Beyond Kinetic

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"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."
-Guy Nordenson, Ove Arup and Partners

"If a building could mediate our needs and the environment outside: Its demand on physical resources could be slashed. If it could transform to facilitate multi-uses: Its function would be optimized. If a building could adapt to our desires: It would shape our experience."
-Anonymous

Abstract. This research develops a foundation for the application of embedded computation as a means to enhancing the performance of kinetic systems in architecture. The motivation lies in creating spaces and objects that can physically re-configure themselves to meet changing needs. The paper is focused on responsive spatial adaptability and also explores multi-use applications and automated kinetic response with respect to changing environmental conditions. The research illustrates six typological means of controlling kinetic motion in architecture from simple biometric control to high-level self-learning control. We demonstrate how high level kinetic systems can integrate a heuristic or learning capacity into the control mechanism. Such systems can learn through successful experiential adaptation to optimize a kinetic system or spatial form of an environment in response to change. When we look at the high levels of computer controlled kinetic systems behaviors an interesting phenomenon can also be observed with respect to actual physical built form. What we are describing is a structure as a mechanistic machine that is controlled by a separate non-mechanistic machine: the computer. In a sense, creating a building like a body with a system of bones and muscles and tendons and augmenting that body with a brain that knows how to respond. In numerous applications then, much of the structure can be reduced through the ability of a singular system to facilitate multi-uses via transformative adaptability. The paper highlights several built examples by the author of kinetic systems with embedded computational intelligence and builds upon this precedent through identifying applications of both transformable kinetic objects occupying predefined physical space as well as how moving physical objects can share a common physical space to create adaptable spatial configurations.

INTRODUCTION

Our capabilities of utilizing kinetics in architecture today can be extended far beyond what has previously been possible. This article looks at the potential of advanced kinetic architectural systems; what they are, what they can do for us, and how we can go about designing them. Advancement will only be accomplished when kinetic structures are addressed not primarily or singularly, but as an integral component of a larger system that takes advantage of today's constantly unfolding and far-reaching technology. Necessary are the use of advanced computational design tools, material development and embedded computation. It is important to point out that this article shall remain safely grounded in science-fact and not science fiction. In other words, to make convincing extrapolations based on where we stand today through inclusively appreciating and marshalling correctly the existing facts with respect to technological development. The irony is that from an architectural standpoint we are in a relative infancy even with respect to our extrapolations, further exacerbating the matter is the foolishness to name what we are experiencing in terms of general technological advance as a revolution; it is an evolution, to which an end cannot be predicted outside the parameters of political and economical entanglement.

Prior to explicitly defining why advanced kinetic architectural systems will be useful or even necessary, we will state simply that the motivation lies in creating spaces and objects that can physically re-configure themselves to meet changing needs with emphasis on the dynamics of architectural space. Such systems arise from the isomorphic convergence of three key elements: structural engineering, embedded computation and adaptable architecture as situated within the contextual framework of architecture.

Kinetic Architecture: a definition

Concerns in structural engineering will focus explicitly upon kinetic design. Kinetic architecture is defined generally as buildings and/or building components with variable mobility, location and/or geometry. Structural solutions must consider in parallel both the *ways and means* for kinetic operability. *The ways* in which a kinetic structural solution performs may include among others, folding, sliding, expanding, and transforming in both size and shape. *The means* by which a kinetic structural solution performs may be, among others, pneumatic, chemical, magnetic, natural or mechanical.

Kinetic Typologies

Kinetic structures in architecture are classified here into three general categorical areas:

Embedded Kinetic Structures

Embedded Kinetic structures are systems that exist within a larger architectural whole in a fixed location. The primary function is to control the larger architectural system or building, in response to changing factors.

Deployable Kinetic Structures

Deployable Kinetic structures typically exist in a temporary location and are easily transportable. Such systems possess the inherent capability to be constructed and deconstructed in reverse.

Dynamic Kinetic Structures

Dynamic kinetic structures also exist within a larger architectural whole but act independently with respect to control of the larger context. Such can be subcategorized as Mobile, Transformable and Incremental kinetic systems

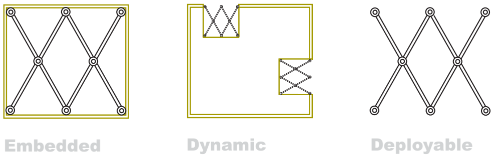


Fig. 01: Diagram of Kinetic Typologies in Architecture

Controlling Kinetic function

The *ways* can be described diagrammatically as mechanical motions. Contemporary innovators such as Chuck Hoberman and Santiago Calatrava continue to demonstrate that the last word has not been spoken in novel kinetic implementation at an architectural scale. Yet, we as designers ought to focus our attention in this area upon the vast wealth of resources that have been accumulated over numerous centuries of engineering. 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. Materiality will prove to be the one great promise for advancement in this area primarily as a result of technology providing both an unprecedented vision into microscopic natural mechanisms and advanced manufacturing of high quality kinetic parts with new materials such as ceramics, polymers and gels, fabrics, metal compounds and composites with unprecedented structural properties. The integrative use of such materials in kinetic structures facilitates creative solutions in membrane, tensegrity, thermal, and acoustic systems.

Embedded Computation

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 non-mechanistic devices. Today it does not take much effort to extrapolate existing computation as a means for kinetic actuation. We are rapidly approaching a time where the integration of embedded computation and kinetic function becomes a practical and feasible reality.

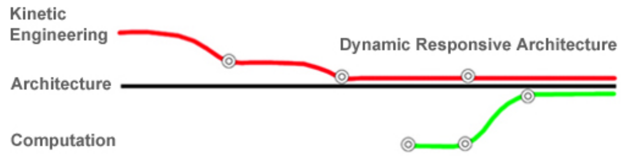


Fig. 02: Intersection of Embedded Computation and Kinetic Architecture, Diagram by MIT KDG

When we look at the major trends in computation we see a clear transition of three general human-computer relationships. Initially there was the use of one computer (mainframe) by many people. This evolved to a one on one relationship with computers. As this article is written, we are witnessing a trend towards one person using many computers. This relationship was coined "Ubiquitous computing" by Mark Weisner of Xerox PARC in 1988. Ubiquitous computing forces the computer to live out in the world with people but at the same time, will recede into the background of our lives. The concept of Ubiquitous computing integrates human factors, computer science, engineering, and social sciences. We are at a time when Metcalfe's Law (which states that the network benefit increases as a square of the # of connected devices) is starting to replace Moore's Law (which states that CPU performance doubles every 18 months) as the driving force behind the development of computational devices.

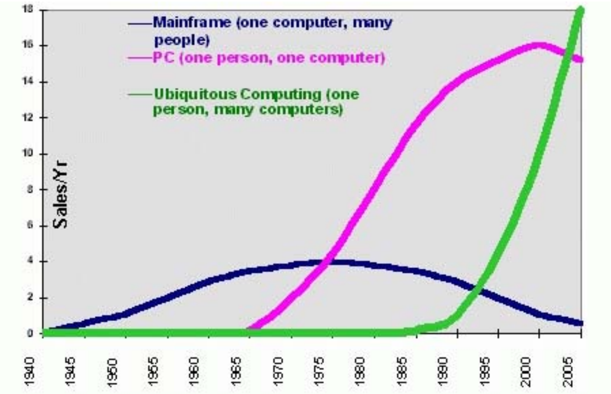


Figure 03. The Major Trends in Computing, Graph by XeroxPARK

6. Extrapolating Precedent in Embedded Computation

What then are the implications of ubiquitous computing to built form? From an architectural standpoint, embedded computation has taken an interesting foothold. Work in embedded computation has arisen primarily out or the field of computer science, reaching into the sub disciplines of both artificial intelligence and robotics. The research has come out of both academia and the corporate world and there are currently numerous precedent examples of embedded computation in that have begun to define a field now known as intelligent environments (IE). The projects cover a diverse range of scales; from the Biosphere2 project which is arguably the most sophisticated building constructed by man, to the Adaptive "Neural Network" House in Colorado.

Figure 04. Biosphere2 by Columbia University

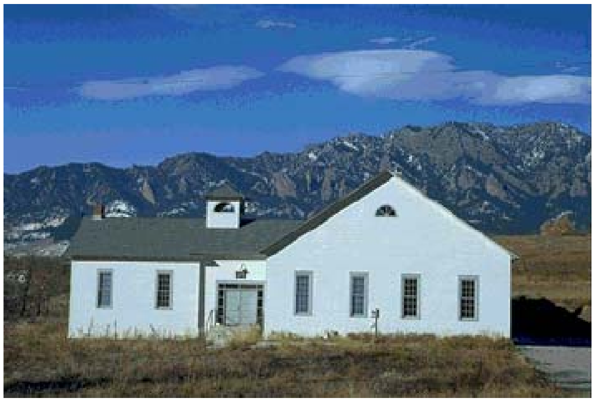


Figure 05. The Adaptive House by The University of Colorado

Ironically the most sophisticated intelligent environments built to date have been constructed for space travel where the environmental conditions are extreme yet relatively constant and yet a residential house in Phoenix, Arizona typically could not be identified as different from one in Anchorage, Alaska. The primary goal of intelligent kinetic systems should be to act as a moderator responding to change between human needs and environmental conditions. The primary target clientele for research in Intelligent Environments has been the military, the elderly and the handicapped, typically in that order. Not surprisingly, the vast majority of the work has been both highly tectonic in dealing with recognition tasks such as Speech, Gesture, Motion, and the Environment while focused on managing human interactions and novel applications of Internet Technology

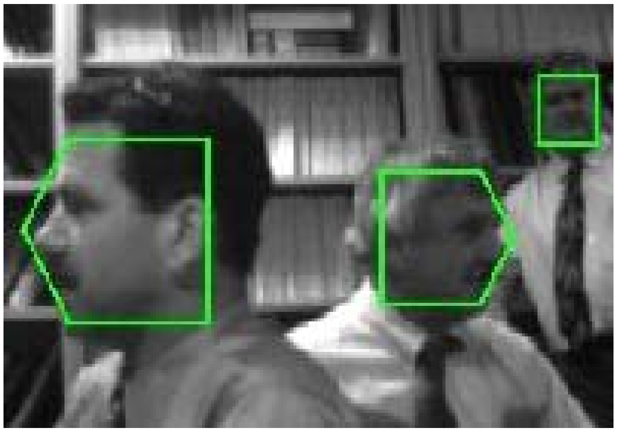


Figure 06: Specialized Tasks in Embedded Computation Research. Carnegie Mellon

Figure 07: Specialized Tasks in Embedded Computation Research. Vision & Autonomous Systems Center and Georgia Tech: Future Computing Environments Group

The motivation for such research lies in embedding computers in ordinary environments so that people can interact with them the way they do with other people; in other words it is aimed at enhancing everyday activities. The major problematic of what has been accomplished outside the field of architecture is the myopic nature of enhancing everyday activities. When embedded computation is employed to control physical built form the most obvious application should be to foster an extension of manual capabilities. With due respect to the advantages such systems can provide to the elderly and handicapped they are at best equalizing the current advantages of built form, and not extending them. Architects need to design with an understanding of the current capabilities of embedded computation that have attained sufficient maturity to act as independent subsystems that can be beneficially incorporated into kinetic design. A consequent result of this motivation has been to create a seamless integration of computation into the built environment. It transcends a question of aesthetics to ask if embedded computation should be hidden from the users that inhabit an intelligent space or if there is due an honest expression of form where computation is embodied.

Another relevant area coming out of the field of computer science is research into the development of robots. Unfortunately, while highly sophisticated, robots are typically autonomous with respect to the built form they inhabit and tend to be fixed function devices. Not only should robots become mutating, multi-function machines but also they need to be developed with respect to the architectural built form they inhabit. If the architecture itself were embedded with the intelligence of a robot with the capability of completely controlling the built form, then the development of single-task autonomous robots would by all practical means be rendered negligible.

Perhaps the most applicable research to draw upon in designing intelligent kinetic systems lies in an area of study within Active Control Research that focuses upon the design of structures to control the movements of a building through a system of tendons or moving masses tied to a feedback loop to sensors in the building. Changes are brought about by both environmental and human factors and may include axial, torsion, flexural, instability and vibration and sound. Such systems have been successfully employed in numerous large buildings situated in high-wind or earthquake-prone locations.

Controlling Kinetic Function by Computational Means

Precedent in embedded computation will serve as a foundation for the explicit means of controlling kinetic motion. Such means can be described diagrammatically as the controlled source of actuation. Specifically we are interested in addressing embedded computation as a control mechanism for kinetic function to accommodate and respond to changing needs. Such systems will be utilized to interpret functional circumstances and direct physical movements to adaptively better suit changing human needs. The issue of controlling kinetic motion is central to issues of design and construction techniques, kinetic operability and maintenance, as well as issues of human and environmental interaction.

Outlined below are the six general types of control, which can possess both centralized and decentralized case-specific advantages:

Internal Control

Systems in this category contain an internal control with respect to inherent constructional rotational and sliding constraints inherent. In this category falls architecture that is deployable and transportable. Such systems posses the potential for mechanical movement in a construction sense, yet they do not have any direct control device or mechanism.

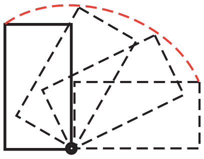


Fig. 08a: Diagram of Internal Control

Direct Control

In this category, movement is actuated directly by any one of numerous energy sources including electrical motors, human energy or bio-mechanical change in response to environmental conditions.

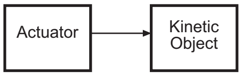


Fig. 08b: Diagram of Direct Control

In-Direct Control

In such systems, movement is actuated indirectly via a sensor feedback system. The basic system for control begins with an outside input to a sensor. The sensor must then relay a message to a control device. The control device relays an on/off operating instruction to an energy source for the actuation of movement. We define In-direct control here as a singular self-controlled response to a singular stimulus.

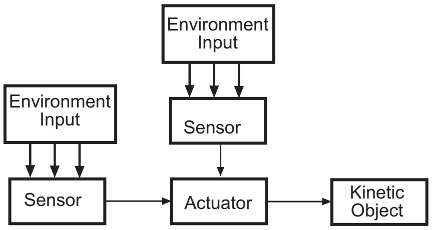


Fig. 08c: Diagram of In-Direct Control

Responsive In-Direct Control

The basic system of operation is the same as in In-Direct Control systems, however the control device may make decisions based on input form numerous sensors and make an optimized decision to send to the energy source for the actuation of movement for a singular object.

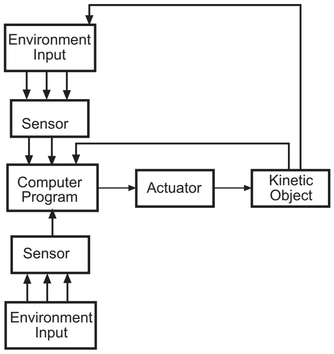


Fig. 08d: Diagram of Responsive In-Direct Control

Ubiquitous Responsive In-Direct control

Movement in this level is the result of many autonomous sensor/motor (actuator) pairs acting together as a networked whole. The control system necessitates a "feedback" control algorithm that is predictive and auto-adaptive

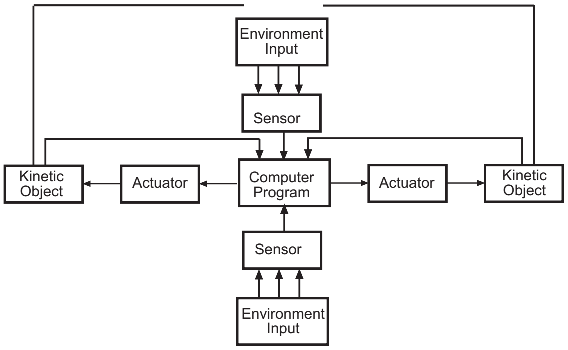


Fig. 08e: Diagram of Ubiquotous Responsive In-Direct Control

Heuristic Responsive In-Direct control

Movement in this Level builds upon either singularly responsive or ubiquitously responsive self-adjusting movement. Such 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.

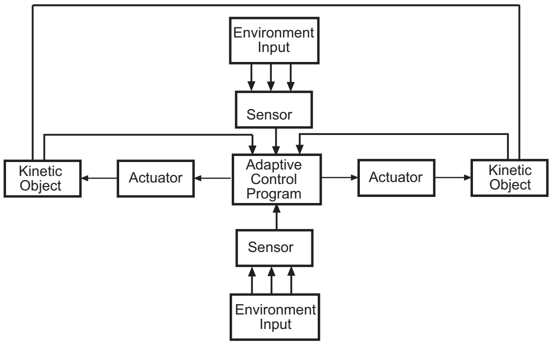


Fig. 08f: Diagram of Heuristic, Responsive In-Direct Control

Novel Applications for Kinetic Adaptability

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. Adaptability is taken in the broadest sense to include issues such as spatial efficiency, shelter, security and transportability. Such systems that are inherently deployable, connectable and producible are ideally suited to accommodate and respond to changing needs. An adaptable space flexibly responds to the requirements of any human activity from habitation, leisure, education, medicine, commerce and industry. Novel applications arise through addressing how transformable objects can dynamically occupy predefined physical space as well as how moving physical objects can share a common physical space to create adaptable spatial configurations. Applications may range from multi-use interior re-organization to complete structure transformability to response to unexpected site and program issues. Specific applications may include intelligent shading and acoustical devices, automobile-parking solutions, auditoriums, police box stations, teleconference stations, devices for ticketing and advertising, schools and pavilions, as well as flexible spaces such as sporting, convention and banquet facilities. Other spaces of consideration are those with necessary fixed exterior configurations such as airplanes, boats, transport vehicles and automobiles. Through the application of intelligent kinetic 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. Kinetic adaptability further considers the rapidly changing patterns of human interaction with the built environment. New architectural types are emerging and evolving within today's technologically developing society. These new programs present practical architectural situations for unique and wholly unexplored applications that address today's dynamic, flexible and constantly changing activities.

Future human interaction with the built environment is extremely difficult to predict even as science-fact extrapolations because it is ensnared with contradictions. In the example set forth by Arthur Clarke: 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? Our cities are the result of our mastery over neither. A topic of great interest today is the effect of our current mastery of communication on urban built form. What would be the effect if our mastery over travel had preceded that of communications? More relevant to applications of intelligent kinetic systems is the still science fiction issue of planetary engineering or climate control. If climate control were localized by architectural means at an urban scale would there be any desire to investigate planetary engineering given the potentially adverse effects on terrestrial equilibrium?

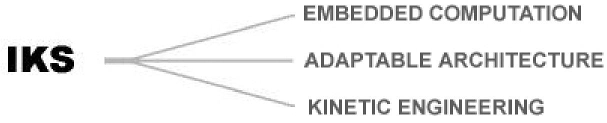


Fig. 09: Diagram of Ubiquotous Responsive In-Direct Control

Intelligent Kinetic Systems as Living Mechanisms

What we are describing then with advanced kinetic systems in architecture is a structure as a mechanistic machine that is controlled by a separate non-mechanistic machine: the computer. An interesting phenomenon can be observed when we look at the higher levels of control. The engineer Guy Nordenson describes the phenomenon in embedded kinetic systems as creating a building like a body: A system of bones and muscles and tendons and a brain that knows how to respond. 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 intelligent static kinetic system. If the building could change its posture, tighten its muscles and brace itself against the wind, its structural mass could literally be cut in half. In deployable and dynamic kinetic systems as well, much of the structure will be reduced through the ability of a singular system to facilitate multi-uses via transformative adaptability. Buckminster Fuller who coined it “Ephemeralization” first illustrated this concept of material reduction. Robert Kronnenberg aptly illustrates the advantage of such systems in that buildings that use fewer resources and that adapt efficiently to complex site and programmatic requirements are particularly relevant to an industry increasingly aware of its environmental responsibilities.

Projects by the MIT Kinetic Design Group

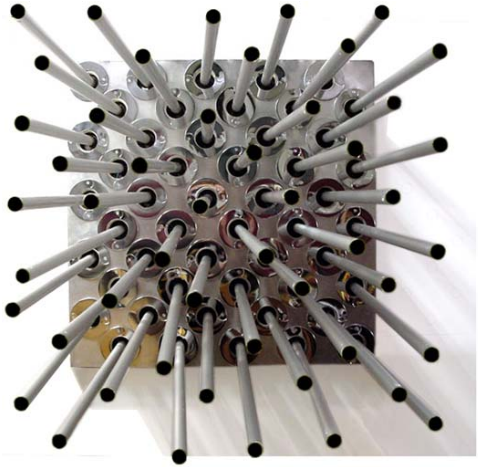
The Kinetic Design Group at MIT is an interdisciplinary research group focused on the design and application of responsive kinetic design in architecture. The motivation for such an agenda lies in extending current trends in intelligent environments to affect physical architectural spaces. Intelligent kinetic systems in architecture are centered on the issues of embedded computational infrastructures, human and environmental interaction, physical control mechanisms and the processes of architects designing such systems.

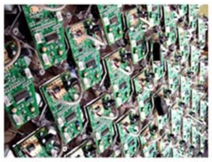
The Secret Garden, with Roart Associates

The Secret Garden is a reading and contemplative place for the children of a New York Public School. It is a place to read in an environment filled with nature, science and art. It is a garden inspired by the imagination of children and the dreams of their parents and friends. Amongst the Giant wood sculpted flower pots which serve as random seating areas are numerous interactive robotic flowers which gently move to track the sun and turn to bend and follow the motions of the children playing in the garden.

Interactive Kinetic Façade, with Roart Associates

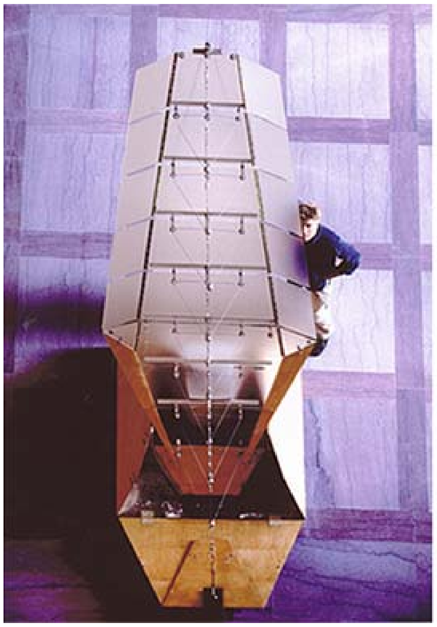
The project fosters direct interaction between an architectural-scale installation and pedestrian activity on the street. The 160' long band of responsive "whiskers" that will wrap around a building in New York allow pedestrians to walk up and interact with the installation through their presence. The bars move in wave-like rhythm driven by sensors mounted beneath each row that monitor the presence of a moving person. If motion is detected, the poles gradually point towards the target creating a ripple through the field. Each element moves in a simple fashion but together more complex patterns evolve. The project at once engages individual interactivity and at the same time actively mirrors the unengaged pedestrian activity as a whole.





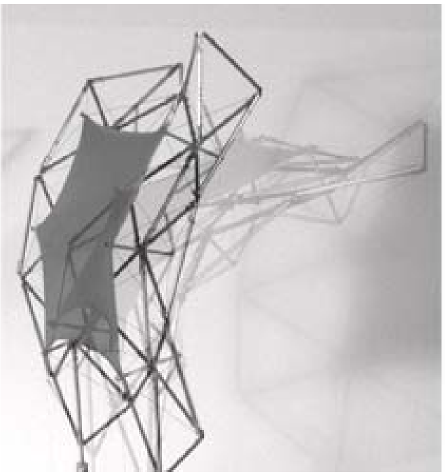
Deployable Teleconference Station

The structure houses a computer exhibit and teleconferencing station. During the “off” hours the object is closed into a simple secure (theft-proof) pyramid. While functioning, the structure transforms into a framed shell for communication. The structure was designed to express the conceptual aspects of a project (for the 1996 Lyon Biennale) in reference to language and communication as constantly transforming systems with multiple encapsulated meanings.



Responsive Wall with Integrated Membrane, KDG/ Bryant Yeh

This project is a large scale kinetic wall with a fully integrated sensor feedback system. The wall can respond to any number of human and environment generated variables including sun, wind, shade, light, whim, desire or impulse. The system is mobile and can be controlled by either an active computer control system or by direct response to human movement.

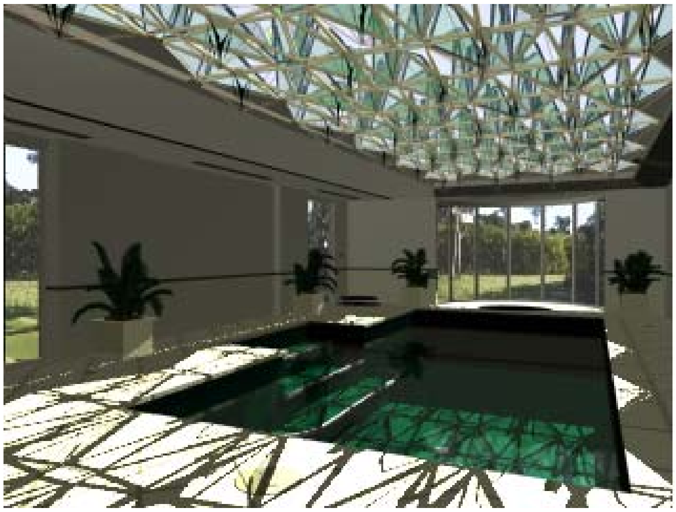


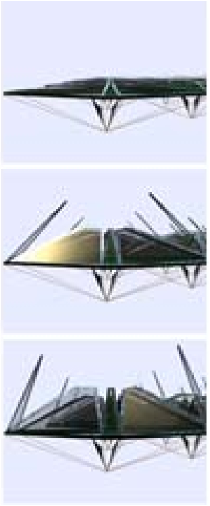
Boeing Business Jet Interior

The goal was to provide a responsive interior space that can be configured as prescribed by the users prior to a specific flight as well as partially reconfigured in-flight. The design introduces to the interior three basic kinetic components, namely sectors, which display variable location (mobility) and variable geometry (transformability). The sectors can technically operate independently; as a complete system, they divide and define zones of the program in the interior. Each is equipped with/provides the technical and the physical/spatial apparatus necessary for various parts of the program.

Moderating Skylights

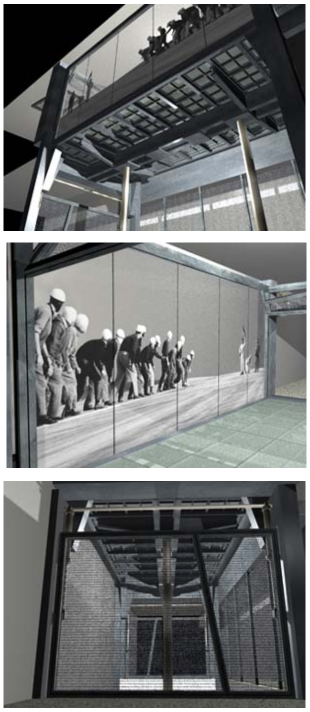
The Moderating Skylights is a networked system of individually responsive skylights that function together to optimize thermal and day lighting conditions. The unique aspect of the Responsive Skylights lies in kinetic function, human interaction and adaptive control under realistic operating conditions. Adaptive control being that the system would be capable of learning the usage patterns on a daily basis. Primary design considerations are to utilize natural daylight in the space where and when it is desired and to optimally take advantage of natural ventilation.

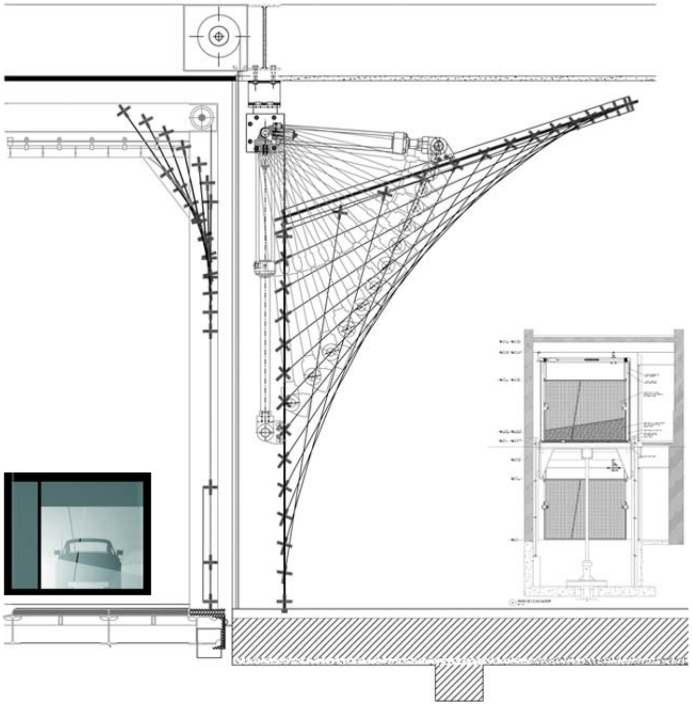




Elevator Choreography, KDG with Roart Associates

This fully automated hydraulic folding door system for an interior large-scale vehicle elevator connects several floors for a private collector. The servo-controlled doors operate through a dynamic sequence of choreographed motions for a Porsche collection that is housed and displayed within the central living space of a Manhattan building.





Conclusion

It is difficult to see if advanced kinetic architectural systems are far on the horizon or inevitably in the very near future. To extrapolate the existing into a future vision for architecture is a conundrum residing in the hands of architects directing the future of their profession. Adaptive response to change must intelligently moderate human activity and the environment and build upon the task of enhancing everyday activities by creating architecture that extends our capabilities. Such systems introduce a new approach to architectural design where objects are conventionally static, use is often singular, and responsive adaptability is typically unexplored. Designing such systems is not inventing, but appreciating and marshalling the technology that exists and extrapolating it to suit an architectural vision. Architects will inevitably hear that “it cannot be done”, and to this should recall that commercialized electric light was not long ago thought impossible, that it was thought a man would suffocate on a locomotive if he were to travel at a speed exceeding 30 miles an hour and of course the impossibility of heavier than air flight. Architects need to grasp a vision that will harness technology transfer from “outside” fields and prevent contradictions in human interaction with the built environment. To a great extent the success of creating intelligent kinetic systems in architecture will be predicated upon the real-world test-bed. Applications must consider the capability for such systems to yield real-world benefits. Actual construction and operation will allow architects to develop realistic consideration of human and environmental conditions, and to overcome simplified assumptions about the costs of manufacture and operations. The result will be architecture of unique and wholly unexplored applications that address the dynamic, flexible and constantly changing activities of today and tomorrow.

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