Intelligent Kinetic Systems

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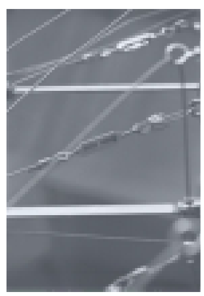


Abstract. This research develops a concept for the design and application of intelligent kinetic systems in architecture. Our motivation lies in creating spaces and objects that can physically re-configure themselves to meet changing needs. Intelligent kinetic systems arise from the isomorphic convergence of three key elements: structural engineering, sensor technology and adaptable architecture. At the intersection of these areas exists an unexplored physical architecture tuned to address today's dynamic, flexible and constantly changing needs. Intelligent kinetic systems are unique to the field of architecture where objects are conventionally static, use is often singular, and responsive spatial adaptability is relatively unexplored.

Keywords. *Adaptable Architecture, Responsive Architecture, Kinetic Structures, Kinematic Design*

INTRODUCTION

This research develops a concept for the application of smart environments to kinetic systems in architecture. The goal is to create flexible and responsively adaptable architectural spaces and objects. Novel applicational issues of smart environments 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. We define kinetic architecture as buildings, or building components, with variable location or mobility and/or variable geometry or movement. Computer systems will interpret functional circumstances and direct the motor-controlled movements to change responsively and adaptively to better suit changing needs. Intelligent kinetic systems arise from the isomorphic convergence of three key elements: structural engineering, sensor technology and adaptable architecture.

Structural Engineering

Our concerns in structural engineering focus upon extending the possibilities of kinetic design. We address kinetic function as a technological design strategy for building types that are efficient in form, lightweight, and inherently flexible with respect to various contexts and a diversity of purposes. Facilitating adaptability, transportability, deployability, connectability and producability, they are ideally suited to accommodate and respond to changing needs. Recently manufacturing technologies have evolved to the degree where the creation of kinetic solutions can be both effectively and feasibly realized. Kinetic solutions are particularly suited to take advantage of technology, materials and techniques that exploit the potential of technological advance from other fields such as automotive, maritime, aviation, and the military. We classify kinetic systems into three main areas of research interest: Embedded, Deployable, and Dynamic kinetic structures.

Embedded Computation

This area addresses sensor technology as a computational control mechanism to accommodate and respond to changing needs. Systems will specifically be utilized to interpret functional circumstances and direct motor-controlled movements to change adaptively to better suit changing human needs. We exploit the case–specific advantages of both centralized and decentralized systems for the control of kinetic functions. Our development of such control mechanisms will draw upon previous research in AI called "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 act as independent subsystems that can be beneficially incorporated into kinetic design. Our motivation lies is sensor technology as a means to actively controlling kinetic objects in the built environment in response to change.

Adaptable Architecture

An adaptable space flexibly responds to the requirements of any human activity from habitation, leisure, education, medicine, commerce and industry. Adaptability may range from multi-use interior re-organization to complete structure transformability to difficult site and programmatic response. 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. (Kronenburg, 1997) Adaptable architecture 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.

Novel Applications in the Built Environment

Architectural applications for Responsive Kinematics arise from issues such as spatial efficiency, adaptability, shelter, security and transportability. 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. Also of consideration are spaces 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.

Although human technical prowess is embracing unprecedented sophistication, the permeation of this technology into architecture as built form remains in its infancy. We believe that in addition to addressing existing needs, intelligent kinetic systems will expose new programs and forms as this technology is incorporated into our everyday lives. An investigation into possible applications must consider the rapidly changing patterns of human interaction with the built environment. New architectural typologies are emerging and evolving within today's technologically developing society. These new programs present practical architectural situations where intelligently responsive kinetic solutions can be considered for unique and wholly unexplored applications. Intelligent kinetic systems are an approach for utilizing technology to create architecture that addresses today's dynamic, flexible and constantly changing activities.

Design Approach

We will describe some general mechanical and technological principals relevant to intelligently responsive kinetic design in architecture as categorized into three general research areas:

- *Structural Innovation and Materials Ad vancement*
- *General Kinetic Typologies in Architecture*
- *Control Mechanisms*

Structural Innovation and Materials Advancement

In developing such systems, the role of structure needs to be addressed not primarily or singularly, but rather as an integral component of a larger intelligently responsive kinetic system. The structural solutions 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.

Only recently, have manufacturing technologies evolved to the degree where the creation of intelligent kinetic architectural solutions can be both effectively and feasibly realized. Such systems are dependent upon both advanced computer control technology as well as the ability to manufacture high quality kinetic parts. New materials such as ceramics, polymers and gels, fabrics, metal compounds and composites are now available which can be integrated into intelligently responsive kinetic systems for exciting and novel applications. The integrative use of such materials in kinetic structures facilitates creative solutions in membrane, tensegrity, thermal, and acoustic systems.

General Kinetic Typologies in Architecture

We will classify kinetic structures in architecture 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. We draw upon 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. The engineer Guy Nordestrom indicates that if a building were built like a body, it could change its posture tighten it's muscles and brace itself against the wind. As consequence, its structural mass could literally be cut in half.

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. Applications may include traveling exhibits, pavilions and self-assembling shelters in disaster areas. An example may be transportable public computer terminals, which can automate their own security.

Dynamic Kinetic Structures

Dynamic systems act independently with respect to the architectural whole. Applications may include louvers, doors, partitions, ceilings,

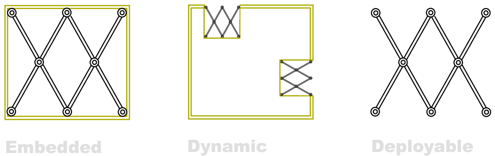


Fig. 00: Diagram of Kinetic Typologies in Architecture

Fig. 1A, Fig. 1B: Folding Egg Sectional Prototype

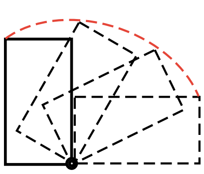


Fig. 1C: Diagram of Internal Control

walls and various modular components. An example may be an auditorium with ceiling configurations that can change dependent upon the audience and the performer locations for obtaining optimal acoustic properties. We will explore dynamic structures categorically as Mobile, Transformable and Incremental kinetic systems.

Control Mechanisms

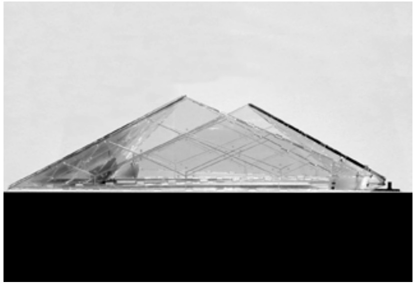
We have defined kinetic in the context of architecture as the application of objects having mechanical parts that can be set in motion. Within each of the three typologies of kinetic structures: Embedded, Deployable and Dynamic, several levels of machines may exist simultaneously. Prior to describing the types of controlled movement for such kinetic systems, we will list a general breakdown of the levels of machines (Zuk, 1967) by their ability to adapt to differing needs: 1) Singular in function 2) Multi-variable in function 3) Multivariable in function with automatic control and 4) Multivariable with heuristic control.

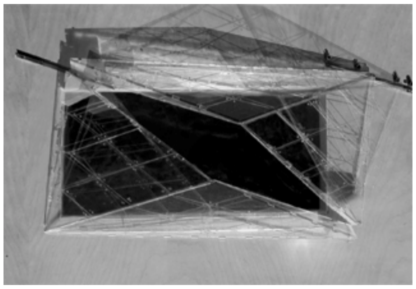
Types of Controlled Movement

To date we have developed numerous prototypical projects to study design and construction techniques, kinetic operability and maintenance, as well as issues of human and environmental interaction. Central to all of the projects is the means of controlling kinetic motion in architecture. We will illustrate the six general types below.

- 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. The "Folding Egg" is a prototype





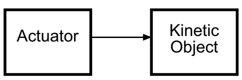


Fig. 2C: Diagram of Direct Control

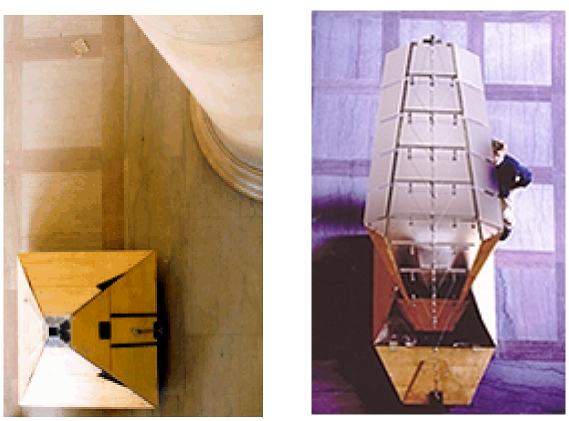


Fig. 3A, Fig. 3B: Deployable Teleconference Station

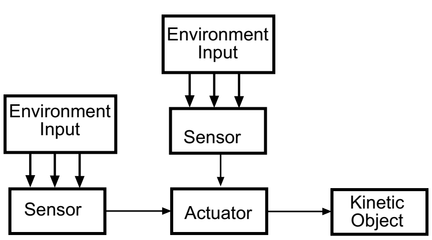


Fig. 3C: Diagram of In-Direct Control

kinetic folding sheet structure shown if Fig. 1a and Fig. 1b demonstrating internal control. It is constructed from a low-cost recyclable material and forms a structurally stable collapsible three-dimensional truss structure. The Structure has a 5:1 folding ration and naturally „locks" into a stable open position. It can be constructed at a very low cost, with an R-value of 25 and a weight of less than 5.7-lbs/per sections.

- Direct Control

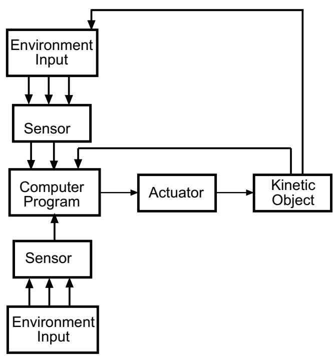
Movement is actuated directly by any one of numerous energy sources including electrical motors, human energy or biomechanical change in response to environmental conditions. This skylight shown in Fig. 2A and Fig. 2B, is one example of a simple rule based rotational system that can be applied to numerous geometrical configurations. Direct motor control actuates a 3-dimensional transformation resulting from one straight sliding motion. This skylight consists of eight glass panels held in compression against an aluminum frame. The glass is lined with an adjustable shading film to accommodate varying degrees of day lighting conditions.

- In-Direct Control (Computer control via sensor feedback)

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 stimuli. The deployable teleconference station shown if Fig3A and Fig3b is a structure that houses a computer exhibit and teleconferencing station. The structure was designed to open automatically for use via a single motion sensor that triggers the deployment. When not in use, 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 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. The self-deployable macro-modular tent system shown in Fig. 4 can be combined into numerous structurally stable configurations. It has been conceptualized for a distributed sensor system to respond to natural day lighting conditions. Each vertical row of panels contains an individual sensor; as a vertical row deploys it pulls it's neighbor row of panels into a partially deployed position. The individual panels are supported on a steel structure made up of tie-rods, struts and columns. The membrane is made up of lightweight, semi-transparent anticlastic surfaces. The modular, lightweight units can be easily disassembled for transportation. A medium scale light-sensitive vault is currently under construction.



(Fig. 4A: Diagram of Responsive In-Direct Control

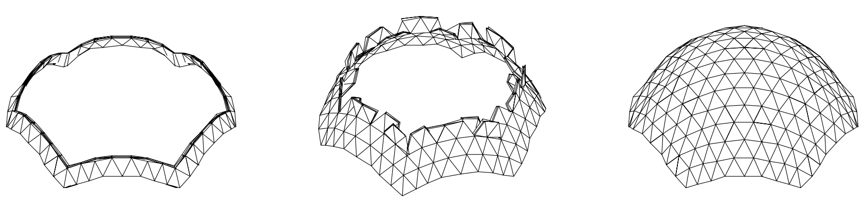


Fig. 4: Macro-Mod Folding Tents

- *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. The structure is at once both structure and envelope, both solid and plastic, a super-skin that could be used either as a temporary structure or incorpo-

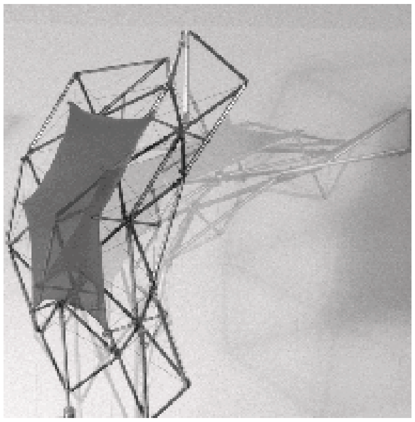


Fig. 5A, Fig. 5B: Kinetic Wall

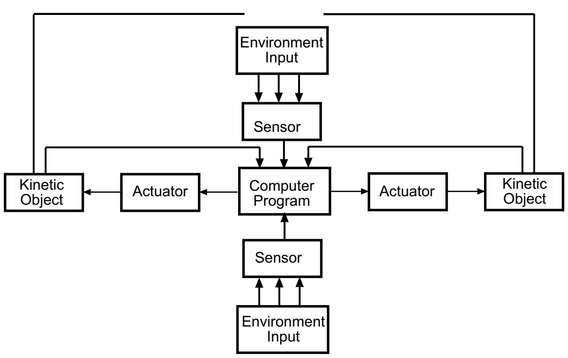


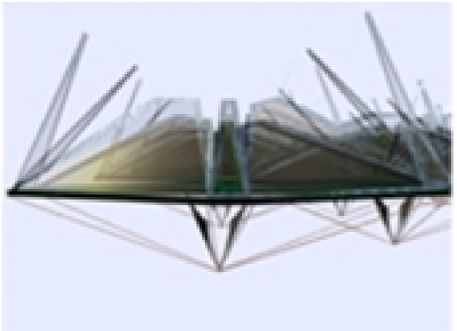
Fig. 5C: Diagram of Ubiquotous Responsive In-Direct Control

rated into an existing structure. The structure is basically an assembly of one primary cell design. Each 'cell' is a grouping of three equal sized members that form a equilateral triangle. A larger hexagonal unit of comprised of six triangles grouped together around a central mast, which forms a 'panel' unit. To facilitate motion, a cable is strung along the back of the two vertical members formed by each cell. The cables begin at the top vertex of each hexagonal panel and run through the top of the panel's mast and then back down the adjacent vertical members of each preceding cell. This configuration allows individual control of each panel in relation to the adjacent panel. It also affords the ability to add more panels to create larger total surfaces. In this way a controllable dynamic surface skin is formed. Control is achieved by a series of computer-controlled servos that control each cable

Three separate servo-motors actuate each cable and are located below the base. The servomotors are actuated by a servo control device that is in turn controlled by a computer interface. Each servo controls the rotation of one panel. A controlled curvature can be created by activating all three servo-mechanisms in unison. Integrated computer control is done with a system of positional sensor devices attached to each panel. Control is based on a feedback loop system. The system is mobile and can be controlled either by an active computer control system or by direct human movement.

- 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. The Moderating Skylights shown if Fig. 6A and Fig. 6B, demonstrate a networked system of individual skylights that function together to optimize thermal and day lighting conditions. Each unit contains



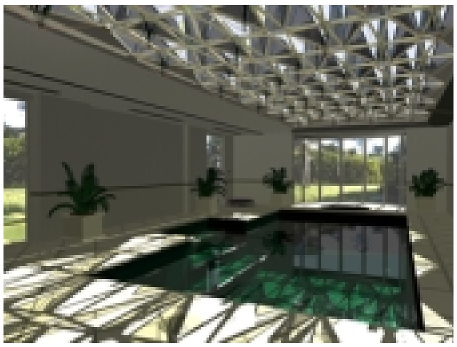


Fig. 6A, Fig. 6B: Moderating Skylights

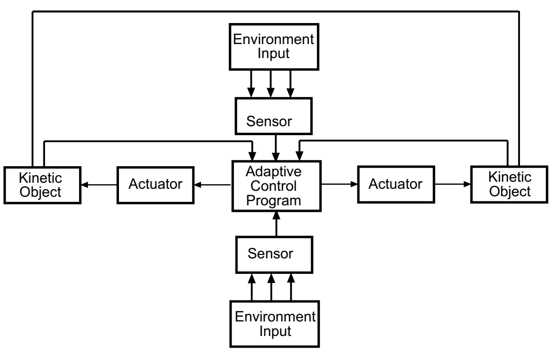


Fig. 6C: Diagram of Heuristic, Responsive In-Direct Control

eight individual panels that slide along 4 straight lines towards the center of the panel to create an open position. The system maintains structural stability throughout all stages of deployment of the individual units. One of corner joints of a singular unit contains an individual cable attached to a servomotor that deploys the unit as an individual whole through sliding that joint towards the center of the unit. Integrated computer control is done with a system of positional sensor devices attached to each panel. Each panel further consists of photovoltaic cell paneling under which lies a layer of shading film/moisture barrier of variable self-adjusting opacity. This skin is affixed to a ribbed Plexiglas panel affixed to a structural aluminum frame. Optimum thermal and natural day lighting conditions can be achieved through the algorithmic balance between the individual deployment of the panel units and the individual opacity variances.

When we look at the higher levels of computer controlled behaviors an interesting phenomenon can be observed with respect to actual physical built form with respect to all three of the illustrated types of kinetic structures: Embedded, Deployable and Dynamic. What we are describing is a structure as a mechanistic machine that is controlled by a separate non-mechanistic machine: the computer. Guy Nordenson describes the phenomenon 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. In deployable and dynamic 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. Novel applications of smart environments arise both through addressing how transformable kinetic objects occupy predefined physical space as well as how moving physical objects can share a common physical space to create adaptable spatial configurations.

Conclusion

Intelligent kinetic systems arise from the isomorphic convergence of three key elements: structural engineering, sensor technology and adaptable architecture. At the intersection of these areas exists an unexplored architecture tuned to address today's dynamic, flexible and constantly changing needs. In developing a general concept for the application smart environments to kinetic systems in architecture, we introduce a new approach to architectural design, where objects are conventionally static, use is often singular, and responsive adaptability is typically unexplored

Only recently have computer-based control technologies and manufacturing technologies evolved to the degree where the creation of intelligent kinetic architectural solutions can be both effectively and feasibly realized.

Acknowledgments

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