Adaptive Kinetic Architecture: A Portal To Digital Prototyping

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Abstract

This paper presents a definition for adaptive kinetic structures in architecture, generated from an examination of research in engineering and architecture. This characterization introduces the challenges presented both by modeling form and environment, and simulating their interaction. Adaptive kinetic structures react to a changing environment, as well as generate their own. These conditions make them appropriate subjects through which the design and implementation of tools for 'digital prototyping' may be explored.
Digital prototyping serves performance and simulation-based design. In general terms, it is an interdisciplinary integrated approach for modeling, predicting, and analyzing the behavior of a system. It is at the core of virtual engineering. In the aerospace, automobile, and manufacturing industries, it is practiced extensively through discrete-event and continuous simulations, as well as simulation environments. This paper provides an overview of digital prototyping commercial software for engineering applications that can be transferred to architecture, and identifies some of the unresolved issues. It thereby extends the vision of the comprehensive building information modeling initiative.

Introduction

The assertion that architecture needs adaptive kinetic structures responds to the profession's continuous search for adaptable design that optimally serves changing human needs. This search is coupled here with an examination of approaches that allow modeling and simulating complex behaviors within complex environments. When an adaptable kinetic architecture responds by adjusting itself to a changing environment, it forms an ecological system. It is ecological because the system components have shifting interdependencies. Currently in architecture there is no single modeling and simulation environment that allows designing these structures in an integrated manner. There is also limited data about the actual behavior of the systems and its consequences. The lessons afforded by the excellent examples built by many over time await full compilation and ongoing analysis for future use. This means that at the heart of any model or simulation is empirical research.

A host of tools to model form and material in detail, assigning attributes to components and spaces, and to execute mainly discrete simulations to evaluate performance have been developed for architectural design. Through digital fabrication (rapid prototyping and manufacturing) digital models are translated into physical prototypes and construction components. Although novel in its actual implementation, it follows an ancient tradition: to evaluate a structure to predict its performance in the future: it is necessary to build, test, and document its behavior. Fabrication is but one phase of virtual engineering. Virtual engineering is "a simulation-based [design] method requiring a virtual environment, where the geometric and physical properties of systems are accurately simulated," covering the life of the design from concept development to manufacturing processes, to prototype. [Lee, p.433] This paper explores the application of digital prototyping or digital mock-up, which requires an integrated interdisciplinary approach to modeling, simulating, and analyzing the behavior of a system.

The term 'kinetic' in this context stands for having the capacity to be affected by reversible geometrical changes in whole or in part without losing the integrity of the system. When a kinetic structure is also adaptive, it gains the ability to respond to changing conditions, such as the weather, the time of the day, and the location of the sun. Thus, the justification for adaptive kinetic structures is founded on three reasons: economy of means, responsibility towards the natural environment, and the satisfaction of human needs and desires. These are no different from those given for most architectural projects; however, adaptive kinetic structures can better modulate efficiencies, broaden the contemporary aesthetic, and give it more relevant meaning. The single attribute that distinguishes the adaptive kinetic from other forms is that embodied energy becomes fully visible when it produces work, when it moves in a perceptible way. Applied energy is work, and work as motion is intrinsic to the system as is the transformation of energy.

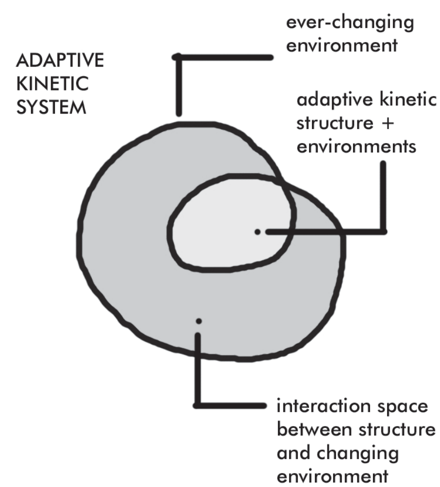

Figure 1. *Conceptual diagram of the adaptive kinetic system*

Uniquely an adaptive kinetic structure moves in a predictable and visible manner responding to expected excitations. It has a built-in capability to change state through motion, while maintaining its structural integrity and stability. This movement can be produced automatically through programmed responses to changes, or manually. Motion is fundamental to the life of the system. We use 'system' instead of 'building' to better reflect all that entails architecture. An adaptive kinetic system is characterized by energy/control, purpose/function, condition/state, geometry, structure, and material. The system is immersed in an ever-changing environment. At the same time the system, in architecture, also creates its environments.

The Kinetic Factor

Far from whimsical, kinetic structures have proven to be essential in space, in extreme or hazardous environments, and in emergencies caused by natural disasters and human will. Examples of adaptive kinetic buildings are usually found among those that have been referred to as intelligent, smart, responsive, dynamic, and active [Fox, 2003; Kroner, 1997]. These characteristics are mainly exhibited by structures that are foldable and unfurlable, collapsible or demountable, deployable, transportable and portable, mobile and nomadic, mass-produced, ephemeral, and transformable.

One may argue a building that moves in whole, or in parts, is like a machine. A machine applies energy to do, or produce work. It uses energy. Kronenburg references Vitruvius' siege towers as one of the earliest precedents to mobile environments, [Kronenburg, 2002, p.140] with kinetic components. A siege tower was a tall frame several stories high with an interior staircase set on a platform with wheels pushed by soldiers, and in some cases special mechanisms facilitated movement. The exterior was plastered with lime or padded rawhide, depending on whose account one consults. In Vitruvius' time, a siege tower was a building constructed under the purview of an architect. Today we categorize objects functionally into succinct groups, where siege tower is war machine. Yet, Paul Shepheard writes "a Boeing [airplane] is not a building, but as a refabrication of the world, it is architecture." [2003, p.vii] He proposes architecture has three scales: landscape, building, and machines. The difference between the three is time, where landscapes are "long term strategies," and on the other side of the spectrum machines "have short lives and are closely fitted to their purpose." [Shepheard, p.33] Therefore, four conditions exists where buildings can still be conceived of as machines exhibiting kinetic capacity, only excluding full mobility to avoid infringing into the territory of vehicles.

Buildings as machines:
Automated Car Tower, Volkswagen Autostadt, Germany
Buildings that house machines:
Thames Water Tower, England, Brookes Stacey Randall
Buildings with machine-like components:
High Sierra Cabins, U.S.A.; Jones Partners Architecture.
Building components as machines:
Sapporo Dome, Japan; Hiroshi Hara and Atelier BNK

What is kinetic architecture? Perhaps influenced by the Pop Art movement, Zuc and Clark coined the term "kinetic architecture" offering the first formal definition: "an architecture free to adapt to changes taking place within the set of pressures acting upon it and the technology that provides the tool for interpretation and implementation of these pressures." [1970, p.11] Their vision was far-reaching, incorporating mechanisms, sensors and embedded processors allowing the structure to react automatically to change, as in the work of Fox and Oosterhuis, among others. Their proposal fits between mechanistic and organic models for architecture. Yet, the 'biologic' argument takes precedent in their thinking, because they surmise "every principle of kinetic structure may be found in the physiology and morphology of the human body." [1970,p.20] Current research conducted on the biomechanics of organisms further supports their position. Of the eight groups or types of *kineticism* advanced by Zuc and Clark, only five are truly kinetic within the definition established at the beginning of this section. These five can be further organized into three groups: mechanisms (kinetic components), reversible and non-reversible self-erecting structures, and deformable or transformable structures. To date these continue to be the main types.

Zuc and Clark' self-erecting structures find a new form in Scott Howe's kit of parts composed by geometric primitives or "motion primitives," intended for pre-fabrication and automated construction. The kit defines a form of "kinematic architecture that includes mechanisms to construct itself, or to change the configuration or form of the structure over its lifetime." [Howe, 2001] It consists of: joint-based, panel-based, module-based, and deployable. Howe's proposal aims for efficiency and accuracy. [2001] Howe has defined three levels for achieving construction automation based on the combination of *kinematic* and *robotic* mechanisms:

Kinematic Mechanisms: “a structure containing two or more elements that have the capacity to alter their configuration in relationship to each other based on a known or given transformation.”

Robotic Mechanisms (RM): “a structure containing one or more kinematic mechanisms, one or more actuators, one or more sensors, and a controller.” A RM produces *work*.

System-Wide Work Cells: “Complex systems consisting of multiple kinematic and robotic mechanisms require coordinated behavior and work areas.” [Howe, 2001].

Responding to a question on the nature of his design for the 2000 Olympics arch, Hoberman explained the arch was a hybrid between structure and mechanism, where the structure reacts by changing size or shape, and the mechanisms do the work “yet [the structure] is stable and self-supporting.” [2004] Hoberman’s definition for kinetic architecture is one offering “the possibility of movement,” to create “transforming environments, responsive building elements, or interactive public spaces.” [2004] Fox defines kinetic architecture as ‘buildings and/or building components with variable mobility, location and/or geometry.” [2003] Terzidis defines kinetic architecture as “the integration of motion into the built environment, and the impact such results have upon the aesthetics, design and performance of buildings.” [2004] Hoberman and Terzidis expand the definition beyond space or building, to environment. Both consider motion and its consequences, essentially kinetics. Through the use of the term aesthetics, Terzidis implies there is a human imperative, while Hoberman’s use of “responsive” and “interactive” environment is less specific.

In the discussion of various authors kinetic architecture intersects intelligent and responsive architecture. The occupants and the idea of interaction between environment and building is clearly stated in Kroner’s definition for intelligent architecture: “built forms whose integrated systems are capable of anticipating and responding to phenomena, whether internal or external, that affect the performance of the building and its occupants.” [Kroner, 1997] Zerefos et al proposed the concept of responsive architecture: “Dynamic modifications of the external envelope of the building and of the interior spaces, according to the needs of the occupants, as well as the extended use of new ‘intelligent’ materials that extend the effectiveness of existing control systems.” [Zerefos et al, 2000; based on Atkin, 1988] For Kroner the occupants are passive, they are affected by the intelligent system, while for Zerefos et al the kinetic function explicitly responds to human needs. The Zerefos’ team also includes materials as active participants in the process of modification.

Of all versions, Fox’s proposal for “intelligent kinetic systems” is the most encompassing: “architectural spaces and objects that can physically reconfigure themselves to meet changing needs,” in the interaction between human activity and the conditions of the physical environment. Fox presents kinetic architecture as an adaptable interface between people and their environments. [2003, p.115] He qualifies change as “responsive and adaptive to optimize.” For Fox, a kinetic system is justified by the need for adaptability or accommodation in any of these areas: spatial efficiency, shelter, security and transportability. Fox proposes three categories of kinetic systems: embedded, deployable, and dynamic. The embedded exist within a “whole in a fixed location,“ and has the ability to control the whole. In the deployable, the kinetic is an “inherent capability to be constructed and deconstructed.” This second category would be more specifically defined as reversible. The dynamic “exist within a larger whole“, but “acts independently“. [Fox, 2003] Fox’s intelligent kinetic systems types fit almost exactly into Zuc and Clark’s scheme.

Zuc and Clark	Fox
Mechanisms or Kinetic Components	Dynamic
Reversible Assembly and Non-Reversible Self-erecting Structures	Deployable
Deformable or Transformable Structures	Embedded

Table 1. *Comparing the types of kinetic structures; Zuc and Clark [1971] and Fox [2003]*

Zuc and Clark	Fox
Time-oriented development	Operating conditions / Human interaction
Dynamic control mechanisms	Adaptive control
Power systems and power usage	-
Kinematics	Kinetic function
Materials	New materials

Table 2. *Comparing the characterization of kinetic structures according to Zuc and Clark [1971] and Fox [2003]*

Evidence of Zuc and Clark's encompassing vision for kinetic architecture is also demonstrated by the fact that almost thirty years later the characteristics of kinetic architecture are basically presented using similar terms:

An up-to-date full characterization of a kinetic structure needs to distinguish between: energy source or force required to move, types of movement, degrees of freedom, level of transformation (morphing capabilities) and speed, reversibility and permanence, controllability, precision of movement, dynamic elements and their function, level of articulation, type of articulations, structure, strength, stability, geometry, material, and environments manifested. Any description of a dynamic system must also include the means for energy production or transformation, energy transmission to produce work, and the storing of energy. These last three elements have been largely ignored in the discussion of adaptive or kinetic structures.

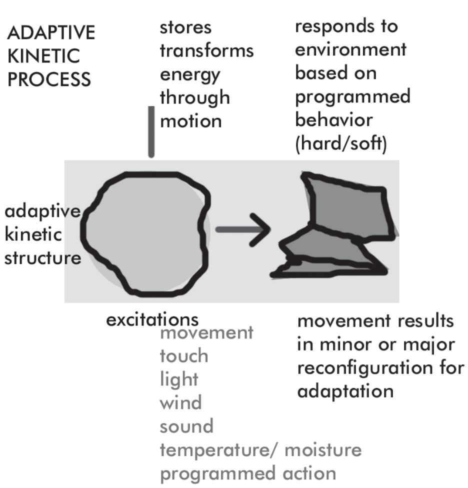

Figure 2. *Conceptual diagram of the adaptive kinetic interaction process*

Adaptability and Transformability

The idea that adaptive kinetic structures are forms of intelligent and responsive architecture has been presented thus far. In this section, a connection is established with transformable structures. Definitions for transformable structures have varied depending on the knowledge domain, and the historical period in which they have appeared. Fifty years ago, Giedion referred to furniture that changed form and purpose as 'transmutable,' and 'convertible.' [1947, p. 434] Eileen Gray in collaboration with Jean Badovici had patented the 'paravent' window, an operable folding window assembled between an inner and outer layer of shutters. She had written "a window without a shutter is like an eye without an eyelid." [St. John Wilson, p.117] Norbert Wiener, had published the seminal work where he stated "the many automata of the present age […] coupled to the outside world both for the reception of impressions and the performance of actions […] contain sense organs, effectors, and the equivalent of a nervous system to integrate the transfer of information from the one to the other." [1961, p.43] Giedion, his contemporary, was not looking at furniture, or at architecture, as automata. Although aware of motion as a particularly difficult issue when designing folding furniture, he was not ready to consider possible implications on architecture. Therefore, the kinetic, adaptive or transformable was mostly absent from the discourse of the time.

It was not until the 1970s, when Jencks borrows from cybernetics to put forth his predictions for the future that it resurfaces: "Substitutes for fur, skin and other anthropomorphic effects will proliferate until it will be quite possible for everyone to have a responsive environment." [1973, p.112] Certainly, Archigram's early work directly references cybernetics, among other things. Today, Saggio writes about the 'effective mutation' of architecture, or 'physical interactivity' when referring to the ability of architecture to change through controlling lights, moving partitions, and the increasing responsiveness of materials and mechanical systems. [2001, p.27] Dorsthorst and Durmicevic define transformable building as unfinished products, dynamic structures “made of pre-made components, which are assembled in a systematic order suitable for maintenance and replacement,” [2003] adjusting to users’ requirements and facilitating re-use and recycling. They establish the domains where transformation takes place as: spatial, structural, and material. This is an area of agreement among many authors. They contribute the notion that the capacity to transform impacts a “sustainable development in the future.”

Three metaphors are used here to discuss the levels of transformation of adaptive kinetic structures in relation to general types of geometrical configurations: origami, transformer robot toys, and the cartoon character Gumby. Liapi [2002] and Sánchez [1996] have used origami as a metaphor for folding structures. Betsky [1990] used gobots transformer robots as an analogy to the early work of Jones and Pfau. Morphing or adaptive-shape systems are somewhat akin to Gumby, where the structure acts as if it was continuous.

A transformable structure through folding is created using moves similar to origami, the art of paper folding. Fox would categorize these under “deployable kinetic.” A folding or foldable structure acts as if it was continuous, rather than an articulated assembly, where folds act as hinges. It can consist of rigid planes with contiguous elastic edges. The edges or folds are elastic because they permit deformation without breaking. Planes can also have some tolerance for surface deformation, thus accepting a slight curvature. Interestingly, elastic edges and planes maintain their length and area. They are referred to as “inextensible” and “developable.” A developable surface is one where “the sum of angles around an arbitrary point on the surface is 2 ð.” [Miura, 1993, p.3] Tents, space structures, such as solar

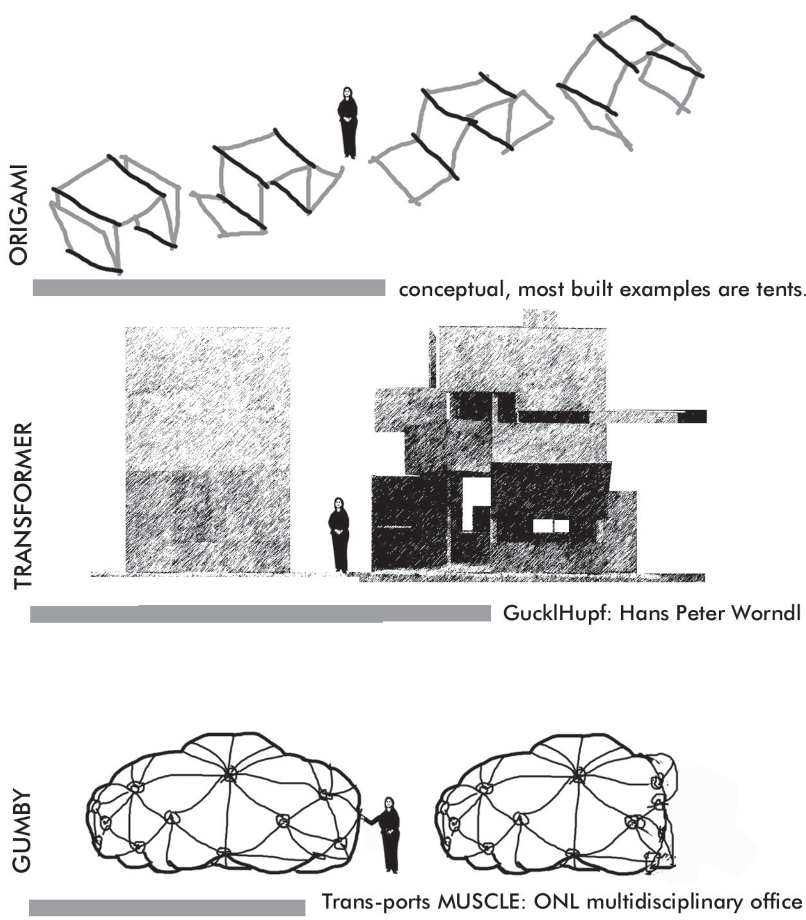

Figure 3. *The three types of transformation of an adaptive kinetic structure*

sails, and dECOi's piston wall project where transformation occurs through "inextensional deformation" of triangular plates. In this case, the surface or structure is fragmented and articulated.

Transformer robot toy figures are made of specialized distinct parts and flexible joints. Through a sequence of operations, mainly rotation and translation, the toy is transformed, for example from robot to airplane. In architecture examples of "transformer" structures are the Schröder/Reitveld House, the GucklHupf pavilion by Hans Peter Wörnl, and Michael Jantzen's M-house. Also representative of this type is Morphosis' 1983 proposal for the Venice III house, where "weights and pulleys control sun-sails that respond to the wind and sun, changing the physical aspect of the house from an unfinished ruin to a temporary tent." [Betsky, 1990, p.189] Howe's 'motion primitives' belongs to this group. A transformer-like structure is submitted to reversible change, and therefore it is kinetic. It is fragmented and articulated.

The third metaphor, the 1950's cartoon character 'Gumby', helps visualize the behavior of an adaptive-shape structure. Gumby was made out of clay with a soft wire inserted into the limbs and head to maintain the pose while the film frame was produced. Although uncommon in architecture, this metaphor has some relevance to aerospace engineering, particularly in the design of adaptive-shape airplane wings. For example, in the adaptable or morphing wing, skin and structure act together to change while maintaining the strength needed to keep the wing functioning. The morphing wing needs to have a memory of the various states adopted so that it may return to those states multiple times. Therefore, the change needs to be reversible without degradation of formal integrity or structural function. The materials necessary to build a fully functioning morphing wing are not yet available. Escrig describes a type of mobile structure as: similar to an "animal body with bones, tendons and muscles." [1996, p.18) His descriptive analogy represents a Gumby-like structure. Kas Oosterhuis Associates 'Trans-ports 'projects 2001 and the 'Muscle' are close approximations to this third metaphor. The first project is "a spaceframe composed of pneumatic bars that are individually controlled by software so that they work together like the filaments in a muscular bundle." [Zellner, 1999,p.73]; The second is a pressurized volume covered by "a mesh of Festo muscles." The Gumby type is a kinetic structure shaped as a continuous yet composite body.

Adaptive and Active in Engineering

In structural engineering an example of active structure are "statically determinate trusses where some of the members are linear actuators, enabling the truss to articulate." [Williams et al 1997, 77] They can generally be defined as controlled structures that contain sensors and/or actuators highly integrated into the structure, and have structural and control functionality. [Wada et al, 1990] Similarly, an adaptive structure has actuators that allow the alteration of "system states and characteristics in a controlled manner." [Wada et al, 1990] It is also defined as a structure that can purposefully vary its geometric configuration, as well as its physical properties. [Miura and Furuya] And in more detail: "structural systems whose geometric and inherent structural characteristics can be changed either through remote commands and/or automatically in response to external stimulations." [Miura, 1993] The main difference between active and adaptive is that the latter responds to external conditions, in addition to commands.

Research into active and adaptive structures in engineering considers kinematics and dynamics, mechatronics, adaptronics, robotics, and bionics. *Mechatronics* comprises "products and processes with moving parts requiring manipulation and control of dynamic constructions to a high level of accuracy." [Giurgiutiu et al, 2002, p.170] This is further complemented by the field of *adaptronics* involving "the creation of material systems with intelligence and life features integrated in the microstructure of the material system." [Giurgiutiu et al, 2002, p.170] All of these must be carried on into the study of adaptive kinetic buildings.

Simulation Environment for Adaptive Kinetic Structures

Fox has argued kinetic structures must be seen as parts of larger systems, and "to achieve this it is necessary to use advanced computational design tools," among other resources. [2003] This assessment is shared by colleagues both in architecture and engineering. [Angelov et al, 200] Liapi argues that in engineering there are no standards for the design and analysis of transformable structures. [2000, p. 267] She proposes in the case of origami-based transformable structures: “animated simulations of the transformation process during folding can identify problems in the initial geometric conception (…), and can be used for further morphological explorations.” [Liapi. 2002, p.385] The modeling and simulation of kinetic structures is complex. Frei Otto, a strong advocate for physical prototypes conceded some structures can only be accurately established through digital modeling. [Dickson, 2004] Yet, as has been pointed out before, the precision of future digital models depends on the testing of the physical models of unbuilt proposals not yet analyzed.

A simulation is goal-oriented, it serves a purpose. It can assist the “design, analysis or optimization” of a system. [Birta et al, 1996, p.77] To be simulated, a system needs to be conceptualized. A simulation acts on a model of reality or proposed reality. The models used in the simulation need to be validated to confirm they accurately represent the system under investigation. They also need to be verified to determine if the concept of the system has been correctly translated into the simulation. [Birta et al, 1996, p.77] Expert knowledge has to be identified and coded in, and experimental data needs to be collected. Physical prototypes after all are necessary.

Kieran and Timberlake [2004, p.59] have recently made the case for the transfer of aircraft modeling methods to architectural design. They argue simulations provide a “whole model”, where information about the factors constraining the design have been “embedded” in each part. They refer to simulation as an enabling device to ensure that the parts create a “unified whole.” [Kieran and Timberlake, 2004, p.65] Yet, the implementation of such an integrated environment has not been fully realized.

In the aerospace industry, a call has been made for the integration of simulations “to cover lifecycle, from conceptual design, through predefining detailed manufacturing processes to the final assembly without any physical application required.” [Murphy et al, 2001,p.829] This entails developing a system or environment for ‘digital manufacturing’ where different types of simulation types interact. The simulations progress from conceptual to detailed design, to tolerance, mechanical, and ergonomic simulations, including digital mock-up in preparation for assembly concluding with the simulation of the manufacturing facility system required. [Murphy et al, 2001] In this implementation model for a simulation environment ‘digital prototyping’ is only one of many phases. The Murphy et al proposal concurs with the main goal of the performance-based design in architecture: “to predict the behavior of a building from conception to demolition.” [Malkawi, 2004] But, it is often noted that not much has been offered relative to this type of comprehensive simulation environments. [Axley, 2004, p.4]

Design challenges facing whole system simulation applicable to adaptive kinetic structures:

Differences between the representation needed by the simulation tools and that generated in the geometric modeling (CAD) environment. [Mahdavi, 1999; Shepard, 2004] The ‘generative components’ initiative promises to facilitate sharing data.

No ”infrastructure for distributed simulation environments, and transaction data between distributed simulations.” [McLean et al, 2001]

“No satisfying solution for the simulation of the entire system in one software tool,” for multi-body systems and Computer-Aided-Control Engineering. [Gerl, 2003; Williams, 1997]

Need the “ability to define simulation models of various levels of ‘fidelity’ from early in the design process and to have the information determined by those analyses influence the design process.” [Shepard et al, 2004]

“Mechanisms for multidisciplinary analyses and ‘performance based comparison procedures’ that facilitate the collaboration of highly diverse interdisciplinary teams.” Also shared representations. [Augenbroe, 2002; Hu & Fox, 2003]

The purpose of developing a digital prototyping environment for adaptive kinetic architecture would be to evaluate the effectiveness of its form and behavior as a system to achieve the design objectives. The behavior would not only involve motion, but structural, environmental, and control performance, including human interaction. Commercially available packages for engineering applications simulate structural performance, which may include kinematics and dynamics, interference detection, and motion volumes, and control system, or environmental performance, and ergonomics, but not all. Below is a list of currently available software with some digital prototyping capabilities that must be carefully evaluated for possible transfer to architecture.

A model of an integrated simulation environment, currently in development for application in the automobile industry, the "Simulation Environment for Engineering Design" or SEED [Shepard et al, 2004], can be useful for digitally prototyping adaptive kinetic structures. It is built on the concept that a holistic simulation environment is composed by three already existing components that interact with SEED's four new components. Furthermore, it is based on the premise that such an environment is to be shared by an interdisciplinary team, must be accessible to designers, and must be based on multiple representations of increasing detail as they are affected by the results of the simulation.

SEED *Existing* Components [Shepard et al, 2004]	
Product Data Manager	Requests engineering performance parameters to be evaluated.
Computer Aided Design Tools	Geometric domain for design model plus supports interaction with it.
Computer Aided Analysis Tools	Engineering analysis programs and their respective models.

Table 3A

SEED *New* Components [Shepard et al, 2004]	
Simulation Model Manager	Directly interfaces with **Product Data Manager** and **CAD tools**.
Simulation Data Manager	Directly interfaces with **Product Data Manager** and **CAE tools**. Houses simulation data results.
Simulation Model Generator	Directly interfaces with **CAD** and **CAE tools**. Constructs models for CAE taking into account current design information plus adaptively defined analysis model construction information.
Adaptive Control Tools	Connects to all three SEED ***new*** components, but not outside. Selects and controls simulation models to meet required accuracy level for performance parameters.

Table 3B

Algor Professional Multiphysics	Mechanical Event Simulator Linear and non-linear materials Linear dynamics, heat transfer, fluid flow.
Autodesk Inventor	3D modeling/Assembly Animation Contact Detection/ Interference Analysis
Dynacs DYCOM	3D modeling Multibody Kinematics and dynamics Mechanisms simulation Control system
FEDEM Simulation Software	3D geometrical modeling and animation Non-linear structural dynamics Interaction between structural dynamics and control system Multi-event simulation
MSC ADAMS	FEA Control System simulation
MSC.Dynamic Designer	Kinematics and dynamics
MSC.visualNastran 4D (vN4D)	3D modeling
RAM Perform (Building Performance)	Non-linear modeling Non-linear static and dynamic analysis
Sirona CEREC 3D (for dental restorations)	3D modeling Boundary detection, contact detection Simulation of milling process with thickness constrains
STRAP	Dynamic analysis: seismic, vibrations

Table 4. *Commercially available software with some digital prototyping capabilities*

Conclusion

When placed in the architectural domain, adaptive kinetic structures are extremely complex systems. Investigating the modeling and simulation of adaptive kinetic structures provide opportunities for joint ventures in design among multiple disciplines. Simulation-based design, performance based-design, digital prototyping all become part of the same. Most importantly, this effort extends the vision of the comprehensive building information modeling initiative.

When we consider architecture as a dynamic system we are forced to confront issues of human power, space control, environmental manipulation, material economy, operational effectiveness, and energy investment. An adaptive kinetic structure materializes energy because it approximates a machine, and because it can be seen to mimic a living being. The intent here is not to present them as new commodities, but as ideas architecture still needs to catch up to and grapple with, if it intends to remain present and in conversation with its times, its needs, its machinery.

An integrated platform for evaluating design in architecture is needed. Adaptive kinetic structures provide the subject through which experimental architectural ideas may be tested. It shifts the discussion from digital design to digital prototypes. It recognizes the need, and provides the means for, collaborative interdisciplinary work. It pushes for a shared language that connects and challenges professional expertise without reducing its complexity or its possibilities.

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