Kinetic, an innovative approach in contemporary architecture

Narges Afzali
MA Student, Department of Architectural Engineering, Karaj Branch, Islamic Azad University, Karaj, Iran
Email: narguess.afzali@gmail.com

***Sara Hamzehloo**
Assistant Professor, Department of Architectural Engineering, Karaj Branch, Islamic Azad University, Karaj, Iran
Email: sara.hamzehloo@gmail.com

*Author for Correspondence

Abstract
There have been a variety of architectural scales and applications for using kinetic systems in architecture in the past and is continuing to be used today. Due to advancements in technology; its application has become more practical in architecture. More of it can be found in the twentieth and twenty-first centuries. In the early twentieth century, kinetic systems were more theoretical aspects of science, but in the late twentieth century, due to improvements in various fields such as mechanics, electronics and robotics, creating kinetic buildings became more practical and popular. This paper aims to introduce the concept of kinetic as a novel approach in contemporary architectural design, and review its history in architecture from the past to the present. The method is a descriptive and analytical study that, after considering all kinds of kinetics, concludes with an analysis of its functional aspects. Today, the kinetic approach in architectural design can lead to the creation of flexible structures that respond to their occupants, meet more needs as well as provide solutions to environmental problems and urban issues. Kinetic systems, with their living structures, should be considered in future designs, so that by interacting with their occupants and environment, they could lead to the creation of more efficient living spaces.

Keywords: Adaptability, Flexibility, Interactive, Kinetic architecture, Mobile architecture

Introduction

Today, because of the wide range of information, real progress comes to a hybrid look and generally the creation of interdisciplinary sciences in the second half of the twentieth century is very important for the future of science. In the field of interdisciplinary science, the collision of ideas makes progress. (Taraz et al, 2015). Therefore the study said one of the achievements of various sciences combined with architecture is kinetics and its application in contemporary architectural design. Although the kinetic and dynamic structures in architecture have history and they've used in different scales of applications, in the late twentieth century with the development of science, such as mechanics, electronics and robotics that have opened up new possibilities leading architecture, applications of dynamic architecture were intensified(Moor,2003).

In the early decades of the twentieth century, dynamic architecture was completely theoretical perspective but in 1970 William Zuk published a book called kinetic architecture that inspired a new generation of designers in the process of creating a wide range of flexible buildings (Zuk, 1970). In this study, first by using existing definitions and studies in the field of kinetic architecture, origins and meaning of the kinetic in architecture will be discussed. Then the history and progress of this approach in contemporary architecture will be analyzed with referring to the built examples (case studies). So the development and optimization techniques to achieve this approach would become easier and the appropriate combined methods in the future design would be considered in order to achieve the most optimal responses.

1- The definition and concept of kinetic architecture

The kinetic concept originated in art. Artists at the beginning of the nineteenth century started to make their sculptures that reflected movement. The "wooden merrier" by Daniel Rozin in 1999 is an example of kinetic art that uses electronic technology. The kinetic art has been also introduced in architecture as art pieces in building and sometimes within the building; Ralfonso (2004) (Figure 1) gives examples of kinetic art that merge in architecture; a sculpture like Exocentric Spirits that is suspended in indoor space.

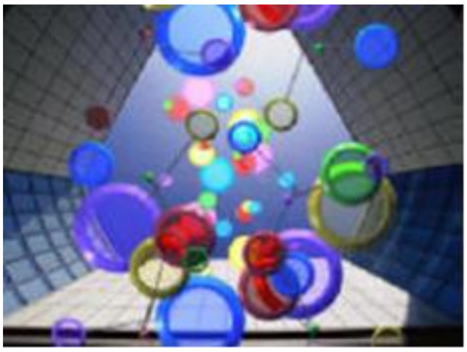

Figure 1 .Exocentric. (Sherbini et al, 2004)

In architecture, kinetics has been used by nomadic tent-dwellers. The tent is a kinetic structure since people can fold it up and carry it. The kinetic structure as a folding and portable system is still seen in kinetic architecture. Fox (2000) for example, defines kinetic architecture as "a building with variable location or mobility and/or variable geometry or movement." He was describing various types of kinetic systems; one of which was the folding system. So the kinetic concept is not originally an intelligent one, but it represents the ability of controlling the structure by moving part or all of it. The

new direction is to introduce the kinetic concept to the intelligent as one of the responses that may alter the form of the building.

The next step starts with the definition by Oosterhuis (2003), which states that kinetic architecture "refer[s] to a building that [is] controlled by sensorsactuators system to be able to respond according to the data received in form of movement." (Sherbini et al, 2004). Thus, according to the definition of the concept of kinetic, in order to better understand its practical application in the field of architecture, first the history of mobility in architecture and conducted theoretical studies from past to present will be studied and then international experience in this field as well as the progress and achievements, will be discussed.

2-1- Background tends to create dynamic architecture

There has been kinetics' practical experience in the distant past including movable bridges in the medieval and earlier and also compounds canopy structures in ancient Romans that were used in a number of sports fields (Moore, 2003).

2-2- Experiences in the 60s and 70s

The first concepts of an adaptive, responsive architecture as it is understood today were born in the late 1960s and early 1970s, primarily as a result of developments in cybernetics, artificial intelligence, and information technologies. Such architecture, however, was first envisioned in science fiction. James Graham Ballard, a British novelist, described in a short story from 1962 a "psychotropic house," a machine-like, mood-sensitive house that could respond to and learn from its occupants, becoming "alive" as it was occupied. (Ballard, 2001) The imagined responsive house was made from a material Ballard referred to as "plastex," a combination of plaster and latex that allowed the house to change its shape as needed. The house also had many "senso-cells," distributed all over it, which were capable of "echoing every shift of mood and position of its occupants." (Kolaveric & Parlak, 2015)

Ron Herron's Walking City hypothetical project from 1964 (Figure 2) imagined cities as giant mobile, transformable robotic structures that could move to wherever their resources were needed. Intelligent, robotic buildings -self-contained "living pods"-would move within the cities; the pods were envisioned as independent, yet parasitic: they would "plug in" to way stations to replenish resources, moving, connecting, and disconnecting as instructed (Figure 3). The cities could interconnect to form larger metropolises or disconnect and disperse as required or desired.

Figure 2- Ron Herron's Walking City (Archigram, 1964) (Thun & Velikov, 2012).

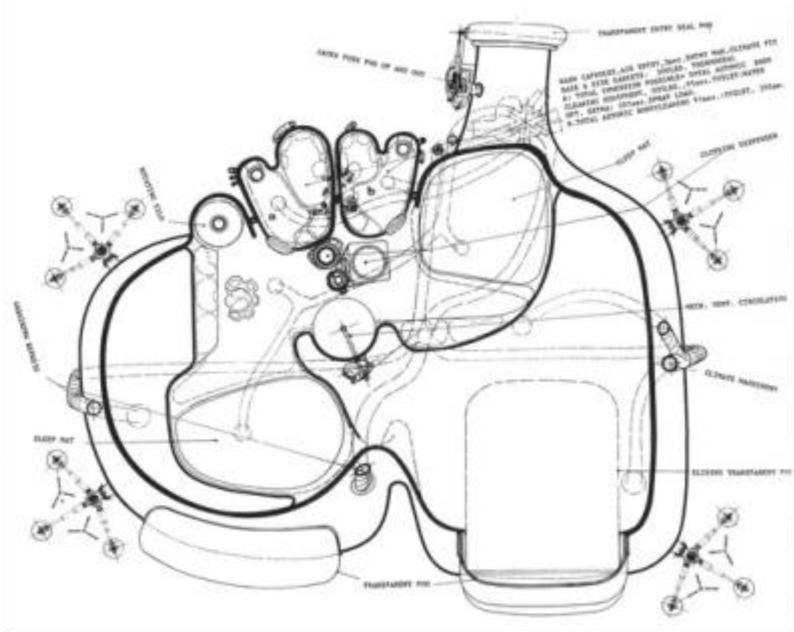

Figure 3- David Greene's Living Pod (Archigram, 1966). (Thun & Velikov, 2012).

While Ballard and Archigram's Herron and Greene were among the first to envision "alive," changeable buildings and cities capable of interacting among themselves and with their occupants, Gordon Pask, as an early proponent of cybernetics in architecture, is often credited with setting the foundations for interactive environments in the 1960s with his concept of Conversation Theory,(Pask, 1969) intended as a comprehensive theory of interaction. Pask's ideas had a tremendous influence on both Cedric Price and Nicholas Negroponte, with whom he collaborated. Cedric Price adopted concepts from cybernetics to articulate the concept of "anticipatory architecture," demonstrated by his seminal Fun Palace and Generator projects. Nicholas Negroponte proposed in 1975 that computing power be integrated into buildings so that they could perform better, turning buildings into "architecture machines" that are "assisted, "augmented/ and eventually replicated' by a computer."(Negroponte, 1975) The aim was to "consider the physical environment as an evolving mechanism." In the last chapter, he made a prediction that "architecture machines" (in the distant future) "won't help us design; instead, we will live in them." (Kolaveric & Parlak, 2015) At roughly the same time that Negroponte was working on his "architecture machines," Charles Eastman developed in 1972 the concept of "adaptive-conditional architecture," (Eastman, 1972) which self-adjusts, based on the feedback from the spaces and the users. Eastman proposed that automated systems could control buildings' responses. He used the analogy of a thermostat to describe the essential components: sensors that would register changes in the environment, control mechanisms (or algorithms) that would interpret sensor readings, actuators as devices that would produce changes in the environment, and a device (an interface) that would let users enter their preferences. That is roughly the component make-up of any reactive system developed to date (Kolaveric & Parlak, 2015).

In addition to interactivity and adaptability in these two decades, the debate was highly regarded intelligence in buildings and kinetic was considered as a tool to provide this purpose. The widespread availability and use of mechanical conditioning equipment during the postwar era was certainly a factor in the development of intelligent buildings. This mechanically regulated environment released the building envelope from its primary role as thermal barrier, calling into question its very necessity – an observation eloquently developed by Reyner Banham and Francois Dellagret in their 1969 article "A Home is Not a House".

The use of mechanical systems for interior climate regulation resulted in buildings designed with ever increasing amounts of glass, which in turn necessitated variable shading and ventilation as an integral part of the envelope.

As buildings often follow on the heels of advancements in the automotive and household appliance industries, the rise of automation was another factor which led to the development of intelligent building envelopes.One of the first automated climate-adaptive envelopes was Buckminster Fuller's façade for the United States pavilion built for the 1967 Montreal Expo (Figure 4). The skin of this geodesic dome was made of a transparent cladding of acrylic panels, with interior canvas sunshades controlled by a computer program that would adjust their position relative to the movement of the sun (Thun & Velikov, 2012).

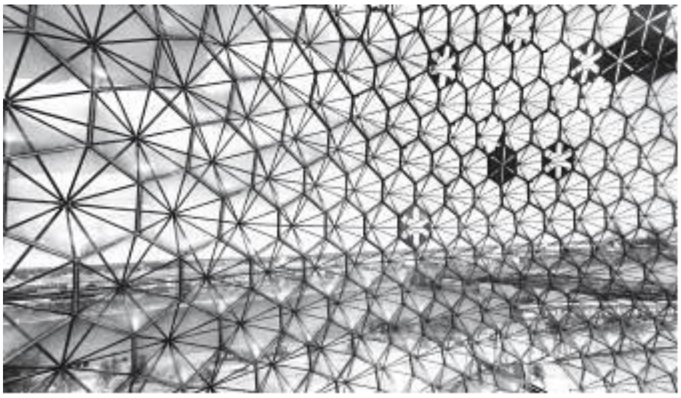

Figure4- Buckminster Fuller's façade for the United States pavilion.1967(Thun & Velikov, 2012).

2-3 Experiences in the 80s until the present

After much initial interest in the late 1960s and early 1970s, not much happened in the next two decades, with the exception of Jean Nouvel's Institut du Monde Arabe (Figure 5) (Kolaveric & Parlak, 2015).L'Institut du Monde Arabe was designed as a cultural center in Paris in 1988 by Jean Nouvel. Inspired by Arabic patterns, his idea was to incorporate numerous mechanically driven lenses to interactively respond to light. Being a very advanced implementation at the time, the dynamic modules turned out to be expensive to maintain, susceptible to erosion and noisy.(Tashakori,2014)

Figure5- Kinetic curtain wall at Jean Nouvel's Institut du Monde Arabe (1989) in Paris, France. (Kolaveric & Parlak, 2015)

With greater attention to buildings' energy demands and increasing capacity to monitor and manage energy use, the building envelope became the locus of technological innovation in the late 1990s. As emphasis shifted away from simply creating energy barriers (to block heat gain or heat loss) towards

harvesting energy from the environment and channeling it where it is needed, architects and engineers started to incorporate electronically controlled, mechanically activated shading and ventilation systems into building façades. Double-skin façades with a controlled vented air cavity and operable, integrated shades or blinds started to emerge in the 1990s. Then over the last decade, adaptive, kinetic or dynamic façades, active and high-performance building envelopes entered architecture's vocabulary – and practice.(Kolaveric & Parlak, 2015)
The ability for a building envelope to change and adapt its configuration relative to the sun (either by blocking its rays to prevent overheating and/or glare, or by allowing them to penetrate for passive heat gain and/or daylighting), has been a primary source of formal and technological innovations in intelligent building skins. The Terrence Donnelley Centre for Cellular and Bimolecular Research at the University of Toronto, completed in 2006 by ArchitectsAlliance and Behnisch Architekten, has a south facing double skin façade with intelligently controlled internal blinds and ventilation louvers that together manage light, heat gain and natural ventilation in this energy efficient, all-glass building (Figure 6). (Thun & Velikov,2012)

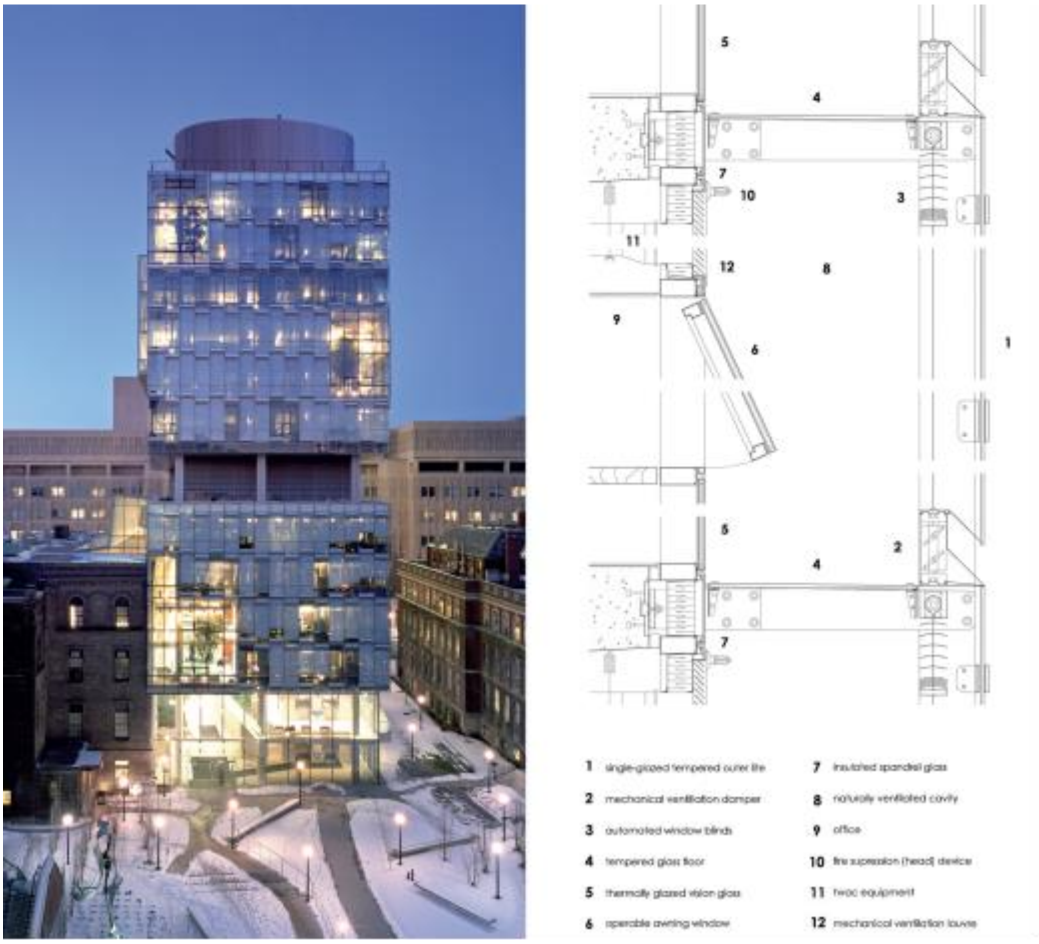

Figure6- Intelligent double-skin façade system with integral automated shading for the Terrence Donnelley Centre for Cellular and Bimolecular Research at the University of Toronto, architectsAlliance/ Behnish Architekten, 2006(Thun & Velikov,2012).

In 2008, engineering firm Buro Happold, in collaboration with deployable structures innovator Chuck Hoberman, have established an intelligent surfaces unit called the Adaptive Buildings Initiative (ABI). This design unit has developed a number of kinetic shading and cladding systems, including the Strata™ System, which consists of automated modular kinetic units that can retract into a slender profile (Figure 7). The Strata™ system was the basis for the Helio Trace Façade, developed in collaboration with SOM and the Permasteelisa Group, that improves envelope performance relative to daylight and glare while reducing solar heat gain by as much as 81 percent (Figure 8)(Thun & Velikov, 2012).

Figure7- ABI Strata™ System demonstrated in the continually transforming Emergent Surface exhibition at MoMA, 2008 (Courtesy of ABI) (Thun & Velikov, 2012).

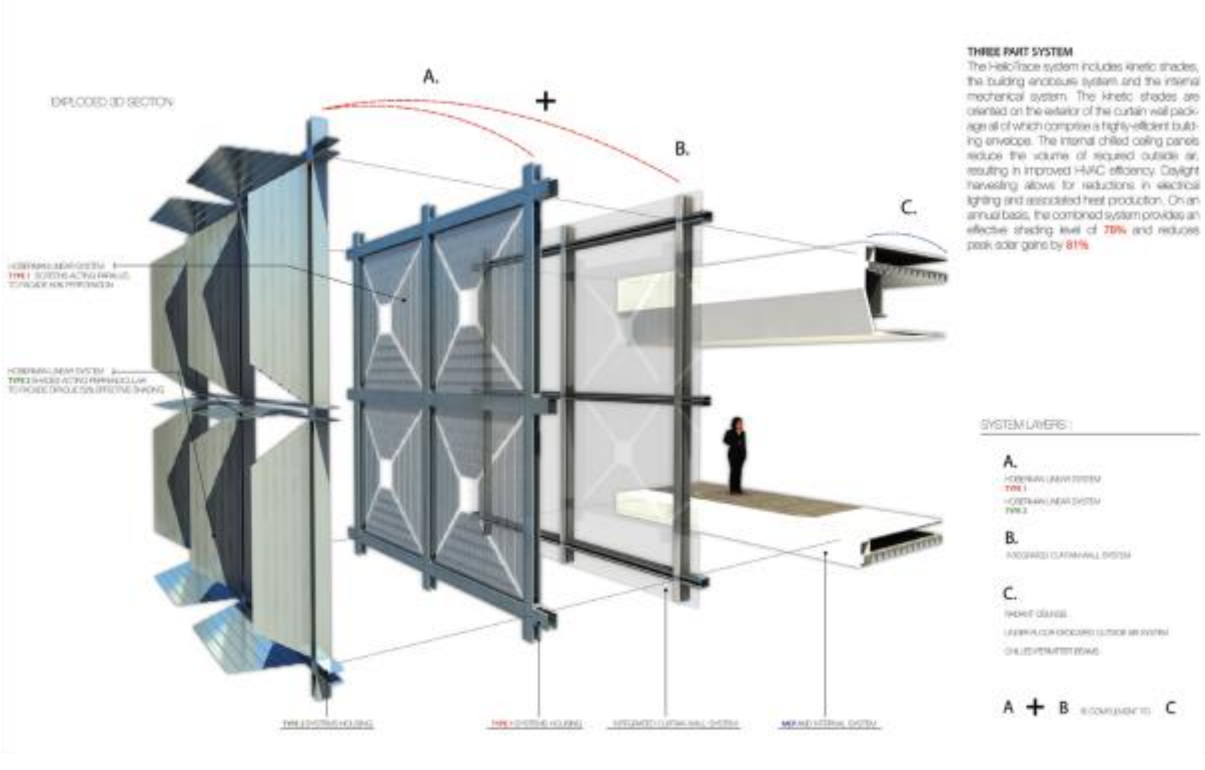

Figure8- The awardwinning HelioTrace , Adaptive Façade system by SOM/ABI/ Permasteelisa, 2010(Thun & Velikov, 2012).

The Media-TIC building, constructed in Barcelona in 2011 and designed by Cloud 9 Architects and envelope specialists Vector Foiltec Ltd. The envelope features a pillow cladding system made of the polymer ETFE with encased lamella fins whose pneumatic mechanisms are automatically activated by light sensors that respond to the presence of solar energy (Figure 9) (Thun & Velikov,2012).

Figure9- Smart envelope comprised of ETFE encased solar-activated lamella shades developed for the Media-TIC building in Barcelona, Cloud 9 Architects, 2011(Thun & Velikov,2012).

One of the most recent examples made in the context of kinetic envelopes is the Al bahr towers that were built in 2012. Sunshades on the towers facades are the most important idea that works with solar energy batteries and can control the amount of light entering in the spaces. Special mechanisms projected to move accordingly and each of them is like a paper flower that can be easily opened and closed. They are on the front to control the amount of light passing through. The sunshades will be closed as needed so that they reduce large amounts of outside light and the heat from it (Figure 10,11) (Khabazi, 2014).

Figure10- The Al bahr towers. (Khabazi, 2014)

Figure 11- Details of the Al bahr towers (Khabazi, 2014)

The notions of adaptivity and responsiveness are not limited to building envelopes only. There is an emerging interest in dynamic structures that could enable buildings to change their overall shape and internal configuration, either in response to environmental conditions or different programmatic or use arrangements. If not changing its shape, the building, for example, could reorient itself through rotation so that it always presents a smaller surface area to the sun, as was proposed by OMA in 2005 for a large office building in Dubai (Figures 12). Greg Lynn describes his RV (Room Vehicle) Prototype House as having a small footprint of 60 m^2 but 150 m^2 of usable surface area, which is accomplished by rotating the house around two axes on a robotic base, so that its one wall and ceiling become floor surfaces (Figures 13). According to Lynn, the “dwelling challenges the sedentary typologies of a home and introduces a new one based on movement and interaction.”10 The Sharifi-ha House (2013) in Tehran, Iran, designed by Nextoffice (Alireza Taghaboni), features entire rooms that rotate in and out of the building’s volume to either open or close it, exposing or protecting the interior from the seasonal weather (Figures 14) (Kolaveric & Parlak, 2015).

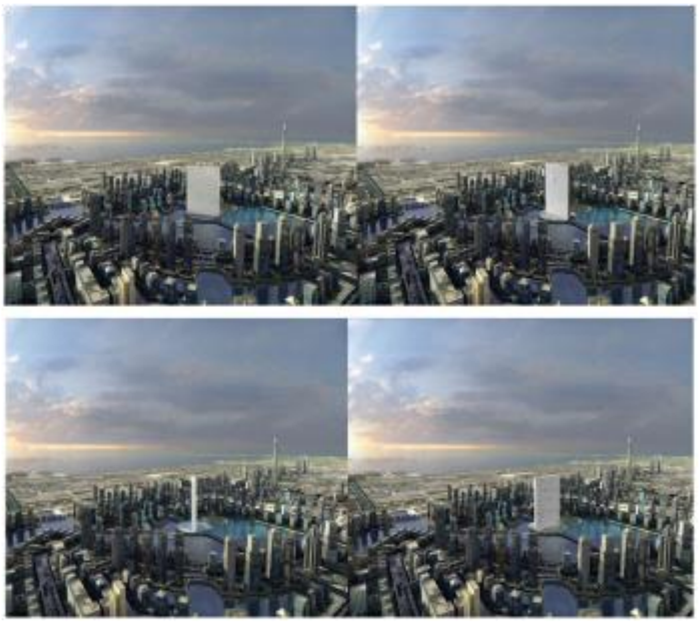

Figure12- OMA’s design for a building in Dubai (2005) that would rotate around its vertical axis, so that main façades would receive no direct sunlight. (Kolaveric & Parlak, 2015).

Figure13- Greg Lynn's RV (Room Vehicle) Prototype House rotates to increase the usable space of a house. (Kolaveric & Parlak, 2015).

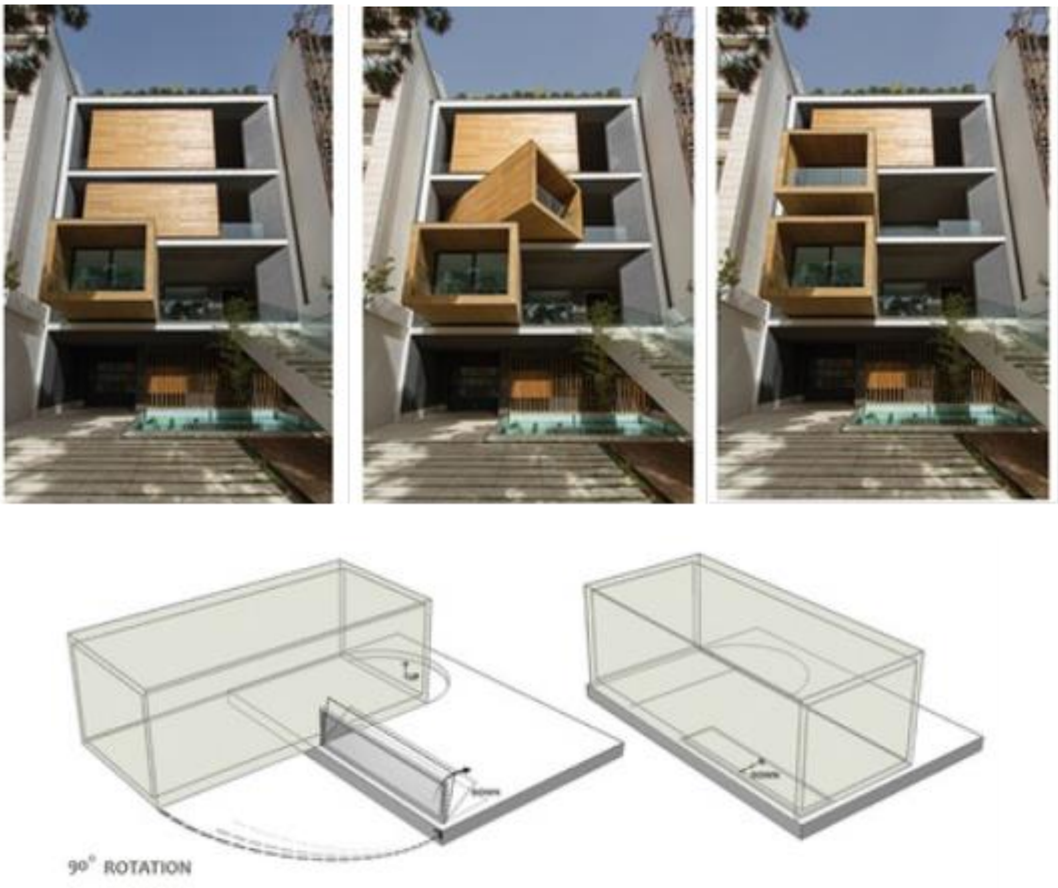

Figure14- The Sharif-ha House (2013) in Tehran, Iran, designed by Nextoffice, features entire rooms that rotate in and out of the building's volume (Kolaveric & Parlak, 2015).

Referring to the primary kinetic strucure examples , famous architect Santiago Calatrava has two well-known works named Kuwait pavilion and Milwakee art museum.His tends to use natural daylight creates his kinetic works.

Kuwait Pavilion was built in 1991-1992 and it is a symbolic structure which was commissioned at the behest of the emirate for the 1992 World's Fair in Seville, Spain. The roof structure is made up by mobile elements which come together as tapered fingers of two hands, or better in this case, as the leaves of two palm branches. Seventeen 25 meter long finger elements, constructed in timber and supported by hydraulically operated reinforced-concrete columns, interlock to form an impenetrable vault and then unfold to reveal the gentle barrel-shape of the 525 square meter piazza. The piazza is glazed with panels of laminated structural glass and translucent marble that illuminate the gallery bellow during the day and grow with an enigmatic inner light at night when uncovered. When half closed, the roof casts light and shadow on the piazza bellow, providing protection from the sun, like a palm shaded oasis (Figure 15) (Tzonis,1999).

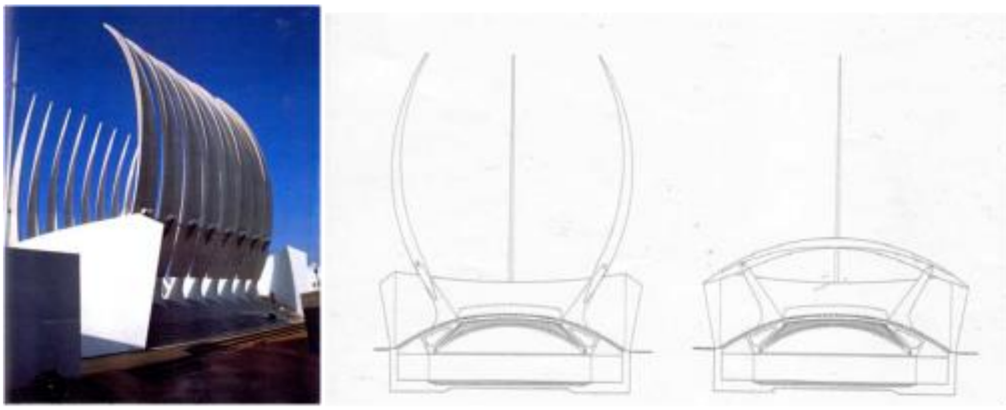

Figure15- Kuwait Pavilion (Tzonis,1999).

In 1994, Santiago Calatrava assumed responsibility to design and construct the area of 13,000 square meters for additional space to the original museum building that was designed in 1957 by Eero Saarinen. The extension building that was completed in 2001, is now the most important characteristic of the museum and the city of Milwaukee. The number of visitors increase from 1,000 to 5,000 visitors per day. The design, consists of two main parts, the entrance and huge multi-purpose hall that has a dynamic roof and some of it has gone down below the ground. Multi-purpose hall enjoys a good light in the parabolic form and the ceiling height is about 30 meters and over it there is a bird-like solar panel that has 72 steel flakes to control temperature and light, like a bird flapping around an axis goes up and down (Figure 16) (Talebian et al, 2011).

Figure16- Milwakee art museum (Talebian et al, 2011).

Today, with the development of technology kinetic architecture is growing, and more buildings are designed and built with this approach. Which are known as smart kinetic systems.

3- Intelligent Kinetic Systems

Intelligent kinetic systems are architectural spaces and objects that can physically re-configure themselves to meet changing needs. In these systems, computer systems will interpret functional circumstances and direct the motor-controlled movements to change responsively and adaptively to optimize usage needs. Intelligent kinetic systems arise from the isomorphic convergence of three key elements: structural engineering, embedded computation and adaptable architecture.

3-1- Structural Engineering

Concerns in structural enginering are focused 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. Kinetic systems are classified into three main areas of research interest: Embedded, Deployable, and Dynamic kinetic structures.

3-2- 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 motorcontrolled movements to change adaptively to better suit changing human needs. 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.

3-3- 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. Robert Kronenberg aptly states how 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.

4- Kinetic Typologies

Kinetic systems are classified into three general categorical areas of research interest: Embedded, Deployable, and Dynamic kinetic structures.

4-1- 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.

4-2- 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.

4-3- 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 (Figure 17) (Fox, 2001).

Figure17- Diagram of Kinetic Typologies in Architecture (Fox, 2001).

Conclusion

There have been a variety of architectural scales and applications for using kinetic approaches in architecture. In the late twentieth century, due to improvements in various fields such as mechanics, electronics and robotics, more practical works in kinetic architecture were created by architects. With the emergence of automation, greater attention to buildings' energy demands and the increased capacity to monitor and manage energy usage, the building envelope became the locus of technological innovation in the late 1990s. Finally, these concepts were not only lead to the building envelope and also kinetic structures were noted. With the advancement of robotic technology in the last decade, the possibility of moving in three dimensions has first been seen in smaller houses, and then in large-scale construction. This progress would not have been possible without the development of other technologies and fields associated with architecture, which puts a greater emphasis on the architects' relationship with the other fields' experts.

Today buildings must be flexible to respond to their occupants' needs, and this flexibility has a direct relationship with their mobility. Considering the use of the kinetic approach in architectural design, could lead to the creation of flexible structures which are smart and occupant responsive. In the past centuries, kinetic architecture was a theoretical concept, discussed only in science fiction stories, and was not considered affordable; today with the advancement of technology, building these structures and envelopes, not only provides aesthetic issues and respond to the occupants' demands but it also can provide solution to the urban environmental problems. Although today, creating an interactive and responsive architecture with movable structures does not seem cost effective, in the future, this living structure would be able to self-restore and would develop the urban environment. As a result, kinetic systems in architecture would be considered economically justified as a profitable approach.

References

1. Ballard, James G. (2001). the Thousand Dreams of Stellavista. in Vermilion Sands. London: Vintage, originally published in 1962, then 1971.

2. Eastman, Charles (1972). Adaptive-Conditional Architecture in N. Cross (ed.), Design Participation: Proceedings of the Design Research Society Conference. London: Academy Editions. 51–57

3. Fuller Moore (2003). Understanding Structures, Translated by : Dr. Mahmood Golabchi, Tehran : Tehran university press.

4. Fox MA, (2001). Sustainable applications of intelligent kinetic systems, , Singapore: Second International Conference on Transportable Environments

5. Kolaveric, B. & Parlak V. (2015). Building Dynamics: Exploring Architecture of Change Londan, New York: Routledge.

6. Negroponte, Nicholas (1975). Soft Architecture Machines. Cambridge, MA: MIT Press.

7. Oosterhuis, Kas: 2003, Hyperbodies: Towards an e-motive architecture.

8. Pask, Gordon (1969). Architectural Relevance of Cybernetics, Architectural Design, September, 494–496

9. Tashakori, Mahzad (2014). Design of a Computer Controlled Sun-Tracking Façade Model, Submitted in Partial Fulfillment, The Pennsylvania State University The Graduate School College of Arts and Architecture

10. Tzonis ,Alexander, (1999) Santiago Calatrava, The Poetics of Movement, Thames & Hudson Ltd, London

11. Sherbini, Kh. & Krawczyk, R. (2004) Overview of Intelligent Architecture, 1st ASCAAD International Conference, e-Design in Architecture, Dhahran, Saudi Arabia.137

12. Talebian, Nima. Mehdi, Atashi and Sima Nabizadeh. (2011). Museum. Publications: Specialized architecture and urbanism Ketabkadeh kasra. First Edition.

13. Taraz, Masoumeh. Taghizadeh, katayoon. and Azizi, Mehrad.(2015). Energy analysis and the efficiency of a dynamic façade in Tehran . Quarterly Journal of Naghsh-e Jahan. No.5. 55

14. Thun, G.; Velikov, K. (2012). Responsive Building Envelopes: Characteristics and Evolving Paradigms. In Design and Construction of High Performance Homes; UK: Routledge Press: London, 75–92

15. Khabazi, Zubin.(2015). Digital design processes. Publications: Specialized architecture and urbanism Ketabkadeh kasra. First Edition.

16. Zuk, William and Clark, Roger H. (1970). Kinetic Architecture, Van Nostrand Reinhold.