in real space with tangible objects. Much of the current gestural language used to control these types of interfaces continues to be developed by various interactive media agencies worldwide. Multitouch systems lend themselves to direct proximity interaction between users and objects and/or users and systems. In of the area of game design, the Wii controller unveiled by Nintendo in 2005 has in certain regards revolutionized interaction in terms of general public acceptance. The wireless remote controller can be used as a handheld pointing device and detects movement in three dimensions. Toby Schadt points out that the way you control your character in a game is a more realistic analog to what you would do in the real world, as opposed to pressing buttons.[11] Jane McGonigal takes the notion of realism a step further. While she agrees that Wii game play is much more intuitive than traditional console games because it provides a better analogy between real-world gestures and in-game actions, she points out that the reason the Wii is so compelling is that you are really playing. "You are not vicariously playing through an avatar whose movements you immerse yourself in."[12] When you play such games, you are moving, sweating, and exercising.

It is worth noting that sensor technology is becoming accessible enough to bring interface design exploration into the hands of the general public. As applications such as

> Fig. **6**: Sergi Jordà, Marcos Alonso, Günter Geiger, Martin Kaltenbrunner, *The Reactable*.



> Fig. **7**: Oliver Irschitz/Peyote Cross Design Concepts, *iFrame.*



Cognitive control is perhaps one of the most fascinating areas of interface design, whereby users wearing a headset will have the ability to wirelessly control objects (formerly through gesture) through cognitive, emotional, and physiological commands registered in their brain activity.

Google Earth and live webcams allow us an unprecedented understanding of remote environments, there are numerous fascinating DIY interface projects being created today that take advantage of such technologies. One recent example is a project by Mike Pegg, who used SunSPOT (a three-dimensional sensor device that has a Java software interface) and a plethora of other sensors in order to modify his mountain bike to serve as a flight control joystick for Google Earth's flight simulator.[13] > Fig. **7**

A number of different types of gesture-based control systems are significant to architecture in that they allow a user the ability to directly control and interact with real objects in an environment. The Peyote gesture control system, for instance, allows such control from a distance using cameras and infrared technology.[14] Currently the amount of control is based on the resolution of input information; this means that while it is possible to control interfaces without devices, devices augmented with accelerometers and other sensor input hardware allow for more precise control. Gesture-based systems are much better at manipulating larger quantities of data or objects over a large visual field and currently lend themselves well to the control of interfaces relating to television and large-scale display. These systems also allow for the interface to become more spatially integrated into three-dimensional architecture, as the sensor recognition system or systems can be placed around a user. > Fig. **8**

Cognitive control is perhaps one of the most fascinating areas of interface design, whereby users wearing a headset will have the ability to wirelessly control objects (formerly through gesture) through cognitive, emotional, and physiological commands registered in their brain activity. One example of this is the Emotiv headset, which is setting a new precedent for how interfaces can be integrated with user input.[15] The amount of resolution and granularity that this product is capable of providing for interaction with architecture is largely unknown, and the interpretation of diverse cognitive languages is just beginning to be developed, yet it is likely this will be an extremely interesting means by which to control space. Given the complexity of the brain and the amount of different parallel processing that is possible in the brain, it is conceivable that we will be able to use this technology to simultaneously interact with various architectural systems at once. Taking cognitive control a step further, Matthew Nagel, who is a paralyzed man, has become the first person to benefit from a brain chip that reads his mind and allows him to control objects in the physical world. The pioneering surgery performed at New England

These new technologies in combination with current trends in user experience and interface design are beginning to blur the space between user control and digital information as interactivity becomes more lifelike.

Sinai Hospital, Massachusetts, means he can now control everyday objects by thought alone. The brain chip reads his mind and sends the thoughts to a computer to decipher. He can think his TV on and off, change channels, and alter the volume, thanks to the technology and software linked to devices in his home.[16]

These new technologies in combination with current trends in user experience and interface design are beginning to blur the space between user control and digital information as interactivity becomes more lifelike. As these new interfaces continue to embrace spatial constructs, we are simultaneously seeing new models of control whereby users are able to more tangibly manipulate and interact with digital content, further blurring the lines between digital and physical space. As objects in space become increasingly empowered with computational intelligence, sensors receiving input (hardware), and computational logic (software and information), users will have the ability to interact with the architecture around them. In architecture we are seeing a number of parallel trends that are currently in development; once used in conjunction with the trends in interfaces and control technologies, architecture will attain an unprecedented level of interactivity. We are already beginning to see a number of gesture-controlled systems in our everyday environments, and it is only a matter of time before we use these types of devices, and the technology and gestural language they employ, to control more architectural-scaled applications. Ubiquitous computation is becoming increasingly integrated into the objects and structures that make up our environments; based on current trends, this will only increase in the future. It is up to architects and designers to embrace such unfolding technology in interactive media design in order to study and develop the new languages that we will use to control and interact with architecture.

> Fig. **8**: Professor Allan Snyder, Neil Weste, Tan Le, and Nam Do, *Emotiv EPOC*.

The beginning of a paradigm shift from the mechanical to the biological in terms of adaptation in architecture can be seen as the end of mechanics.

The End of Mechanics

The beginning of a paradigm shift from the mechanical to the biological in terms of adaptation in architecture can be seen as the end of mechanics. Kinetics was defined in "Embedded Computation" as either transformable objects that dynamically occupy predefined physical space, or moving physical objects that can share a common physical space to create adaptable spatial configurations. The means by which the above are carried out was discussed in both mechanistic and biological terms. In biological terms, the end of mechanics refers to the rising promises of organic theory: "Organic theory emerges from nature, an environment that possesses evolutionary patterns that have a base code and an inherent program where information is strategically interrelated to produce forms of growth and strategies of behavior, optimizing each particular pattern to the contextual situation."[17] Organic theory is intrinsically tied to the performative aspects of the operational scale and the inherent behavior of materials, as well as the role that innovative materials may play in designing and building environments that address changing needs.

Developments in architecture have always been intrinsically tied to developments in materials. Recently, "architectural practice has moved from working within the limits of static materials to transforming them into dynamic elements by combining, laminating, casting, and weaving."[18] Materiality will prove to be important for advancement in the area of IA: technology will provide both an unprecedented understanding of microscopic biological mechanisms and advanced manufacturing of high quality kinetic parts with new materials such as fabrics, ceramics, polymers and gels, fabrics, shape-memory alloy compounds, and composites with unprecedented structural properties. As Mori points

Smart materials are inherently tied to a function of scale. Nanotechnology is a new area of research based on the control of matter on a scale smaller than one micrometer, as well as the fabrication of devices on this same scale.

out: "We can theoretically produce materials to meet specific performative criteria; this transformation often takes place at the molecular level, where materiality is rendered invisible." [19]

Intelligent materials and smart materials are general terms for materials that have one or more properties that can be altered. Blaine Brownell describes transformational materials as those materials that undergo a physical metamorphosis triggered by an environmental stimuli; such change may be either based on the inherent properties of the material or user-driven.[20] Addington and Schodek divide smart materials and systems into two classes. Type one materials undergo changes in one or more of their properties (chemical, electrical, magnetic, mechanical, or thermal) in direct response to a change in external stimuli in the surrounding environment. A type two smart material transforms energy from one form to another. This class involves materials with the following types of behavior: photovoltaic, thermoelectric, piezoelectric, photoluminescent, and electrostrictive.[21] Of great promise to IA is how smart materials can be used as sensors, detectors, transducers, and actuators. As a piezoelectric material is deformed, it gives off a small but measurable electrical discharge. An example of a piezoelectric material is the airbag sensor in your car. The material senses the force of an impact on the car and sends an electric charge to deploy the airbag. John Fernandez points out that such embedded sensors, self-healing composites, and nanoscale and responsive materials are perfectly timed to facilitate an era of smart buildings aimed at environmental adaptation for reasons of sustainability.[22] Such buildings can respond in a humanlike way to counteract loads and reduce material, change shape to block sunlight, allow for active ventilation and insulation, and prevent their own degradation.

Smart materials are inherently tied to a function of scale. Nanotechnology is a new area of research based on the control of matter on a scale smaller than one micrometer, as well as the fabrication of devices on this same scale. Nanocomposite materials are being developed that are self-sensing and self-actuating to improve strength, reliability, and performance. Perhaps even more relevant to the discussion of IA is the area of bionanotechnology (as opposed to nanobiotechnology, which is nanotechnology used to further the goals of biotechnology). This area is the logical integration of biological functions and nanoscale precision. Nanobiosensors are currently being fabricated and commercialized. Such technology based on the principles and chemical pathways of living

The utilization of new materials in IA, in particular relative to the discussion of scale, clearly reaches beyond the performative to include aesthetic, conceptual, philosophical, and technical issues.

organisms, ranging from genetically engineered microbes to custom-made organic molecules, provide the basis for the development of nanomachinery, which might be guided by studying the structure and function of the natural nanomachines found in living cells. Mavroidis and Yarmush use the term molecular machines to describe such nanomachines as devices that can produce useful work through the interaction of individual molecules at the molecular scale of length.[23] When such technologies are applied to materials' biosensing, biocontrol, bioinformatics, computing, information storage, and energy conversion used in architecture that can adapt at a nanomechanical scale, the implications relative to sustainable architecture are potentially profound.

The utilization of new materials in IA, in particular relative to the discussion of scale, clearly reaches beyond the performative to include aesthetic, conceptual, philosophical, and technical issues. The visionary example set forth by Arthur C. Clarke articulates well the conceptual issues we are faced with new materials in architecture:

> There are many great scientists of a thousand years ago who would have had no difficulty understanding an automobile or an engine or a helicopter and certainly not the most advanced architectural system. The craftsmanship would have been astonishing but the principles straightforward with respect to an understanding of the novel material properties. If we were to show the same great scientist of the past a television or a computer or a radar, it would have appeared magical to them. The difficulty for them would not have been one of complexity; but rather they would have been lacking in the mental framework required to conceptualize such nonmechanistic devices.[24]

For many applications ranging from exploring space to household cleaning, designers are moving away from figural humanoid robots to transformable systems made up of a number of smaller robots.

Autonomous Robotics

The landscape of projects that make up the field of robotics is also seeing a shift in the way that people design robots. For many applications ranging from exploring space to household cleaning, designers are moving away from figural humanoid robots to transformable systems made up of a number of smaller robots. The manufacturing technologies discussed above compounded with recent advancements in software (computational intelligence) for these systems allow robots to be increasingly smaller and smarter. Current advancements in metamorphic, evolutionary, and self-assembling robots, specifically dealing with the scale of the building block and the amount of intelligent responsiveness that can be embedded in these modules, are setting new standards for the construction of robotics. As designers create more diverse, responsive, and autonomous robotic systems, it becomes easier to imagine architectural applications. As architects and designers familiarize themselves with these new systems, they are beginning to understand ways to apply them to dynamic situational activities and build them into systems that make up space. The future of IA will most certainly involve reexamining and adjusting the scale of interactive materials. As physical robotic parts scale down, it will become increasingly possible for future systems to be built out of nanotechnological and bionanotechnological means. Designers in the future will need to simultaneously develop the movement, method of connection, geometry, and the embedded intelligence of these smart objects. These new interactive assembly systems will bring new unprecedented levels of customization and reconfigurability. In the future, users will be able to purchase these robotic parts with the capability of adding their own intelligent, customizable settings.

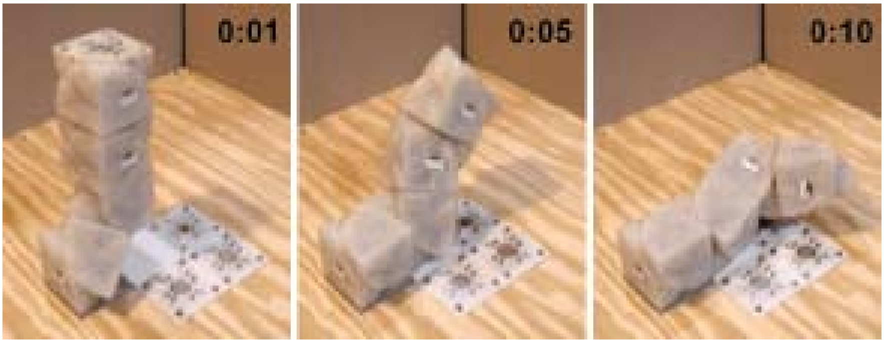
Current advancements in metamorphic, evolutionary, and self-assembling robots, specifically dealing with the scale of the building block and the amount of intelligent responsiveness that can be embedded in these modules, are setting new standards for the construction of robotics.

Researchers at Caltech are moving away from looking at robotic locomotion through "legged" robots and are instead developing robots made up of modular parts that work as a system to interpret and act upon information.[25] Hod Lipson and other scientists at the Cornell Computational Synthesis Lab have begun developing multiple types of modular reconfigurable robots and evolutionary robots. These self-replicating prototypes were designed to allow for each object to be able to attach, detach, and reattach to different self-similar faces based on predetermined computational logic. These modular objects are able to connect to each other through electromagnetic connections, and the entire system has the ability to change its physical shape based on how it is programmed.[26] > Fig. **9**

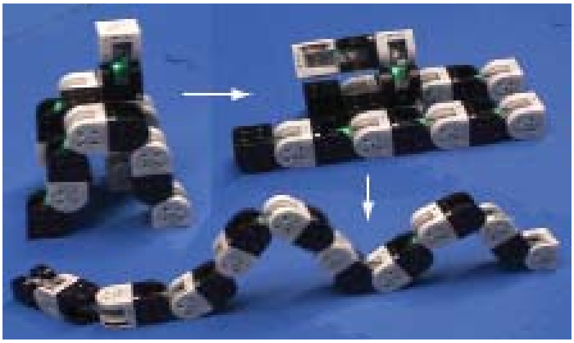
Advancements in technology associated with manufacturing are paving the way for the ability to physically produce increasingly sophisticated modular parts at a large scale. The M-TRAN robot system, developed by Distributed System Design Research Group (DSDRG) at the Institute of Advanced Industrial Science and Technology (AIST) in Japan, is a reconfigurable modular robotic system that is made up of an entire sophisticated system of milled parts.[27] > Fig. **10**

The technology to produce these parts is so precise that DSDRG is able to reproduce dozens of different modules to test in a variety of experiments. While these prototypes are currently expensive to produce, digital manufacturing technology will pave the way for new robots to be made more efficiently and cheaply. The robots developed at Cornell were also manufactured using digital fabrication technology. The sensors, hardware, and wiring for these robots were added after the form of the objects was produced. Both the DSDRG and Cornell modular systems were limited in how small they could be produced because of the technology that was available at the time of production. As digital manufacturing technology advances, it will be possible to produce smaller parts, and future 3-D printing machines will be able to physically print out electrical circuits, microcontrollers, actuators, and servos in one seamless final product. Printing out mechanical parts with computational systems as whole objects will bring about unprecedented levels of efficiency and will allow molecular parts to become ever increasingly smaller. The Liquid Metal Jet Printing (LMJP) laboratory at the University of Texas at Arlington, for example, is developing a manufacturing process that builds combinatorial mechanical parts and electronic interconnects together in an additive manner.[28] It is likely that the gap in scale between mechanical manufacturing and nanotechnological manufacturing will become

> Fig. **9**: Cornell University, Viktor Zykov, Efstathios Mytilinaios, Bryant Adams, Hod Lipson, *Molecubes*—Self-replicating robotics



> Fig. **10**: Haruhisa Kurokawa (& Satoshi Murata), M-TRAN (Self-Reconfigurable Modular Robot)



As **digital manufacturing** technology advances, it will be possible to produce smaller parts, and future 3-D printing machines will be able to physically print out electrical circuits, microcontrollers, actuators, and servos in one seamless final product.

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increasingly smaller. Researchers at Xerox PARC Research Lab in Palo Alto, California, have also developed a number of different modular reconfigurable robots (MRR) as well as the programming by which these objects can work together to create different types of shapes.[29] Many of the early prototypes were based on rectilinear geometry, which limited their reprogrammable states. Some of the geometry that they employed in later prototypes was based on shapes that were more similar to circular geometries but had the ability to nest using planar surfaces. By using a geometry that has the ability to nest, objects can be programmed to make solid configurations. Xerox PARC has also developed software using different types of algorithms to study and test goal-state-driven configurations. This type of software will be crucial for developing the coordination necessary to organize swarms of intelligent robotic units.[30]

Although there may be no centralized control structure dictating how individual parts of a system should behave, local interactions between individual modules can lead to the emergence of global behavior. Most architectural applications are neither self-organizing nor do they have higher-level intelligence functions of heuristic and symbolic decision-making abilities. Most applications do, however, exhibit a behavior similar to that of swarms based on low-level intelligence functions of automatic response and communication. There are many biological reasons for swarm behavior related to efficiency in foraging, hydrodynamics and aerodynamics, and protection and reproduction, among others. Most of these reasons are related to the goals of the swarm as a whole. With swarm intelligence, there are many discrete systems that, while acting individually, appear to work in unison more like a single organism than a collection of individual elements. Swarm intelligence is an artificial intelligence technique based around the study of collective behavior in decentralized, self-organized systems. Swarm intelligence systems are typically made up of a population of simple agents interacting locally with one another and with their environment. The beauty of such distributed control is that when it is applied to a large system, there is a potential for emergent behavior. An emergent behavior can occur when a number of simple systems operate in an environment that forms more complex behaviors as a collective. The rules of response can be very simple and the rules for interaction between each system can be very simple, but the combination can produce interactions that become emergent and very difficult to predict. The more decentralized a system is, the more it relies on lateral relationships, and the less it can rely on overall commands.

Our furniture might someday be comprised of a multitude of **interconnected assemblies of robotic modules** that can **reconfigure** themselves for a variety of needs or desires.

Since it will be possible to build space out of parts that have the ability to reconfigure themselves, it will be up to architects and designers to design how these pieces will come together and how these configurations will respond to the constant flow of information between inhabitant and space. As architects and designers begin to adopt the technology of modular reconfigurable robotic systems, they will begin to reenvision the creation of dynamic space. Miles Kemp has designed an architectural environment composed of a palette of autonomous reconfigurable parts. These materials come together to create a layering of responsiveness and an overall intelligence that is embedded in the structure itself; the material and texture of the space is the intelligence of the space. Users would be able to buy kits of parts—basic building blocks—and reprogram the parts to accomplish their desires. Rather than having predetermined goals, the relationships between users and space would be able to grow over time.[31] > Fig. **11**

In the near future, modular reconfigurable space will hugely impact the way people live in space, and the relationships between users and the space itself. Our furniture might someday be comprised of a multitude of interconnected assemblies of robotic modules that can reconfigure themselves for a variety of needs or desires. Sunny Bains presents a fascinating scenario of the workplace of the future:

> The board meeting is over. In the next 10 minutes, people will be arriving to hear a lecture, so the chairs walk across the room and stand in neat rows, starting at the back. The table, no longer needed, dismantles itself and re-forms into a few more chairs, and these go to join the others. Even more chairs start to emerge from stacks of little square boxes along the sidewall, each one wiggling along to take its place until the room setup is complete. Then, when the lecture is over at the end of the afternoon, the furniture clears itself away while the presenter is still talking to the line of people who waited behind. The conference room is ready to be vacuumed.[32]

She points out that there are two major hurdles with such a scenario, the first of which is the mechanical design that includes connecting to each other with sufficient mechanical strength and then disconnecting easily again without using too much energy. The second difficulty is control, in terms of forming structures and figuring out how to move them around.[33] The Biologically Inspired Robotics Group (BIRG) at the Swiss Federal

> Fig. 11: Robert Miles Kemp, *Meta-Morphic Architecture.*

The area of "redesigning the brick," or creating a new vocabulary of basic architectural building blocks with modular robotics, appears to be somewhat of a transitional step, however, in the evolution of robotics.

Institute of Technology is tackling such issues with Roombots, which are to be used as building blocks for furniture that moves, self-assembles, self-reconfigures, and self-repairs.[34] Modular reconfigurable robotics at the scale of furniture are also being explored at the Self-organizing System Research Group at Harvard University, which has developed some fascinating projects such as a self-balancing interactive table.[35]

The area of "redesigning the brick," or creating a new vocabulary of basic architectural building blocks with modular robotics, appears to be somewhat of a transitional step, however, in the evolution of robotics. Currently such robotics is limited by the possibilities of manufacturing and of the inherent physical mechanics. In the sections that follow, we discuss biomimetics and evolutionary systems as key concepts to a future of interactive architectural robotics that embraces a transfer from a machine paradigm to an organic paradigm.

Biomimetics

Biomimetics was started by Otto H. Schmitt in 1969 as a scientific approach that studies systems, processes, and models in nature, and then imitates them to solve human problems. It lies at the intersection of design, biology, and computation. The architecture profession is rapidly embracing digital design technologies developed and applied in the framework of biologically inspired processes. Put simply, nature is the largest laboratory that ever existed and ever will. In addressing its challenges through evolution, nature tested every field of science and engineering leading to inventions that work well and last. The visionary Yoseph Bar-Cohen sums it up well: "Nature has 'experimented' with various solutions and over billions of years it has improved the successful ones. It has always served as a model for mimicking, and inspiration to humans in their efforts to

A number of architects and philosophers are beginning to formulate the basis for a physically dynamic architecture that arises out of human needs, and which is supported by an improved understanding of biological systems.

improve their life."[36] The core idea is that nature, imaginative by necessity, has already solved many of the problems we are grappling with. Animals, plants, and microbes are the consummate engineers. Nature has found what works, what lasts, what is necessary and not necessary, and, consequently, what is appropriate for this planet. David Oakey nicely sums up a key difference between nature and humans. "Nature rewards mistakes and learns from them."[37] Bar-Cohen puts it well in explaining that "adapting mechanisms and capabilities from nature and using scientific approaches led to effective materials, structures, tools, mechanisms, processes, algorithms, methods, systems, and many other benefits."[38] Specifically in terms of the development of robots, he states "the multi-disciplinary issues involved include actuators, sensors, structures, functionality, control, intelligence, and autonomy."[39]

A number of architects and philosophers are beginning to formulate the basis for a physically dynamic architecture that arises out of human needs and that is supported by an improved understanding of biological systems. We are beginning to see numerous examples in product design, such as the Nike Free 5.0 athletic shoe, whereby the articulated sole results from the study of athletes running barefoot. Through reproducing the performative strengths of a biological model such as the foot, the shoe adopts the range of motion, flex, and grips of the human foot, rather than mirror its form. Another example is modeling the echolocation of bats in darkness and adapting that functionality into a cane for the visually impaired. From an architectural standpoint, it is compelling to imagine such ideas transferred beyond the product into the fabric of our built environment.

Janine Benyus describes biomimicry from a sustainable standpoint in terms of three levels that include form, process, and system. The first level of biomimicry is the mimicking of natural form. For instance, you may mimic the hooks and barbules in an owl's feather to create a fabric that opens anywhere along its surface. Or you can imitate the frayed edges that grant the owl its silent flight.[40] The second level is the mimicking of natural process, or how things are made in nature. Beynus explains it through the following analogy. "The owl feather self-assembles at body temperature without toxins or high pressures, by way of nature's chemistry. The unfurling field of green chemistry attempts to mimic these benign recipes. At the third level is the mimicking of natural ecosystems. The owl feather is gracefully nested; it's part of an owl that is part of a forest that is part of a biome that is part of a sustaining biosphere. In the same way, our owl-inspired fabric must be part of a

Central to biomimicry within the context of IA is an understanding of the process by which organisms **grow and develop**.

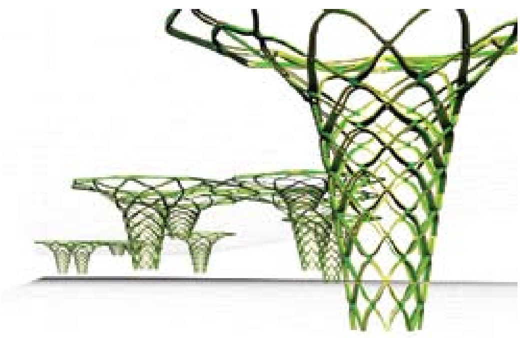
larger economy that works to restore rather than deplete the earth and its people. If you make a bio-inspired fabric using green chemistry, but you have workers weaving it in a sweatshop, loading it onto pollution-spewing trucks, and shipping it long distances, you've missed the point. To mimic a natural system, you must ask how each product fits in: is it necessary, is it beautiful, is it part of a nourishing food web of industries, and can it be transported, sold, and reabsorbed in ways that foster a forest-like economy."[41] Stephens points out that "the very fact that buildings have been designed 'green' but operate and appear just like any other building begs the question: Is sustainability something to hide or would we be better served to celebrate our respect for the environment in a more tangible and visible way?"[42]

> Fig. **12**

Stephens and Prescott point out that, in the near future, buildings will mimic systems in nature with respect to environmental mediation. Technology will allow future "buildings to mimic the sophisticated energy management systems of nature and allow the building to change its enclosure and ventilation systems as required to respond to variations in temperature, wind, daylight and moisture conditions. In addition, sustainable buildings of the future will reflect the local climate conditions and building materials will reflect our values as social creatures."[43]

Central to biomimicry within the context of IA is an understanding of the process by which organisms grow and develop. This area of study is called developmental biology and includes growth, differentiation, and morphogenesis. In terms of adaptation, the area of morphogenesis, which is concerned with the processes that control the organized spatial distribution of cells, is particularly relevant. In the human embryo, the change from a cluster of nearly identical cells to one with structured tissues and organs is controlled by the genetic "program" and can be modified by environmental factors. Bones, for instance, which are full of living cells, can heal and adapt to their environment. In particular, the cells will rebuild the structure to adapt to the load it carries; a bone can change its physical shape after a fracture that heals out of position, so that the load is adequately supported. As Pinkler points out, there are some interesting architectural analogies here: "The microstructure of the trabeculae follow the force lines, officially called stress trajectories, just like in the catenary arch, complete with side braces to prevent buckling movement. Wolf's Law states that bone in a healthy person or animal will adapt to the loads it is placed under. He [Wolf] argued the pattern was inherited, like overall body shape."[44]

> Fig. **12**: Omar Khan, Assistants: Joseph D'Angelo, James Brucz, Brian Clark (media study), Brian Podleski, Vail Rooney, Nick Bruscia, Dennis Cook, Mike Wysochanski, Ashley Latona and Rafal Godlewski, *Open Columns.*



The technology transfer from biology to architecture is inevitable and potentially profound in our profession as it becomes increasingly aware of its environmental impact.

Pinkler continues to explain that this process is only partially correct in that the rebuilding is a very dynamic process called bone remodeling: "The living cells in bone are constantly breaking the bone down in little areas and rebuilding it. This fixes any deterioration, allows the bone to grow, and aligns the structure with the current force lines."[45] Such a process of continuous turnover dynamically ensures the mechanical integrity of the skeleton throughout life.

Benyus's categorization of biomimicry into form, processes, and systems is important when investigating the potential for using biomimetics in IA. While biomimicry does not exclude designing a stadium that emulates the form of a bird's nest, or lily pads of solar panels floating on a river in an organic arrangement, such a direct imitation of form that precludes the processes and systems inherent in nature falls short of the definition being described here. A useful definition relies on a framework of recognizing the larger systems in which all design resides. The Center for Biologically Inspired Design (CBID) at Georgia Tech defines biomimicry as "systems" in nature, specifically design solutions that occur in biological processes.[46] The technology transfer from biology to architecture is inevitable and potentially profound in our profession as it becomes increasingly aware of its environmental impact. The next section looks into evolutionary systems from a systems approach as a means for the physical manifestation of IA as a living, evolving system.

The aim is to achieve the symbiotic behavior and metabolic balance found in the natural environment. To do so, architecture operates like an organism, in a direct analogy with the underlying design process of nature.

Evolutionary Systems

The view of evolutionary systems positioning architecture as a living and evolving system relies heavily on biological and scientific analogies, and the sciences of cybernetics, complexity, and chaos. Frazer outlines eight aspects of evolution, including development through natural selection, self-organization, metabolism, thermodynamics, morphology, morphogenetics, symmetry breaking, and the prevalence of instability. All of these aspects of evolution produce change at a variety of scales, and the basis of all such conditions is information.[47] The aim is to achieve the symbiotic behavior and metabolic balance found in the natural environment.

> Fig. **13**

The architectural world has initially embraced evolutionary systems from a computational generative design standpoint. The fascinating potential future of evolutionary systems as an integral part of actual built form is still in its infancy due to our current state of technological advance. With this said, many lessons have been learned from the integration of evolutionary systems in the design process. Most evolutionary models make use of generative computation, of which genetic algorithms are the most frequently used within the context of architecture.[48] According to Dipankar Dasgupta and Zbigniew Michalewicz, "The beginning of genetic algorithms can be traced back to the early 1950s when several biologists used computers for simulations of biological systems. However, the work done in the late 1960s and early 1970s at the University of Michigan under the direction of John Holland led to genetic algorithms as they are known today."[49] Genetic algorithms are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology. Generally defined here, genetic algorithms are implemented

> Fig. 13: Terry Knight, Professor of Design and Computation, Department of Architecture, MIT, and Larry Sass, Associate Professor of Design and Computation, Director, Digital Design and Fabrication Group, Department of Architecture, MIT, *Visual-Physical Design Grammars.*

The architectural world has initially embraced evolutionary systems from a computational generative design standpoint. The fascinating potential future of evolutionary systems as an integral part of actual built form is still in its infancy due to our current state of technological advance.

whereby candidate solutions to an optimization problem evolve toward better solutions. In the case of real organisms, if a developing embryo becomes structurally unviable, it won't survive natural selection. A similar process would have to be simulated in the computer to make sure that the products of virtual evolution are viable in terms of structural engineering prior to being selected by the designer for their "aesthetic fitness." This issue of designer selection brings up a discussion of shape grammars. Shape grammars are a specific class of computational production systems that generate geometric shapes. They are fascinating in that they present a basis for visual computation for design through shapes. The foundation of shape grammars in architectural design were introduced by George Stiny and James Gips in a seminal article in 1971.[50] With shape grammars, forms can be created that are not stored in the computer previously. They were one of the earliest algorithmic systems for creating and understanding designs directly through computations with shapes, rather than indirectly through computations with text or symbols. Shape grammars have been studied particularly in computer-aided architectural design, as they provide a formalism to create new designs. A shape grammar consists of shape rules and a generation engine that selects and processes rules. Color grammars, invented by Terry Knight in 1998, are an extension of a shape grammar that associates attributes (such as color, material, function, and architectural features) with shapes.[51] John Gero defined a high level of design representation with shape grammars, using them to "analyze and describe designs, and to create new designs that are similar in style to the designs the grammar is based on. The grammars are created by hand, involving a large amount of research about the designs and the design process."[52] He presented self-improving codes of a shape grammar, suitable for subsequent "evolution of house plans in a specific architectural style." José Duarte, in fact, created novel designs for Álvaro Siza's Malagueira housing project with a surprisingly simple grammar based on the original architect's work as a case study. His goal was the development of an interactive system for generating solutions on the web, based on a modeling approach called discursive grammar. A discursive grammar consists of a programming grammar and a designing grammar. Essentially, the programming grammar generates design briefs based on user data, the designing grammar provides the rules for generating designs in a particular style, and a set of heuristics guides the generation of designs toward a solution that matches the design brief.[53]

In a sense, evolutionary simulations replace traditional design generation and decision making, because designers can use such software to breed new forms rather than specifically design them.

At this point we should recall the discussion in "Design and the Profession" on heuristics whereby the design processes associated with such tools reposition the role of the designer: architects catalyze design rather than create a finished artifact. In a sense, evolutionary simulations replace traditional design generation and decision making, because designers can use such software to breed new forms rather than specifically design them. At a certain point, however, the designer must play a role in making design decisions. The point here is that we devise concepts and make comparisons not because they satisfy biological constraints, but because they satisfy cognitive constraints. The representational process becomes ever more important in the decision-making processes of design. If architects are to play a role in directing the development of the technology that affects interactive architecture, then they ought to ask what is architectural about computation, not the inverse.

Possibilities and Understandings

Future human interaction with the built environment is extremely difficult to predict, even as extrapolations of scientific facts, because it is ensnared by contradictions. Arthur C. Clarke gives a poignant example in his seminal book *Profiles of the Future*: "A really perfect system of communication would have an extremely inhibiting effect on transportation. Less obvious is the fact that if travel became nearly instantaneous, would anyone bother to communicate remotely?"[54] Although our current cities reflect somewhat of a parallel advance in both communication technologies and travel, a topic of great interest today is the effect that our current advances in telecommunications are beginning to have on urban built form. What would be the effect if our developments in travel had far outpaced those of telecommunications? The point is that advances in architecture are bound up with

Real interactive architectural applications lie in learning to articulate the dynamic possibilities of built form—in learning to think how an architectural environment can be empowered to adapt in a way that goes beyond a mere capacity to adapt.

technological advances in general; the former must continue to adapt and apply what is useful in the latter.

Architects should recall that not long ago commercialized electric light was thought impossible, that it was thought a man would suffocate on a locomotive if he were to travel at a speed exceeding thirty miles an hour, and, of course, the impossibility of flight. Relative to such technological developments within the not-so-distant past, our current state of affairs is not at all astonishing. While it seems every generation believes that theirs embraces unprecedented technological advance, they should always look at emerging technologies through the sobering lenses of history. The world of architecture is not experiencing a technological revolution, but it is increasingly involved in the fast-paced evolution of many of the disciplines from which it draws inspiration and finds proven precedents. The area of IA in particular is finally experiencing the technological and economic feasibility that makes it possible to manifest an area of intellectual thought that has been waiting in the wings for a long time. To a great extent, the success of IA will be built upon the real-world test bed. This test bed lies not in the world of academia and exhibits, but beyond, in the real built environment where humans live, work, and play. The result will be architecture of unique and wholly unexplored applications that address the dynamic, flexible, and constantly changing activities of today and tomorrow. Architecture is in its infancy from an application standpoint, and there are many lessons still to be learned. Real interactive architectural applications lie in learning to articulate the dynamic possibilities of built form—in learning to think how an architectural environment can be empowered to adapt in a way that goes beyond a mere capacity to adapt.

The possibilities in IA from the vantage point of a biological paradigm make the mechanical paradigm seem dated, ironically before it ever had a chance to fully manifest itself.

The End of the Beginning

While many of the interactive architectural projects presented earlier in this book were based on mechanical principles of adaptation, this last chapter described a number of developments and projects in related fields that are beginning to adopt biologically inspired principles that operate like organisms. A biological paradigm in IA requires more than just understanding pragmatic and performance-based technologies; aesthetic, conceptual, and philosophical issues relating to humans and the global environment must also be taken into consideration. Further, it repositions the role of the designer as a catalyst of design that evolves. The organic paradigm also reinterprets the scale at which designers work and view the world. This issue of scale is inherently tied to manufacturing and fabrication. In the recent past we have seen innovations in related fields deriving from electronic systems rather than manufacturing and fabrication, but now we are beginning to experience an explosion of innovation in manufacturing and fabrication that is heavily influenced by both biology and scale. The possibilities in IA from the vantage point of a biological paradigm make the mechanical paradigm seem dated, ironically before it ever had a chance to fully manifest itself. The notion of mechanical shading devices seems absurd no matter how intelligent the system is, when the glass itself can change opacity or tinting or UV resistance. The idea of small robots scaling a building to repair a facade or clean the glass seems absurd when the materials can heal themselves from decay and cracking like a bone remodels itself and the windows can utilize ultrasound to clean themselves. A mechanical device to scrape snow from a roof could be replaced by a material that heats itself and never allows snow to collect in the first place. IA has very quickly

IA has very quickly reached a point where technological aptitude is surpassing visionary imagination. IA as a field is not at the beginning, nor is it by any means at an end; but it is, in a sense, at the end of the beginning.

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reached a point where technological aptitude is surpassing visionary imagination. IA as a field is not at the beginning, nor is it by any means at an end; but it is, in a sense, at the end of the beginning.

While we cannot deny the relevance of interaction design in architecture, considering its increasing prevalence in recent years, it is still difficult to determine to what extent it is here to stay. The subject of IA still has many unanswered questions: Will it be robust enough to withstand failures and gain widespread acceptance? Will it ever become economically feasible enough to allow for the broad dissemination needed to bring about real change in areas of sustainability and other global issues? Will it make our buildings look any different? Will it impact how we actually use our buildings? It is more than likely that IA will accomplish all of the above, and yet ultimately fade to the background of our lives. In the same way that users do not think of how the structural system of a building works to hold the building up against physical forces, or how an HVAC system works to provide thermal comfort, IA systems will also disappear into our buildings and become the architecture itself. Interactivity will become truly seamless. Yet, while we can imagine all buildings integrating various interactive systems that are hidden within their fabric, we must also recognize that it is the responsibility of good design to express interactive architecture and therefore define its relevance.

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A new epoch has begun!

By enabling architecture to become sensate, intelligent, interactive, responsive, and adaptive, a number of developments chronicled in this book are resulting in the emergence of a new way of thinking and being. Nearly five decades ago, long before the computer or the internet became popular, Teilhard de Chardin prophetically proclaimed that human evolution was heading toward a global coalition of an interconnected world. He called such a world the *noosphere,* a world of interconnected human beings, a world much like the neural network of the brain. Deep and cybernetic connectivity is the essence of new interactivity. Through the new interactivity, architecture is becoming the gateway to noosphere!

Architecture of stone and brick has always been the one sphere of life that embodied a sense of timelessness, permanence, and massive inertia. Edifices of stone resist time and define a pattern of space for thousands of years. We no longer build our world in stone for a number of reasons. The notion of timelessness, however, has stayed rooted in the profession, its thinking, and what people expect to see embodied in architecture. Interactive architecture, in all forms of manifestation, represents a gradual shift away from that mindset. Architects are beginning to give up their millennial allegiance to the notion of timelessness. They are beginning to accommodate real-time responsiveness into a network of local forces and global conditions in a time-based environment. There is a crystallization of a desire for architecture to be thought of as an active, evolutionary, and interactive being. Interactive architecture is not about technology, but about revealing new possibilities of global relationships between architecture and people in forming a symbiotic noosphere. A building is a network for living in.

What if we are able to expand the ways by which we see, hear, touch and, sense information? What if we can release more people from the screen for more hours by distributing the interface around the architectural environment? What if the walls, floors, lighting, ventilation, and other facets of the architectural environment begin to communicate information to us and learn from interacting with us? What if architecture as a whole becomes a distributed, immersive interface to connect us to the larger world? What if architecture becomes a spatial synesthetic pump to channel, amplify, and process the temporal flows of digital information? What if, in a break with the past, walls, roofs, and floors transcend being mere delimiters and separators of contiguous space, to becoming connectors of global *telespace*? Interactive architecture begins to question the ontology and epistemology of architecture by embracing physical and telematic space-time. So, the question now becomes not "how do we know architecture" but "*how does architecture know us*?"

—Mahesh B. Senagala

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