Catching up with the Past:
A Small Contribution to a Long History of Interactive Environments

Michael Fox

Introduction: introspection

I've been interested in interaction design in architecture for quite some time now; back to the time when I taught my first course in the late 1990s where the students used LEGO bricks for making little robotic architectural models. That was all we had back then; but the important point is - we did have something, finally, from the standpoint of tools that we could design with. In trying to understand why this journal issue in 2010 is dedicated to a subject matter that is really quite old historically, I speculate that the resurgence in this area has a lot to do with the current accessibility of the design and prototyping tools available to the profession of architecture. Only recently do architectural designers have tools that are both technologically and economically accessible for developing ideas in interactive architecture. We in architecture usurp what we can. Designing interactive architecture in particular is not inventing, but appreciating and marshalling the technology that exists, and extrapolating it to suit an architectural vision. Only recently do we see courses in interaction design and robotics being taught in schools of architecture all over the world whereas twenty years ago there were less than a handful. The illusion is that the field is fresh with new ideas illuminated by a wealth of built prototypes and real projects. While there are some genuinely new developments in terms of technology transfer in the areas of Interface Design, Autonomous Robotics, Biomimetics, etc. that will foster advanced thinking in the field, it is important to understand that the foundations have been around for quite some time.

In writing this article, I have attempted to humbly step back and look at my own development in the area within the context of a much larger historical context. In retrospect, after nearly 15 years in the area, I did find the development to take a number of clear steps in a relatively logical progression. In summary, the journey began with kinetics as a means to facilitate adaptation. Work in this area led to integrating computation as a means of controlling the kinetics. The combination of these two areas led to the use of discrete mechanical assemblies as a systems approach to interaction design, which led to the thinking of control as bottom-up and emergent. Consequently I became fascinated with modular autonomous robotics and the notion that actual architectural space could be made of such systems. This in turn led to the exploration of biomimetics in terms of the processes, which eventually led to the idea that the parts in a system should get smaller to the point that they make up the matter itself. This leads us to where I am today, how I have evolved my thinking in interaction design over the years with students and my office. I am not sure where it goes from here - but at least it is interesting to explore.

Gordon Pask and cybernetics

I cannot really begin to describe my own development without a brief description of the historical context within which it lies. Essentially the theoretical work of a number of people working in cybernetics in the early 1960s laid most of the foundations in interactive architecture. At this time, Gordon Pask and other cyberneticians, including Norbert Weiner,

made advancements toward understanding and identifying the field of interactive architecture by formulating their theories on the topic [fig. 1, 2]. Pask's 'Conversation Theory', served as the basis of much of the architectural development in interactive architecture at the time.[1] Essentially a model was developed in which architects interpreted spaces and users as complete feedback systems. Although recently Pask has been 'rediscovered' by the architectural community, he did fade away for quite some time. Pask's trouble was for the most part a lack of marketing potential in his physical proof-of-concept models. In general, it was also difficult for him and others at the time to get funding for anything that was not directly related to development of the digital computer including research in AI and cybernetics such as neural nets, evolutionary programming, 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.[2] Hence the work in these areas was not generally well funded, and therefore not prototyped, published, and disseminated. It did develop theoretically however in the late 1960s and early 70s by the likes of William Brody, Nicholas Negroponte, Charles Eastman, Andrew Rabeneck and others who expanded upon the earlier ideas explored in cybernetics by Pask and Weiner. Without going into any detail here, most of this theoretical work concerned interactive feedback systems related to adaptability.

Some early architects take interest
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. The main problem at this time however was that the computational means were not evolved to the extent that proliferation of concepts in cybernetics could take a strong foothold. In general it remained in the realm of 'paper architecture'. Cedric Price was perhaps the most influential of the early architects to adopt the early theoretical work in cybernetics and extend it to

an architectural concept of 'anticipatory architecture' [fig. 3]. Many of his unbuilt projects influenced architecture of process that was indeterminate, flexible, and responsive to the changing needs of users and their times.[3] John Frazer extended Price's ideas, in positing that architecture should be a 'living, evolving thing' [fig. 4]. It's important to note that Price and Frazer both worked directly with Pask in developing their work over many years. John Frazer continued his work in the field for nearly thirty years with students at the Architectural Association in London[4] and other collaborators and summarised it in the book *An Evolutionary Architecture*, with an introduction by Pask himself. His work focused heavily on biological and scientific analogies and the sciences of cybernetics, complexity, and chaos. Although not in the same league as the others mentioned here, I worked for Fraser who subsequently became a strong influence in developing my own ideas.

Intelligent environments develop in parallel
While the architects were developing the ideas above based on cybernetics, it is important to also understand that there was another area being developed almost in parallel in digital computation and human interaction. In the late 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. A lot of technologies were developed in this area which dealt with sensing and human behaviours, but the architecture was always secondary as developed under the mantra of 'seamlessly embedded computation'.[5] In other words there was very little architectural involvement in a very exciting area that was developing computationally-enhanced environments. These developments were essentially fuelled by the concept of 'ubiquitous computing'

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Fig. 4

Fig. 1: Gordon Pask
Fig. 2: Norbert Weiner
Fig. 3: Cedric Price
Fig. 4: John Frazer

which was originally defined as a general concept for computation which is thoroughly integrated into everyday objects and activities, and sits at the intersection of computer science, behavioural sciences, and design.[6]

Corporate interests also develop in parallel

Corporate interests also developed market-driven roles which began in the late 1950s and 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. These cultural and corporate interests played major roles in influencing computationally-enhanced environments through the development of numerous market-driven products and systems that directly involved users in the real world. Computationally-driven environmental control systems were developed within buildings as a direct derivative of the introduction of sensors with remote signalling allowing for a central control room.[7] 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. In the 1970s 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. In the 1980s, 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.

Eventually architects usurp enough to make something

In the 1990s everywhere you turned there was a 'smart home' and 'smart workplace' project being initiated that relished the newly 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 fuelled experimentation with many of the ideas of the early visionary architects and theoreticians outlined above that had been stifled by the technological and economic hurdles of their day. It was at this time that the economics of obtaining cheap computational hardware and increased aptitude to integrate computational intelligence into architecture began to be reinvestigated by architects. 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.

My work begins with kinetics as a means to facilitate adaptation…

So it was then in line with the long context outlined above essentially where my work began. I began to re-examine the long history of kinetics in architecture under the premise that performance could be optimised if it could use this newfound computational information and processing to physically adapt.[8] In retrospect I developed an interest in interactive architecture in somewhat of an opposite way than one might expect today. I founded a research group at MIT that was focused on kinetic solutions in architecture and how such systems can facilitate adaptability. After exploring numerous kinetic projects with this focus on adaptability, such as the Abbot Fence [fig. 5] and the Auto Lift [fig. 6], it became an obvious next step that such spaces and objects should be coupled with some sort of digital sensing and actuation that can allow them to reconfigure themselves. I say I came about this topic in a roundabout way because today, when we have these 'smart' environments everywhere, the obvious route would be to say that we have this space that is really smart; that understands the environment
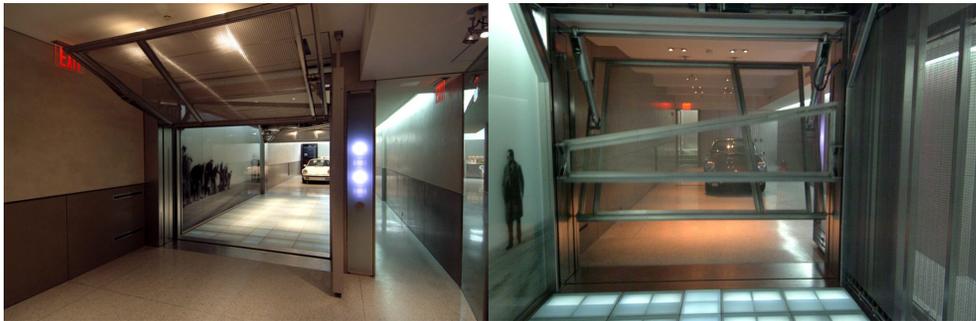
Fig. 5

Fig. 6

Fig. 5: Abbot Fence, Mechanical kinetics - Project by Foxlin.
Fig. 6: Auto Lift, Mechanical kinetics - Project by Michael Fox and RoArt.

inside and outside and understands various data about the users including behavioural patterns, but what is it doing? What is it, or can it, physically do in an architectural way to adapt? I was also very interested in the premise that performance could be optimised if it could use computational information and processing to control physical adaptation in new ways to respond to contemporary culture.

…which led to integrating computation as a means of controlling the kinetics

Relative to the time kinetics has been around in architecture, embedded computation (EC) is in a state of relative infancy. 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 combination of embedded computation and kinetics is necessary to allow an environment to have the ability to reconfigure itself and automate physical change to respond, react, adapt, and be interactive. Advancements in the technology involved with hardware has begun to 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. 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 embedded computation, and not the other way around.

With this in mind, I began to develop a number of projects dealing with both pragmatic and humanistic needs. Many of these projects, such as the iSpa [fig. 7] and the iZoo [fig. 8], were full-scale interactive environments developed by students at various universities. Within these environments, each system in a space is responding not only to the people in the space but also to the behaviours of the other systems. These individual systems 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.

…which led to thinking of systems as discrete mechanical assemblies

Extending the notion of thinking of a room then as a collective whole with different specific task systems, the idea was that each system itself became an assembly as well. Rather than a single skylight with a limited range of capabilities, the skylight could itself become an assembly with a far greater range of inherent capabilities. I developed numerous projects with students at this time exploring such systems of control including the Ex-Com Cubes project [fig. 9] and the large human scaled Flock-Wall exhibit [fig. 10]. The important point is that each individual actuating device is then controlled by a decentralised controller at a local level. This model of decentralised identification and control is based on neural networks and simplifies the implementation of the control algorithm. Decentralisation is valuable on a number of points. In creating many self-similar parts, there is a redundancy in terms of control, an economic savings in terms of mass-production and an increased robustness to failure, in that if any single part fails, the system as a whole does not fail. When there are many unknown stimuli, such as groups of individuals behaving in unknown ways and an exterior environment which is constantly changing, then decentralised intelligence can be a very effective way to handle the sensing and response (perception and action).

…which led to the thinking of control as bottom-up and emergent

I began then to develop a number of projects based on decentralisation which forced a new outlook on how the control of these systems should be dealt with. It was also important that these projects, including the Bubbles [fig. 11] and Neural Sky [fig.

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Fig. 7: iSpa - Interactive Environment Developed in Architectural Robotics Course at Art Center College of Design
Fig. 8: iZoo - Interactive Environment Developed in Architectural Robotics Course at SCI-ARC
Fig. 9: Ex-Com Cubes - Interactive Exhibit Developed in Architectural Robotics Course at Hong Kong Poly U.
Fig. 10: FlockWall - Interactive Environment Developed in Architectural Robotics Course at Cal Poly Pomona

12], were large enough to understand real human interactions and that they were up long enough to understand emergent behaviours. Most architectural applications are neither self-organising nor do they have higher-level intelligence functions of heuristic and symbolic decision-making abilities. Most applications do, however, exhibit a behaviour based on low-level intelligence functions of automatic response and communication. When a large architectural element is responding to a single factor then a centralised system can be effective in executing a command to a single agent, but when there are many unknown stimuli, or many small autonomous parts, then decentralised intelligence is the most effective way to handle the sensing and response. The more decentralised a system is, the more it relies on lateral relationships, and the less it can rely on overall commands. In a decentralised system there is normally no centralised control structure dictating how individual parts of a system should behave, local interactions between discrete systems therefore often lead to the emergence of global behaviour. The idea of behaviour that emerges became very interesting to me and I began to explore this idea in very simple ways through a number of projects. An emergent behaviour can occur when a number of simple systems operate in an environment that forms more complex behaviours as a collective. The rules of response can be very simple and the rules for interaction between each system can be equally simple, but the combination can produce interactions that become emergent and very difficult to predict.

…which led to the idea that architectural space itself could be made of robotic systems
I began moving away from developing traditional uses of automated mechanical devices in architecture to looking at the potential of transformable systems that are made up of a number of small robots. I taught numerous design studios in which students developed modular autonomous robotic modules [fig. 13, 14] that served as the base building blocks for architectural explorations. Manufacturing technologies compounded with recent advancements in software (computational intelligence) allow the robotic parts in these systems to be increasingly smaller and smarter. Current manufacturing technologies have allowed microprocessors to grow increasingly smaller, cheaper, and more powerful and we are seeing that we now have the potential to think of space itself as being organised in a computational network. For many applications ranging from cleaning carpets and windows to adjustable furniture, we are seeing a distancing from the precedent of figural humanoid robots to transformable discrete systems. Current advancements in self-assembling robots, specifically dealing with the scale of the building block and the amount of intelligent responsiveness that can be embedded in such modules, are setting new standards for robotics. These new standards are extremely exciting in light of the role of autocatalytic processes, defined here as a reaction product itself being the catalyst for its own reaction. In the context of modular reconfigurable robotics such processes describe how the pace of technological change is accelerating because of these processes. In other words, the process is 'autocatalytic' in that smart, articulate machines are helping to build even smarter, more articulate ones. The potential is that in the near future, modular reconfigurable space could hugely impact the way people live in space, and the relationships between users and the space itself. Then if it is possible to build space out of parts that have the ability to reconfigure themselves, it is really 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. So then in light of the potential of autocatalytic processes, robotics in architecture 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.
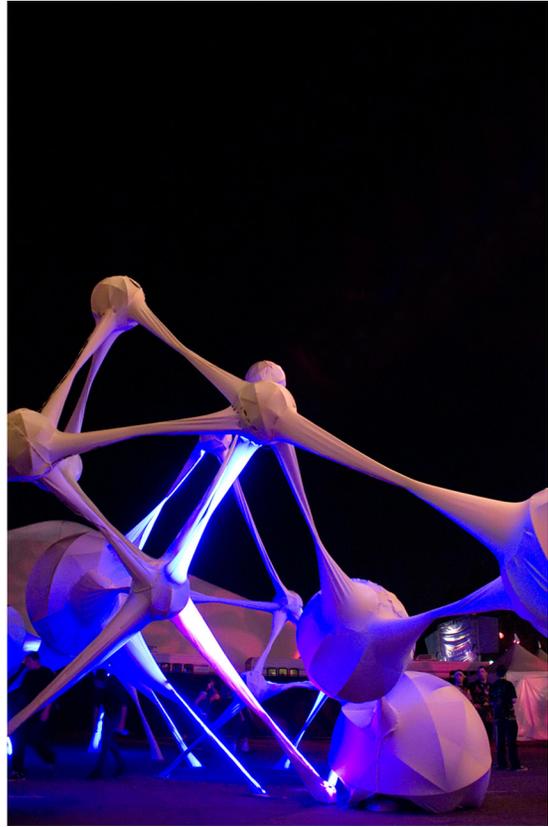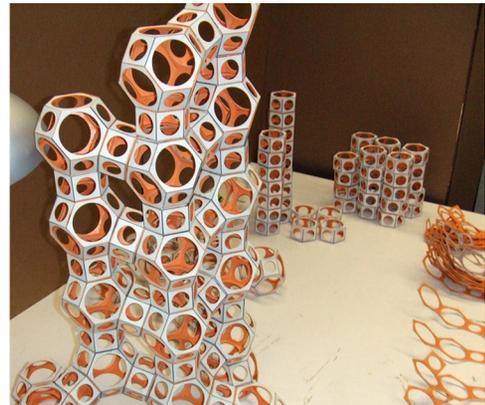
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Fig. 11: Bubbles, Interactive Environment - Project of Foxlin

Fig. 12: Neural Sky - Interactive Environment Developed in Architectural Robotics Course at Cal Poly Pomona

Fig. 13: Modular Autonomous Robotic Module Components - Student project at Cal Poly Pomona

Fig. 14: Modular Autonomous Robotic Module Components - Student project at SCI-Arc

…which led to the exploration of biomimetics in terms of processes

I became fascinated at this point by modular autonomous robotics that had the potential to reproduce themselves. New available technologies like the fab@home 3-D printer, which has the capacity to print with a wide palette of materials, and mobile CNC routing robots became the inspiration for what might be possible architecturally with modular robotics. With the possibilities of such new CNC processes, I directed several studios under this premise of what I call 'redesigning the brick'. The heuristic approach is very bottom-up, in that you first design the brick (robotic module) and then the architectural possibilities are very much influenced by the inherent possibilities and limitations of that particular module. These modules began with nature as an inspiration for how they could adapt [fig. 15, 16].

Consequently this approach led directly to an exploration into biomimetics. I was interested in architectural systems that could operate like an organism, directly analogous with the underlying design process of nature. Architectural robotics utilised at such a level could allow buildings to become adaptive much more holistically and naturally on a number of levels. Biomimetics 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. Put simply, nature is the largest laboratory that ever existed and ever will.

Understanding the processes by which organisms grow, develop and reproduce then became an invaluable precedent for how such small mechanisms in an architectural environment could potentially operate. 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 organised spatial distribution of cells, is particularly relevant.

The important thing here is that such systems reposition the role of the designer. As Gordon 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.'[9] While such ideas have been around for quite some time in the architectural world in terms of scripting, generative design etc., biomimetic possibilities seem very different as they have the potential to affect the architecture itself after it is built. I am not saying that we are going to see buildings made of computational sand anytime soon but it has become hard-science fiction and therefore quite easy to speculate fascinating potential futures based on extrapolating existing technologies.

…which led to the idea that the parts in a system should get smaller to the point that they make up the matter itself

It seems we are nearing the end of large-scale architectural robotics before we ever got a chance to really know it. Just at the time when we are starting to see many built projects come to fruition, it seems that any application of mechanised robotics in architecture is starting to seem very quickly outdated. The notion of an embedded mechanical shading device seems absurd no matter how intelligent the system is, when the glass itself can change its visible transmittance, reflectance, or UV resistance. The idea of small robots scaling a building to repair a facade or clean the glass seems equally absurd when the materials can heal themselves from decay and cracking like a bone remodels itself and the windows can utilise an internal strategy such as creating ultrasonic vibrations 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. Not long ago a futuristic paradigm for interac-
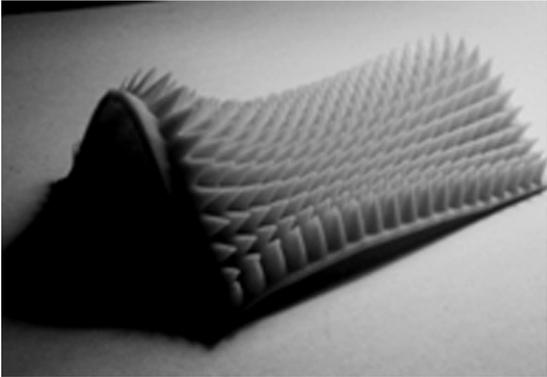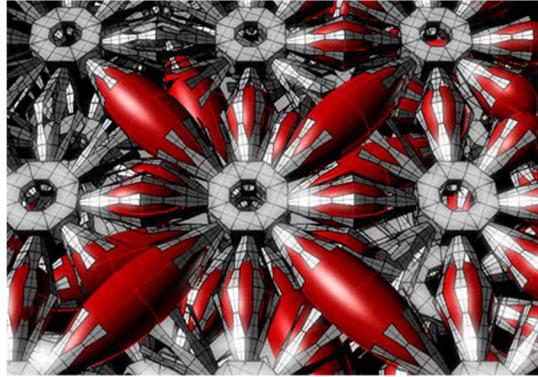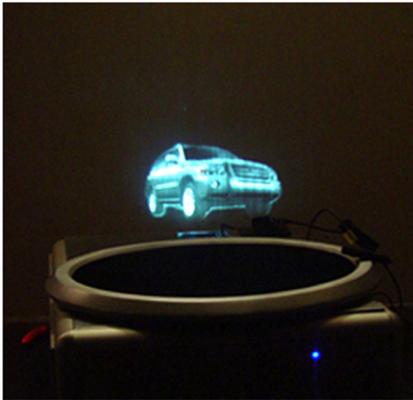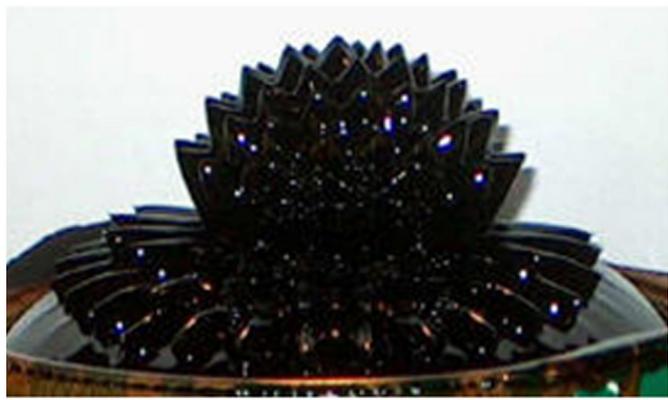
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Fig. 18

Fig. 15: Biomimetic Module - Student project at Cal Poly Pomona
Fig. 16: Biomimetic Module - Student project at Cal Poly Pomona
Fig. 17: HelioDisplay, Interactive 3-D display system - Developed by Foxlin
Fig. 18: Nanocity Exhibit, Robotically controlled interactive forms in ferrofluid - Project of Foxlin

tive architecture seemed visionary if the whole of a building had kinetic potential and was computationally controlled and networked to adapt to any architectural scenario. The problem with this vision today is one of scale: it is focused on a building as a composition of discrete systems or devices rather than on the potentials of the materials that compose the building. My office was fortunate to develop several projects that served as inspiration for the scale of robotics in architecture such as the Helio-Display interactive 3-D display system [fig. 17] and the Nanocity project [fig. 18].

We must change our general preconceptions of robotics with respect to scale to understand the potentially profound role in architecture. To illustrate, let's use the example of a smart kitchen with an 'intelligent' mechanical countertop which can raise and lower itself when needed and a smart cabinet above which can assist you in retrieving food items as desired. Both the countertop and the cabinet understand the actions of each other and while only one may deduce a response based on environmental sensing, the other may operate accordingly based on the actions of the other device. For example, as the countertop senses the height of an individual it may lower itself to accommodate a specific food preparation need, and the cabinet will use the information of the countertops' action and lower itself and organise the food items accordingly to a learned pattern of behaviour of what the person typically eats at a specific time of day. The above scenario, while perhaps not commonplace, is very realistic and achievable by today's technological means. Let's expand the scenario further now by imagining that both the countertop and the cabinetry are not mechanically-driven 'devices' but are rather composed of thousands of smaller mechanical modules (the size of dice) which make up the devices themselves. The distributed sensing and control would now happen not at the level of the countertop and the cabinetry but at the level of each of the tiny modules. The geometrical flexibility,

sensing capabilities and robustness of each of the larger 'devices' would then be greatly enhanced. Let us then extend the example above once again whereby the countertop and the cabinet are not composed of small modules but are composed of bionanotechnological materials which can morph their shapes to adapt at a very high degree of resolution. The materials are not veneers to traditional devices but are the fabric of the devices themselves with sensing and control operating biomimetically at a very small scale. At this level the countertop and cabinet can control additional attributes such as temperature, texture, colour, opacity, etc., and potentially then large-scale kinetics as well. Large-scale kinetics can and will also still be possible but they will actuate much more holistically which takes a bit of a change in mindset to conceptualise. An example might be that rather than a cabinet door opening by a traditional computer-controlled linear actuator rotating the static door on hinges, the door would essentially be one with the wall and all along the seam of rotation would be thousands of very small hinges which could be actuated by means of hydraulics much like the stem of a plant. The point is to think of modular autonomous robotics scaled down to the point of becoming the material itself. Several transformational materials have already been developed which demonstrate exciting potential, particularly in the area of fabrics and polymers. A new robot developed by 'iRobot' for instance, can change its shape and squeeze into tight places using a concept called 'jamming skin-enabled locomotion'. The potential attributes of kinetics working at such a very small scale can extend beyond strictly facilitating needs, to simultaneously engage a wide range of human sensory perceptions. These new interactive assembly systems will bring new unprecedented levels of customisation and reconfigurability to the architectural palette

Such an extrapolation of advancements in both robotics and new materials demonstrates an architectural future whereby adaptation becomes much

more holistic and operates on a very small internal scale.

Conclusion

In conclusion, technical advancements in manufacturing, fabrication and computational control will continue to expand the parameters of what is possible in robotics, and consequently influence the scale by which we understand and construct our environments. This scaling down is beginning to force a reinterpretation of the mechanical paradigm of adaptation. The future of interactive environments will most certainly involve re-examining the scale by which things operate to the extent that much of the operations happen within the materials themselves. In many cases traditional mechanical applications seem to be approaching the beginning of the end. Ironically, I came about these conclusions with a foundation in strictly mechanical typologies. While I believe that there is a great aesthetic honesty and dynamic appeal to mechanised kinetics in architecture, the potential benefits of a biological paradigm seem to outweigh those of the traditional mechanical paradigm. It is also important to remember that I am not advocating the end of mechanics, but simply a reinterpretation of the scale of the mechanics. Mechanics then are interpreted more literally as biologic rather than mechanical in the sense of a machine.

I am very excited to witness the explosion of interest in interactive architectural environments, but caution that such should be pursued with an understanding of the inclusive historical context which laid the foundations in this area quite some time ago. Designing such environments is not inventing after all, but appreciating and marshalling the technology that exists at any given time, and extrapolating it to suit an architectural vision. As we continue to expand the possibilities of what is possible today with the accessibility of new tools we can begin to catch up with the past.

Notes

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Biography

Michael Fox is the founder and a principal of Fox Lin Inc. in Los Angeles, California. In 1998, Fox founded the Kinetic Design Group at MIT as a sponsored research group to investigate interactive architecture. Fox directed the group for three years. His practice, teaching and research are centred on interactive architecture. He is an associate professor at Cal Poly Pomona and has taught previously at MIT, The Hong Polytechnic University, Art Center College of Design and SCI-Arc in Los Angeles. Michael Fox is the author of the book *Interactive Architecture* published by Princeton Architectural Press.