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# Kinetic Building Envelopes for Energy Efficiency: Modeling and Products

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**Abstract** Adaptive Building Envelope was discussed in recent years and became a possible solution for energy efficiency. We conducted a study of kinetic building envelopes for energy efficiency in the context of an interdisciplinary design & modeling course in 2010 Fall. The goals of these experimental design & modeling projects are to explore the possibilities of motion modes, the integration with whole envelopes and the potentials of applications, and to provide insight into sustainable design. This paper provides an experimental account of kinetic logics and products, and summarizes kinetic motion patterns and potential applications.

## Introduction

Intelligent, adaptive, interactive, smart and kinetic are often used interchangeably within the field of building envelopes because the processes these words are supposed to denote usually overlap. The kind of envelope is designed to have responsive changes according to stimulus such as climate, human needs, activities or others. In this research, we prefer to use “Kinetic” as the term for this topic because it is more to do with components behavior and dynamic responses. The issue of kinetic building envelopes initially was first demonstrated by the literature “Kinetic Architecture” wrote by William Zuk and Roger H. Clark in 1970. It shows the systematic knowledge about kinetic architecture, also proposed the relations between kinetic responses and outside stimulus [1]. In recent years, the envelopes are gaining importance as a wide-spread movement in sustainable design for environmentally conscious building energy efficiency. Actually, building envelopes’ properties including lighting and thermal conditions are very important design elements affecting final building energy performance [2]. There are some of practices and research consistently justify that kinetic envelopes may offer promising energy savings and indoor comfort [2, 3]. Sponsored by AIA (American Institute of Architects) / BSA (Boston Society of Architect) research fund, our research group was found in Jun. 2010 and related to an international collaboration of Texas A&M University in U.S., Tianjin University and North China University of Technology in China. The research proposes a new design insight into the integration between biomimicry and kinetic building envelopes for building energy efficiency based on BIM parametric design methods [4].

However, at present there is little understanding of the behavioral logics and construction process of kinetic building envelope as a design activity. The current paper provides an experimental account of the kinetic envelopes research in the context of an undergraduate interdisciplinary studio course on building construction & design of the Department of Architecture at Tianjin University. Although this stage was conducted in the terms of a classroom, the goals of this study were both to understand the nature of envelopes’ kinetic logics and to identify opportunities for enabling more effective practice of kinetic envelope design at large. The advantages of experimental accounts of design include three points: 1) it provides a realism kinetic behavior of building envelopes’ components; 2) it shows the possible and effective pattern of these behaviors; 3) the more research may be developed in the context of the big issues like problems and solutions related to domain knowledge of architecture. Thus, the research showed in this paper is a part of whole study.

## The content of the study

**Course introduction.** This course is a project-based undergraduate course, named Building Construction (ARCH 2060062), which includes 20 teams of 5-8 students on assigned modeling projects within 6 weeks. The class introduced some external students from other majors such as mechanical engineering, automation, industrial engineering, material science and biological engineering. Each group needs to do physical modeling work with specific materials, to write a final report and to provide an oral presentation in the end of the semester. In 2010 fall, the course also included guest lectures and instructions by several researchers from other schools like Texas A&M University. The structure of this class embraced a series of lectures following the textbook, small construction exercises (like typical windows, roofs, stairs and etc.), and a final construction & design project which was the experimental kinetic design & modeling projects.

**Final design & modeling projects content.** The aims of these final projects are to explore the possibilities of kinetic modes, the relations of components to envelopes and the potentials of materials for environmental sustainability and building energy efficiency. It includes two major parts: one is the modeling process of kinetic components and its' behavioral modes; another one is to integrate the designed kinetic components into whole building envelopes. The materials including ABS (Acrylonitrile butadiene styrene), glass, wood, film, rubber and others can have reversible changes through mechanical units. In order to facilitate students' creativity on this issue, we conducted two lectures in terms of case studies and literature reviews about kinetic envelopes design before the students started the modeling works. The procedures of the projects are according to week-tasks: 1)1$^{st}$ week ---- To search information and do literature studies, and in turn to summarize the results; 2) 2$^{nd}$ week ---- To propose design plan and elaborate detailed methods by using hand drawings and computer modeling; 3) 3$^{rd}$ ~ 5$^{th}$ week ---- To conduct physical models manually, but some specific materials and shapes can be done through laser cutter, rapid prototyping technology and other tools; 4) 6$^{th}$ week ---- The teams need to present their final designs during the final week of class and submitted a final report, which includes the potential applications in terms of environments and energy.

As instructors and observers, we collected all course materials, documented discussion contents. Also, the kinetic designs can behavior and motion, thus we took the videos for recording the process and mechanism of these kinetic models.

## Kinetic envelopes design projects

This section provides a summary of two of the final design projects submitted by the design teams that highlight responsible behaviors to climatic factors. In Section 4 these practices are tabulated for all projects and emergent patterns of practice are noted.

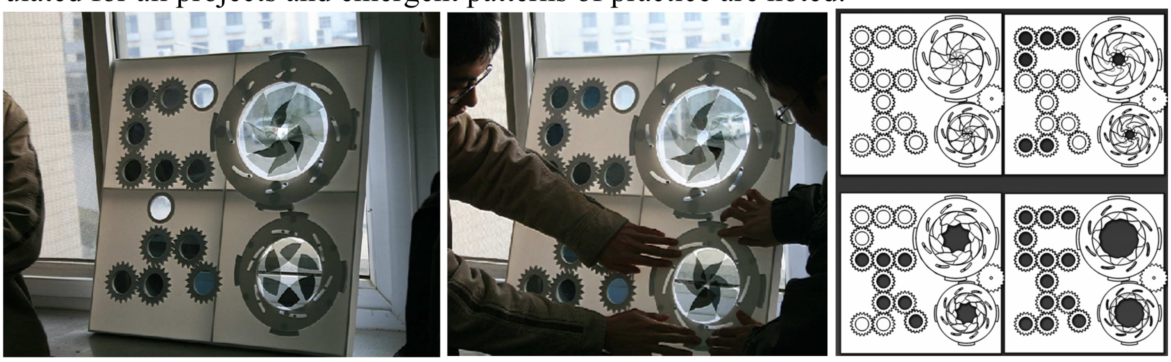

Figure 1. Gear-window project and its motion process

**Gear-window.** The Gear-window project (Fig. 1) followed the logics of camera shutter relations by setting a series of interconnected gears. Thus, the pattern of motion is named as "Rotational Motion". In this system, the most important parts are made of polarizer units which can change the transmittance of incident light. When two polarizer overlap, the transmitted lighting level will be lower (the minimum will be arrived when the two polarizer are perpendicular). Two polarizers' units and a group of interconnected gears are composed to form a rectangular panel which is easier to be organized for a whole building envelope. The deep meaning of this kinetic component is the responsive behavior for responding to outside sunlight level. In the result, the indoor lighting environment will be balanced and save the electrical lighting energy. Actually, from the reframed problem, the designers found several important sources including human eyes' adaptation, the model of camera, and the Arab World Institute designed by Jean Nouvel in Paris.

**Water-filled wall.** Elastic materials including inflated or water-filled material can change shapes and properties following external forces from human, rain, wind or others. This project named "water-filled wall" (Fig. 3) is designed by PEF (High pressure polyethylene) materials and metal frames, and can be set onto traditional walls. From the perspective of building energy efficiency, through the motion of filling water will enable the walls' U-value to be changed and in turn affect thermal transfer from outdoor to indoor environment. From the interactive needs, the flexible construction can change its shape to respond to the human activity.

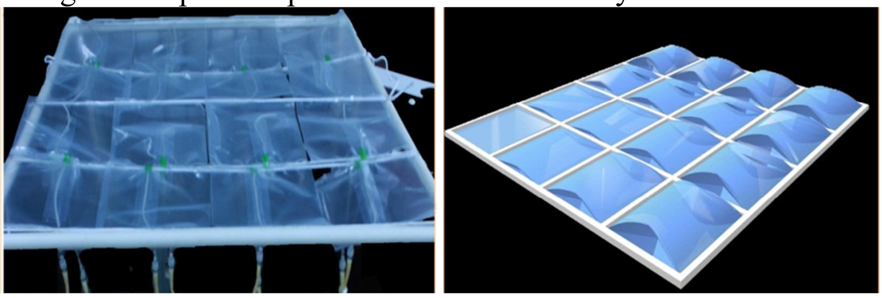

Figure 2. Water-filled wall project

**Sliding room.** This project (Fig. 3) is at the different scale compared to other products, and concentrates on the building thermal responses for different outdoor climate conditions. The track or rails are the central for the sliding room, so some rooms with solar room ability (absorbing solar radiation through windows and store the heat through mass) can slide from day to night in winter. In summer, it also may slide according to outside temperature. For instance, at night or rainy day, the room can slide out to get heat loss quickly if the outside temperature is appropriate. The ideal result involves the energy saving on cooling and heating building environment.

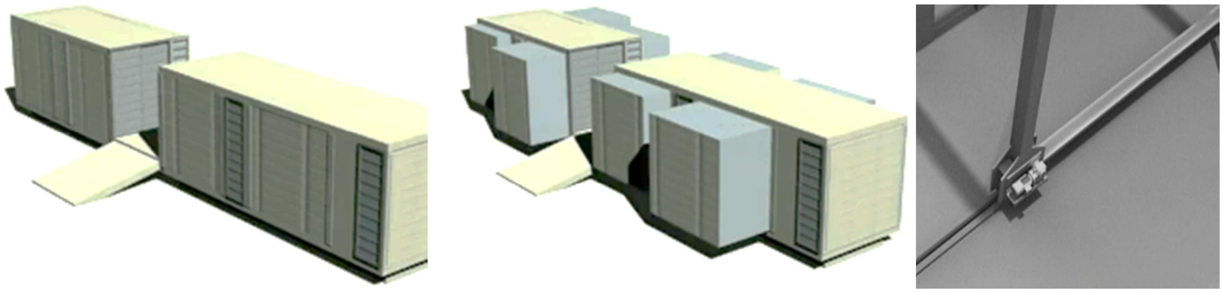

Figure 3. Water-filled wall project

## Analysis of kinetic envelopes

**Integration to whole building envelopes.** In terms of integration methods, we can group them into three categories: deployable, dynamic and embedded (Fig. 4). The deployable kinetic panels mean that those components are existing in a temporary location, and can be easily moveable; the dynamic system refers to some existing kinetic components on a whole envelope, but it can act independently with respect to control of the larger context; and the embedded system exists a part of the building as a whole, acting upon the building through the envelope or skin. They are usually fixed in location and do not act independently of the building.

Based upon our studies, the embedded systems are more suitable to energy efficient goals at the whole building level. The embedded kinetic units can most impact on the building users and their comfort by controlling such factors as light, thermal comfort, and ventilation. Regardless of the reason for using a kinetic system, they all must use various methods for the actual movement of components. These methods can include numerous categories and sub-categories, but only several aforementioned ones are described. These methods of movement refer to the various mechanical motions needed to make a component actually move, as the next section elaborated.

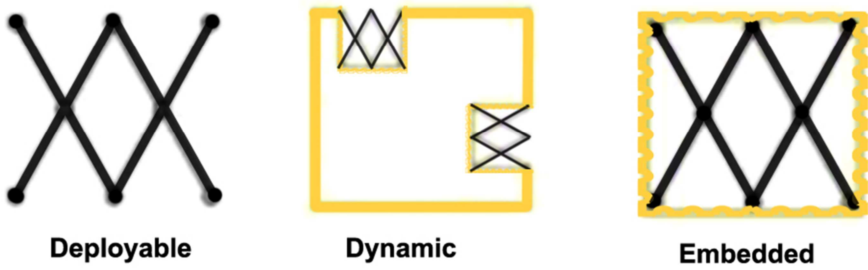


Figure 4. Three intergration ways: deployable, dynamic and embedded

**Patterns of motion.** We recorded all of design projects and observed the process of motion for each model, based on many case studies, and then summarized the patterns of motion, related to kinetic building envelopes, into five types: rotational motion, retractable motion; sliding motion, elastic motion, self-adjusting motion. Each type has its own features on motion modes, materials, and ways integrated into building. The following table shows the related characteristics and usual applications.

Table 1. Five patters of motion for kinetic building envelopes

| | Rotational motion | Retractable motion | Sliding motion | Elastic motion | Self-adjusting motion |
|---|---|---|---|---|---|
| Key element | Central pole or point, rocker | Plate, hinge, hub | Rail, track | Frame | Frame |
| Modes | Rotation with or without axis | 2D or 3D stretch, contract | Slide or glide on the fixed rails | Expand or shrivel | Physical properties' self-regulation |
| Material type | Rigid material | Rigid material | Rigid material | Flexible materials filled air or water | Electrochromic, photochromic, thermochromic materials |
| Applications | Solar control, wind energy generator | Solar control, daylighting, ventilation | Thermal control, ventilation, daylighting | Thermal control | Daylighting control, ventilation |

## Conclusions

Kinetic design is a nascent but rapidly growing area of design research. In this paper, we have analyzed the modeling experiments of kinetic envelopes design in terms of some design products. The introduction of kinetic envelopes that can moderate and adapt to various settings introduces a new way to control the environment. Hoberman [5] states that adaptive systems combine the best of existing strategies: low energy use and control over building environments. For instance, a building's energy requirements can be considerably lowered if its design can adapt to diurnal fluctuations in temperature. An adaptive system that is modulated to control the volume and direction of heat flow in response to external and internal conditions can enhance comfort and energy performance. Based upon our research, the potential applications of kinetic envelopes as an environmental mediator can contribute into the responses to four major variables: solar thermal control, daylighting control, ventilation control, and energy generation.

The construction and design possibilities of building kinetic envelopes have not been the only advancement that will encourage their adaptive abilities; the advancements in the computation technology have greatly increased their potential. Designers are now able to do complex simulations of the proposed systems in order to achieve the best possible solution with computation fluid dynamics (CFD), daylighting, and thermal transfer programs. Also, recent years' digital prototyping technologies enhance time and effectiveness during the construction process especially at materials scales. The technology is far advanced, but may not be there yet, as Moloney's claims that the design simulation to achievable construction is complicated by the kinetic requirement [6]. The degree and speed of translation and rotations in the physical world are constrained by both the geometry of the components and the mechanics of the kinetic system.

Currently, we are conducting the similar experimental modeling study related to kinetic envelopes for the class in 2011 Spring and will continue it in 2011 Fall. The results will support the whole study on bio-inspired kinetic envelopes. Regarding the future works, combined with the studies of biomimicry and the analysis of building energy transfer from envelopes, we can further the design of kinetic envelopes to the building scale by embedded methods, and test the envelopes' responses to climate and the energy performance of whole building in a real world.

## Acknowledgements

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2.Tianjin University Excellent Course Fund: Building Construction

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