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Kinetic Architecture: Concepts, History and Applications

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Abstract: ***Over history, architects tried to convert buildings from a static object to a dynamic system to attain the changing needs of residents. From this concept, they tried to create spaces, building components and buildings that have the ability to take an action from people or the surrounding environment, such as movement, sound, light, wind, heat or humidity. This reaction is achieved by using computation and kinetic systems to achieve adaption with the environment and apply user's needs. This paper provides an overview of kinetic architecture related concepts and definitions. Then, it outlines the history of kinetic architecture. Finally, it presents the kinetic concept applications in architecture and highlights its implementations in environmental design.***

Keywords: Kinetic Architecture, facades, structure

1. Introduction

Substantially, buildings are affected by infinite influencing forces such as time, weather, functions and human needs, these forces are not static and fixed, but rather dynamic and transient. As a result, there is a need to develop buildings as complex systems adjusted to climate and energy optimization [1].

Recently, architects tried to respond to constantly changing human needs by using many design techniques and technologies. The most outstanding technique is kinetic architecture, which was presented by William Zuk and Roger H. Clark in the early seventies in their book "kinetic architecture" .They imagined transformable buildings able to change their physical geometries, such as stadiums with movable seatings and retractable roofs, and flexible buildings with air-filled or revolving structures [2].

The rest of this paper is organized as follow: Section 2 describes Kinetic concepts and definitions in architecture. The kinetic architecture history is introduced in Section 3. Applications of kinetic architecture are discussed in Section 4. Finally. The conclusion is presented in Section 4.

2. Concepts and Definitions

Historically, humans used their building to provide shelter from external weather conditions, like rain, wind, heat and cold. So, the building envelope acts as an outer shell that controls internal climatic conditions and maintains indoor comfort. Therefore, Majority of modern building constructions are made to enhance indoor climate. Depending on this consideration, Improvements in design and construction of building plays an important role in researches for intelligent architecture.

First, the research presents these concepts and definitions such as, intelligent architecture, interactive architecture, responsive architecture, adaptive architecture, and finally responsive kinetic architecture. The aim is to introduce an overview of the adaptive kinetic architecture and all concepts related to it. Figure 1 shows the concepts and definitions which will be presented in the following subsections.

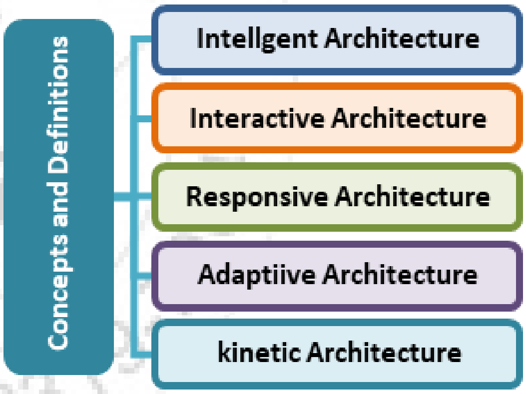

Figure 1: Mentioned concepts and definitions

2.1 Intelligent Architecture

Intelligent architecture concept was introduced to control and manage buildings with a communication between building systems and users. This is attained by using high tech abilities to achieve user's needs, like comfort, productivity, energy saving, return investment, and life cost decreasing. The "building systems" includes all systems that control a building like HVAC, mechanical, structural, lighting control, access control, security, building management, maintenance, local networking, and energy management as illustrated in Figure 2 [3].

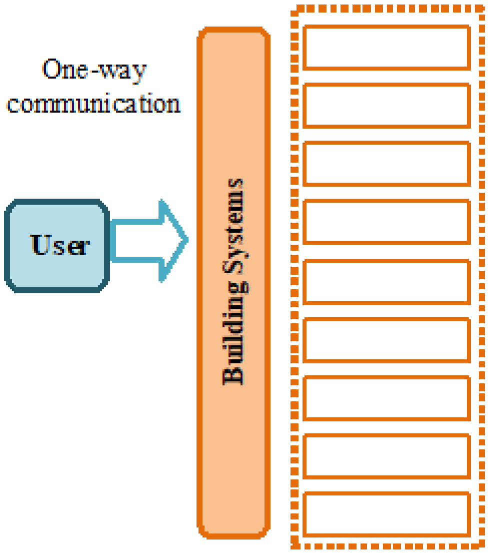

Figure 2: Intelligent Architecture concept

2.2 Interactive Architecture

It is defined as an interactive interface between humans and computers. It considered the building as an enclosure defines a space, which supports some activates. The building enclosures like walls, floor, and ceilings act as interactive spaces. This type of architecture doesn`t deal with people as users but as participants [4].

It is based on two ways communication between people and built components which are divided to: input, processing and output (IPO) devices [5]. The design space of interactive architecture can be categorized in three dimensions as shown in Figure 3 [6]:

1) Sensible spaces
2) Thinker spaces
3) Responsive spaces can be changed

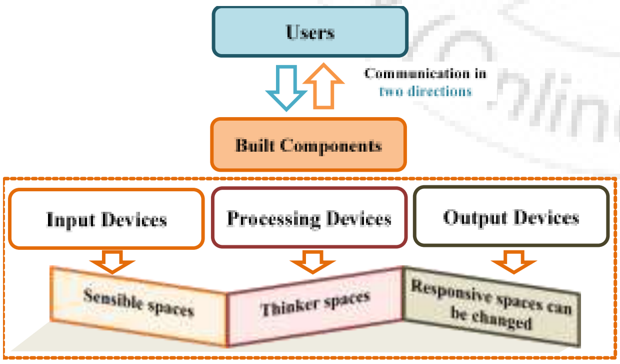

Figure 3: Interactive architecture concept

2.3 Responsive Architecture

Responsive architecture is defined as an active shape-shifting building system which is a response to environmental conditions and user activities. It consists of intelligent frames, systems and skins. The building response is a change in its shape and physical properties by simulating bionic performances of human and natural systems as shown in Figure 4 [7]. Bionics means studying the design and performance of natural systems to design engineering systems and modern technology [8].

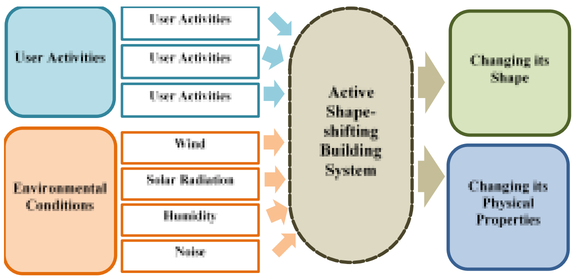

Figure 4: Interactive architecture concept

The concept of responsive architecture was introduced by Nicholas Negroponte in the late 1960s. He defined responsive environment as an environment that plays an active role, as a result and function of complex or simple computations to make a bigger or smaller degree of changes [9].

The responsive building does not have to be intelligent unless its response is a result of an intelligent procedure [3]. A Trombe wall, for example, responds to outdoor heat where it absorbs heat during sunlight hours of winter then slowly release the heat over night hours. It is not an intelligent procedure which must have a result depending on received information and data.

2.4 Adaptive Architecture

The concept of adaptable space means that it compliantly react to the supplies of any human activity from habitation, leisure, education, medicine, commerce and industry. The adaptation ranges from an interior, which is multi-use re-organized to a structure, has the ability to transform and programmatic response. It is capable to respond to various parameters with time. That is mean; time is an essential factor in the concept of adaptive architecture [10]. Therefore, adaptive architecture can be considered a responsive architecture adapting with time as demonstrated in Figure 5.

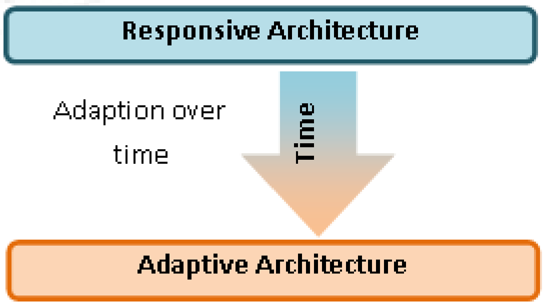

Figure 5: Responsive architecture to adaptive architecture over time

2.5 Kinetic Architecture

Kinetic architecture concept is the design of buildings with transformative and automatic elements. The building]s shape is changed to match the people requirements and adapt to environmental conditions.

Michael Fox classified control systems for kinetics into six types depending on the level of complexity [11]:

1) Internal controls: They do not have any direct control or mechanism like mechanical hinges.
2) Direct control: They are moved directly by an energy source outside the devices.
3) Indirect control: It depends on a sensor feedback system.
4) Responsive indirect control: it depends on multiple feedback sensors
5) Ubiquitous responsive indirect control: It has the ability of prediction by using a network of controls with predictive algorithms.
6) Heuristic, responsive indirect control: It depends on algorithmically mediated networks that have a learning capacity.

3. History of kinetic Architecture

The ability of adaption and moving was a significant matter for human being. In ancient times, people used movable and kinetic shelters to protect their lives and provide food. In Africa, the Bedouin tent was used through history because it is adaptable to the desert climate and it is a mobile shelter. The African tent is a tensile membrane suspended from compression poles [12].

In recent ages, the interest in interactive, responsive, and intelligent architecture has started in the 1960s and 1970s. This interest is caused by the development of computer science field and building technology which converted architecture from a static form to a more kinetic and dynamic form. Evolution of Kinetic designs has a rich history. With the passage of time, initial Kinetic design was made in 1908. Then, transformable architecture as a kinetic design had appeared. Combining kinetic concept with computer science took tens of years. More details will be presented in the next subsections, as illustrated in Figure 6.

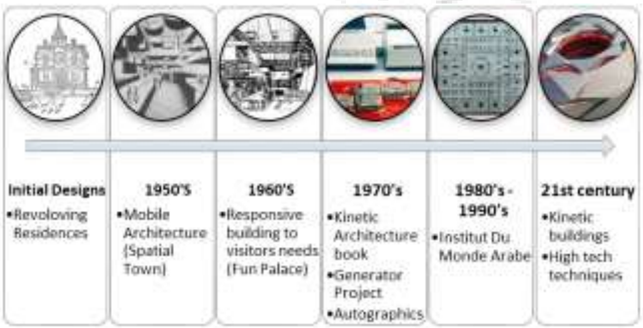

Figure 6: Kinetic architecture through the last century

3.1 Initial Kinetic Designs

One of the early kinetic designs was a Rotary building designed by Thomas Gaynor in 1908 but it was never built. The building sketches are shown in Figure 7 [13].

In 1935, Angelo Invernizzi invited and built another revolving house, which is Villa Girasole, where Girasole means sunflower. The villa is two storied and L shaped, which follows the sun by 44 meters circular base in diameter and a 42 meters tall tower in the center. The motor pushes the house over three circular tracks with 15 trolleys in 9 hours and 20 minutes to rotate fully [14].

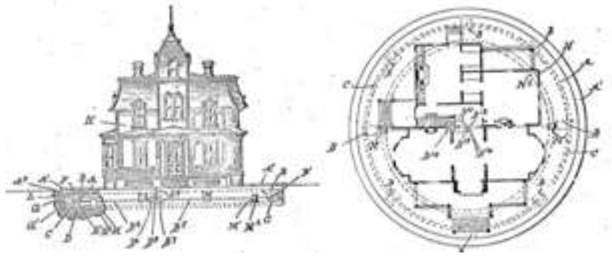

Figure 7: Rotary building by Thomas Gaynor in 1908 [13]

3.2 Mobile and Transformable Architecture in 1950's and 1960's

3.2.1 Yona Friedman

Yona Friedman introduced "Mobile Architecture Manifesto" in 1958, asking an important question: "why should architects decide for the people who live in their buildings". He founded the "Groupe d'Erudes d'Architecture Mobile (GEAM)" [15].

Later in 1959, he introduced 'spatial town planning' where inhabitants would have flexible structures to change their spaces as they need. The GEAM proposed a town with movable walls, floors and ceiling, with easily alterable infrastructure networks and large mobile spatial units that can travel, fly or float as a three levels city as shown in Figure 8 [15].

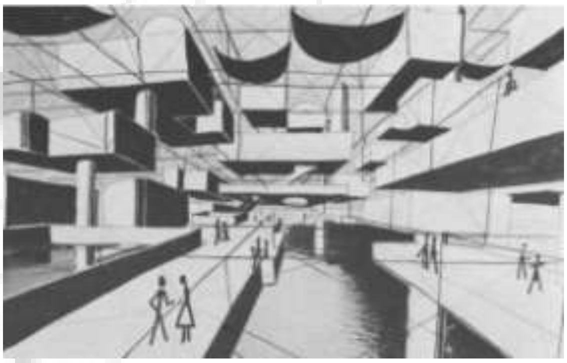

Figure 8: Spatial town idea by Yona Friedman [15]

3.2.2 Gordon Pask

Later In 1960's, Gordon Pask and other cyberneticians - scientists of communications and automatic control systems in both machines and animals including Norbert Weiner - tried to identify the field of interactive architecture by formulating their 'Conversation Theory', and developing a model in which architects understood spaces and users as complete feedback systems [16].

3.2.3 Cedric Price

Then, Cedric Price asked another question: "What if a building or space could be constantly generated or regenerated" [17]. Price tried to answer his question by architecture when he designed the Fun Palace in 1961. The project contains theatres, cinemas, restaurants, workshops and rally areas which can be assembled, moved, re-arranged and scrapped continuously as shown in Figure 9 [18].

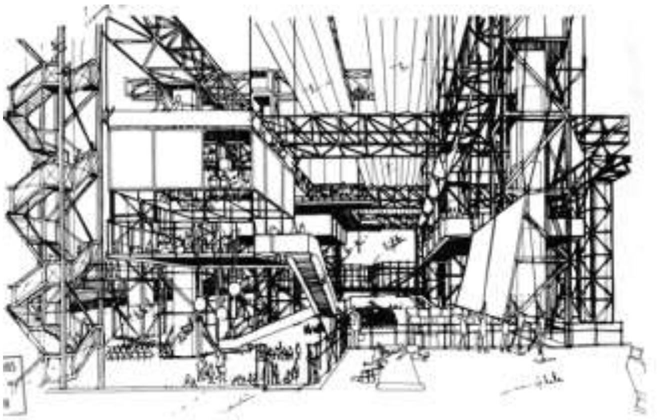

Figure 9: The fun palace sketch [18]

3.2.4 John Frazer

Also, John Frazer confirmed that architecture should be a ‘living, evolving thing’. Frazer and Price worked directly with Pask over many years. John Frazer introduced his work for nearly thirty years with students at the Architectural Association in London in his book “An Evolutionary Architecture” [19]

3.2.5 Archigram Group

Then there were the beginning works of the Archigram such as the design of the walking city in 1964 and Plug-in city in 1967, which is shown in Figure 10. Then, Nicholas Negroponte published his book: "The Architecture Machine" in 1970 [20].

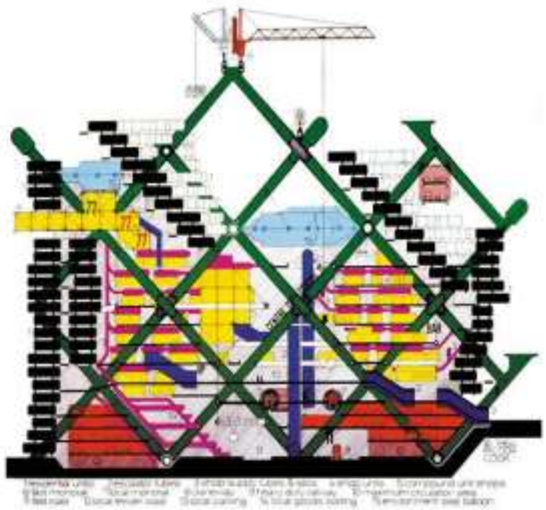

Figure 10: Plug-in city idea by Archigram [20]

3.3 Kinetic Concept and Computer Science in 1970's

3.3.1Kinetic Architecture Book by William Zuk and Roger H. Clark

The concept of kinetic architecture was introduced for the first time by William Zuk and Roger H. Clark in 1970 in their book: “Kinetic Architecture”. Zuc and Clark defined kinetic architecture for the first time as: “An architecture can adapt to changes taking place within a set of pressures acting upon it and the technology that provides the tool for interpretation and implementation of these pressures” [21].

The book introduced a systematic knowledge about kinetic architecture, and the authors combined between natural creatures and buildings. Also this book shows the essential for an architecture that is not static; but it can be adjusted to time changes by using systems with embedded actively controlled kinetic devices [21].

3.3.2 Cedric Price and "The Generator Project"

In the 1970s, human life had been changed by computer and telecommunication technology. In 1976, "The Generator Project" was invented by Cedric Price in collaboration with John and Julia Frazer. They created a computer program which can organize the layout of the site in respond to varying requirements, as illustrated in Figure 11. In addition, they proposed that a single-chip microprocessor that can be embedded in all building components, to work as the controlling processor. This project would help to produce an “intelligent” building which controlled its own components in response to use. [22]

By the end of 1970's, another major step was taken by introducing personal computer and it changed architects' life. Later in 1979 John Frazer founded “Autographics” company which developed the first microcomputer-based design systems in the world [22].

Figure 11: Generator project by Cedric Price [23]

3.4 New Technological Innovations in 1980's and 1990's

In 1987, Jean Nouvel' introduced a major example of a kinetic architecture: the Institut du Monde Arabe in Paris. The building south facade is a grid of 24 × 10 m of square bays, which simulate the geometry of traditional Arab screens. Each bay contains a central circular shutter set within a grid of smaller shutters as shown in Figure 12 [11].

Figure 12: The south facade of Institut du Monde Arabe [24]

3.5 Kinetic Buildings and Twenty-First Century

The twenty-one century is considered the real start point for kinetic architecture because a lot of kinetic buildings are designed and built in current century. For example, the kinetic wall of Brisbane Airport Parking Garage by the artist Ned Kahn in Australia (shown in Figure 13). The building was built in 2011 with a look of a vertical body of water and calm waves. The facade is consists of 250,000 aluminum panels which move with the wind. Inside the building, the movement of the facade gives the interior surfaces attractive patterns of sunlight [25]. Also, an innovative design of retractable roofs is presented in the design of Mercedes-Benz New Stadium in Atlanta (shown in Figure 14). The roof has a rose shape and it is consists of eight panels that open in a diagonal slide like a camera aperture [26].

Figure 13: The kinetic wall of Brisbane airport garage and its panels [25]

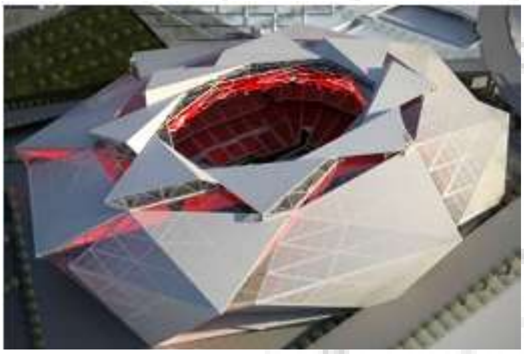

Figure 14: Mercedes-Benz' new rose-shaped stadium in Atlanta [26]

4. Kinetic Architecture Applications

There are various applications of kinetic systems in architecture. The paper presents them in three main categories: kinetic structure systems, kinetic interior and kinetic facades. The next paragraph defines each application as illustrated in Figure 15.

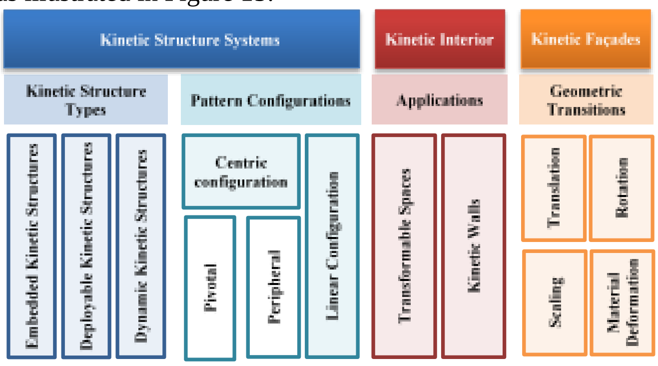

Figure 15: Kinetic architecture appliacations

4.1 Kinetic Structure Systems

Kinetic structure systems are defined as buildings and/or building components with variable mobility, location and/or geometry. The performance ways of a kinetic structural solution can be folding, sliding, expanding, and transforming in both size and shape. On the other hand, the performance means of a kinetic structural solution may be: pneumatic, chemical, magnetic, natural or mechanical" [27]. Finally, Kinetic structures can be categories into three groups as demonstrated in Figure 16.

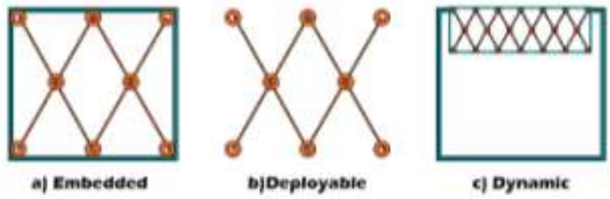

Figure 16: Kinetic structure categories [27]

4.1.1Embedded Kinetic Structures

They are part of a larger architectural system in a fixed location. It aims to control the main architectural system or building, in response to varying factors like structures that dampening earthquakes. [11]

4.1.2Deployable Kinetic Structures

They are easily transportable and usually exist in a temporary location. [28]

4.1.3 Dynamic Kinetic Structures

They are also part of a larger architectural system but act independently with respect to control of the larger system. Such can be subcategorized as: [11]

1) Mobile systems: they can be physically moved from one architectural space to another location.
2) Transformable systems: they can change their shape to take another three-dimensional configuration. So, they are usually used for space-saving or useful requirements.
3) Incremental kinetic systems: they can be added to or subtracted from a building.

On another hand, kinetic devices can be organized in patterns in two or three diminutions to create different kinetic structures. Moreover, there are many possible pattern designs, the most common patterns are:

a) Centric configuration:

This type depends on a center point as a focal point of the space, and there are two typological of patterns in this configuration [29]:

1) Pivotal: it is organized from a main supporting element (pivot) in the center of the form and usually the kinetic devices in this structure are arranged to be operated back and forward from the center to the perimeter of the shape. Umbrella-like structure is a great example on this configuration.

Peripheral configuration: it is organized in a series of supporting elements placed on the perimeter of the form like the retraced roof of Qi Zhing tennis center in china, which is shown in Figure 17.

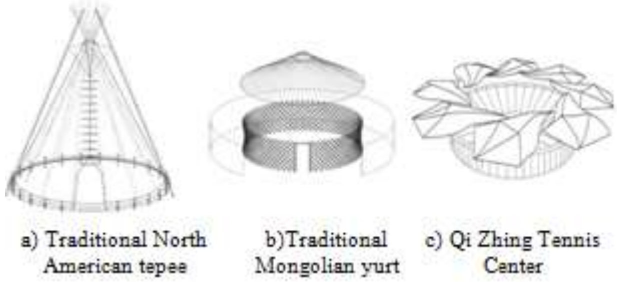

Figure 17: Kinetic architectural structures with centric configuration [29]

b) Linear configuration

This type depends on an axis (strait or curved), it is consisted of a series of modules (kinetic devices) which are linked by their edges or their vertices to transmit the movement from on to the next as shown in Figure 18. Then, Table 1 illustrates an example on each type of the kinetic Structure Systems [29].

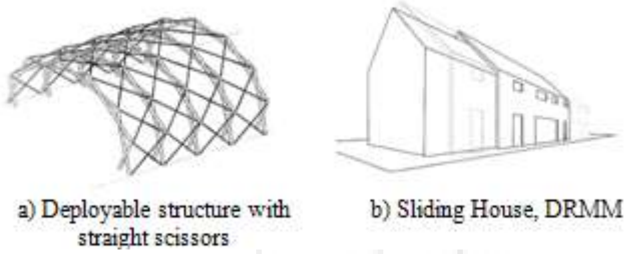

Figure 18: Kinetic architectural structures with Linear configuration [29]

Table 1: Examples of Kinetic Structure Systems

		Example	*Figures*
1.Centric configuration	a. Pivotal	▪ **Project:** Masjid Nabawi courtyard umbrellas ▪ **Architect:** SL-Rasch, and SEFAR Architecture ▪ **Location:** Al-Madina Al-Monawara, Saudi Arabia	 **Figure 19:** Madina Al-Monawara Mosque Umbrella [30]
	b. Peripheral	▪ **Project:** QiZhing Tennis Center **Architect:** Mitsuru Senda **Location:** Shanghai, China	 **Figure 20:** Qi Zhing Tennis Center [31]
2.Linear Configuration		▪ **Project:** AT&T Stadium retractable roof ▪ **Architect:** HKS, Inc, and Bryan Trubey ▪ **Location**: Texas, USA	 **Figure 21:** AT&T Stadium [32]

4.2 Kinetic Interior

This application of kinetic design concept ranges in scale from shop fronts, to kinetic walls. The paper summarizes main categories of this application as:

4.2.1 Transformable Spaces

Architects and interior designers through history tried to make our living and work spaces more dynamic and transformable to provide the changed needs of its habitants. The idea is applied in many levels like the multi-uses furniture, and spatial flexible spaces as illustrated in an example in Figure 22.

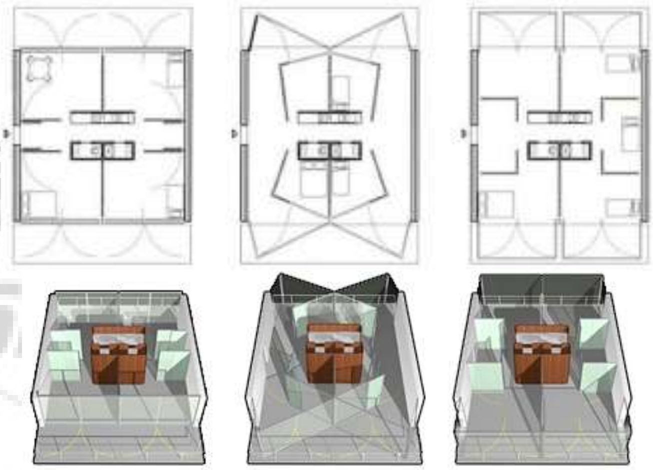

Figure 22: Different options adapting housing by kalhoefer korschildgen [33]

4.2.2 Kinetic Walls

Kinetic walls are used to leave the impression that they respond to our actions. This impression is created by an array of connected elements. The response is created by three different strategies [34]:

1) The movement is captured by centralized means using a camera. Then applying a subsequent inductive computer analysis of the taken images to do a centralized calculation of a corresponding reaction.
2) The movement is captured by decentralized means depend on sensors then applying a subsequent deductive analysis and the centralized calculation of a corresponding reaction.
3) The movement is captured by an entirely decentralized means. Then the direct, local reaction is taken by a large number of small elements.

Table 2 illustrates some examples of kinetic walls by introducing their ideas.

Table 2: Kinetic Wall Examples

Project		*Figures*
Hexi Responsive Wall by Thibaut Sld	It consists 60 mounted panels, which use motion-tracking technology to decode actions of a person near it (walking - jumping - waving a hand) [35].	 **Figure 23:** Hexi responsive wall [35]
Tiny Fans Wall by Roosegaarde Studio	It consists of 8 m long structure with 640 small fans, It move when there is a near body in front of them [36]	 **Figure 24:** Tiny fans wall [36]
Aegis Hyposurface by dECOi Architects	It consists of a basic structure frame contains a number of pneumatic reactive actuators. They react to various motivations like light, movement and sound to move like waves [37]	 **Figure 25:** Aegis Hyposurface [37]
Kinetic Wall by Frank Barkow and Regine Leibinger	The surface consists of a translucent synthetic fabric and a pattern of motorized nodes in front of it. It looks like it is breathing in and out [38]	 **Figure 26:** Kinetic Wall [38]

4.3 Kinetic Facades

The concept of kinetic facades is about using geometric transformation to create a motion or a movement in space. This motion or movement affects the physical structure or material properties of the building facades without impairing the building structure. There are a lot of classifications of kinetic facades, most common one is based on the façade transformation. As shown in Figure 27, kinetic facades can be moved in space by four geometric transitions [28]:

1) Translation: The motion occurs in a vector direction
2) Rotation: The object is moved around all axis
3) Scaling: It is an expansion or contraction in size.
4) Motion through material deformation: it depends on changeable material properties, like mass or elasticity.

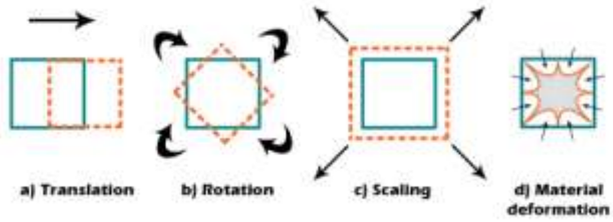

Figure 27: Forms of geometric transitions for kinetic facades [11]

5. Conclusion

In this paper, Kinetic architecture has been presented as a new concept for building design. There are many concepts related to kinetic architecture such as intelligent architecture, interactive architecture, responsive architecture and adaptive architecture. They may be look similar, but every concept focuses in a specific point and aims to achieve particular purposes. The paper outlines what every concept add to the others as illustrated in Figure 28.

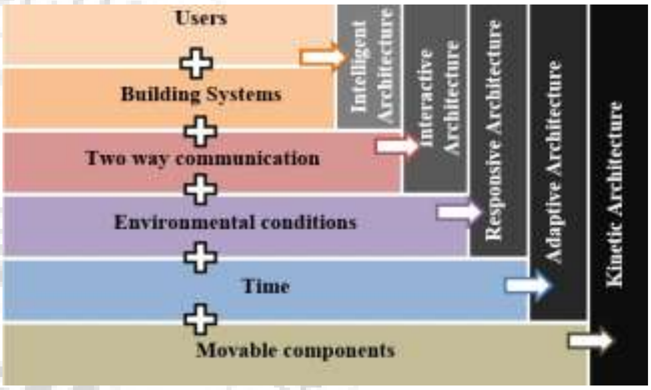

Figure 28: Concluded concepts

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