Kinetic Architecture and its Application to Urban Housing in Tucson

Kristina Lukenda
KINETIC ARCHITECTURE AND ITS APPLICATION
TO URBAN HOUSING IN TUCSON

By
Kristina Lukenda

A Master's Report Submitted To the Faculty of the
COLLEGE OF ARCHITECTURE, PLANNING AND LANDSCAPE ARCHITECTURE
In Partial Fulfillment of the Requirements
For the Degree of
MASTER OF ARCHITECTURE

In the Graduate College
THE UNIVERSITY OF ARIZONA
2002
Statement By Author

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APPROVAL BY COMMITTEE
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Acknowledgments

I would like to express my gratitude and appreciation to Professor Larry Medlin, Chairman of my Advisory Committee, for his sincere cooperation during the entire course of this research project. His continuous guidance, inspiration, and enthusiasm has motivated and helped me immensely. I would like to extend my appreciation to the members of my Advisory Committee, Professor Christopher Domin, and Professor John Folan for their direction and assistance.

I am appreciative to Fred Matter and the Graduate Department of Architecture, for allowing me the privilege to study at the University of Arizona. I am grateful to my many student colleagues for providing a stimulating and fun environment in which to learn and grow.

My thanks go to Gary for his help, encouragement, and patience. Most of all, I would like to thank my family, and especially my parents, Lawrence Lukenda and Karen Lukenda, for their absolute confidence in me.
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Abstract

The topic that the research will be addressing is Kinetic Architecture. The research is focused on embedded kinetic structures, that is, building components that exist within a larger architectural whole. Such components respond to changing factors. Building elements are moveable and adaptable. The question the research will answer is how a Sonoran desert dwelling is designed and formed so that it responds to environmental, adaptable growth, and flexibility factors. The goal is to develop and illustrate design guidelines that occur during a daily cycle, a seasonal cycle, and a life cycle, to create a responsive desert dwelling that is equipped with kinetic strategies and techniques. Housing today is built and then people must adapt their lifestyles to fit into their house that has been designed for a typical nuclear family. The program is intended for a single-family residence that adapts to the changing needs of the people living within it. The focus will also be on a residence in the urban setting, since it is in the city where space is limited and valued, and a kinetic, adaptable solution will be advantageous.
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Problem Statement and Its Significance

Buildings today are static and motionless. They utilize archaic systems to face challenges of varying functional requirements in our constantly changing climate. Such systems are costly, energy consuming, and spatially inefficient. Architecture can be designed so that a building uses what is necessary at a given time of day, a given season of the year, or a given stage of life, by using fewer resources and by creating desirable living environments. It is a structure that facilitates everyday activities and exceeds our expectations. Architecture is fixed, forcing inhabitants into buildings that offer very little flexibility or ability to respond to changing conditions that occur daily, seasonally, or over the span of a building. A kinetic or adaptable architecture can provide users with an environment that they can use to more appropriately and efficiently respond to changing conditions. The intent of the master's report is to demonstrate the potential of kinetic architecture to meet the demands of change and also to offer opportunities for enhanced architectural qualities. The focus of this study will be a
residential building for a specific inner city urban site in Tucson that responds to
daily functional adaptability, climatic factors, and a flexible and adaptable growth
pattern that occurs over a life cycle.

The study will investigate the creation of a living building responding to
what the users need. Investing in a kinetic residence is worthwhile because it
can be more energy efficient, spatially efficient, and offers a lifestyle that takes
better advantage of the unique features of the Sonoran desert climate.

The research will be focused on embedded kinetic structures, that is,
building components that exist in a larger architectural whole in a fixed location.
These components respond to changing factors. The question the research will
answer is how a building is designed and formed so that it responds to the
changes that occur daily, seasonally, and over the course of a life-cycle.

Sub-problems would be the engineering and mechanics of these movable
building systems. Occupant control would be responsible for the spatial and
environmental changes. The materials involved to make a building like this work
and the computerized control of these systems are also related sub-problems. Further exploration into the details of construction and operation is needed.

The intent is to develop an architecture that enables adaptable spatial configurations. The architecture could be physically altered for varying social functions and climatic changes. This adaptable architecture will be studied in an urban setting in the desert climate of Tucson, Arizona. Because of the substantial diurnal temperature swings and seasonal differences of this area, a kinetic building can respond to the environment in a way that is cost saving and energy efficient. Kinetic architecture can also let a building that otherwise would have to counteract the extremes of this desert, take advantage of the inherent qualities of the Sonoran climate so that the residents are able to celebrate the beneficial natural forces.

The topic is significant to the larger professional, academic, and public communities because exploring kinetic solutions to architecture can be a cost saving, energy efficient, and spatially flexible alternative to traditional building types. The objective is to create multi-use interior adaptability, along with a
building envelope that can adapt to climatic factors and to overall growth and change factors. Kinetic systems utilize occupant participation, technology, and landscaping to create architectural solutions that attend to our constantly changing and flexible activities.

By designing an adaptable architecture that responds to our environmental, growth, and functional needs, we can create a more desirable living situation. Like the human body responds to the needs and changes of its environment, so will a kinetic building. By being a moving, adaptive, responsive body, kinetic architecture can have a symbiotic connection with nature.
Goal of Research

The goal of the research is to develop a kinetic design solution to residential use in an urban setting. Through the development of a residential mixed use building in a Sonoran desert urban setting, the potential and opportunities of a kinetic architecture can be demonstrated. Kinetic architecture through its application in housing will be studied in a place where land and space is most valuable, where the available space needs to be taken advantage of – that place is in an urban setting.

The intent of the project is to identify the opportunities and benefits of a kinetic building type in residential and other related uses. By studying how kinetic architecture can respond to the needs of a nuclear family over the course of a life-cycle, and by studying how the building responds to the Sonoran Desert environment in which it is located, a developed rational for the use of kinetic strategies will be presented. The objective will be to study the use of kinetic strategies that respond to the dynamic, flexible, and constantly changing
activities. The result will be the development of a housing project that can be used as a model from which to build upon and, in turn, benefit society.
Project Description

The project is based on analytical research that sets up design guidelines from which a proposed building is developed to test how a kinetic residence can enhance the lifestyle of its inhabitants. The research includes an investigation into a variety of precedents related to kinetic architecture to study ways in which a building can respond to different forces that act upon it. The specific areas of research study are programmatic changes, changes over the course of a building life cycle, and seasonal changes in the Sonoran desert climate.

The principles from these three categories will guide the exploration into what can be an appropriate response using kinetic architecture. An outline that identifies the building life cycle through defined phases of one nuclear family will be used to show how a kinetic residence can satisfy human needs, growth and expansion over time. Changes in program needs that occur on a daily basis and during special circumstances will also be determined, and will be used as a guideline for space planning.
An exploration into the desert climate of Tucson, Arizona will be used to dictate how a building can properly respond to its location. The collaboration of these principles will show how a kinetic residence can be an intelligent and beneficial response to urban living.
Definition of Kinetic Architecture

Kinetic architecture, as applied to this project, is a method by which a structure can be altered based on specific circumstances and environmental conditions. It is the creation of spaces and enclosures that can be physically reconfigured to meet changing needs. It is a structure that is moveable in relation to its site and also in its interior configuration. Walls can slide, swing, and pivot to open up and divide spaces within the structure. Internal service parts can pull apart when used, and compact neatly together when they are not. This is done so as to utilize space for other functions. Spaces within the building can perform more than one function, and the form of the space changes to allow for these different functions. The outside walls of this structure can also behave in ways that allow for different needs. Seasonally, the exterior walls can change with the temperature and environmental conditions. In the winter, the walls can open up to let in light and views. They can let the sun contribute to heating the home. But in the extreme temperatures of the summer, the walls can shield out light to cool...
the interior. The facade can be altered itself to allow for ventilation and different visual configurations. The roof system, as well, can provide for changing environmental needs. Louvers can let in controlled light and air. The building elements work in harmony to control shade and shadows, as well as temperature.

Kinetic solutions to architecture can be beneficial when applied to a residence. Kinetic architecture can allow residents to have their specific lifestyle needs and activities to be accommodated. Families adapt to a home that has a preconceived notion of what type of people should be there, and what they should be doing. The residents adapt and conform to the house. A kinetic home would adapt to the people who occupy it, and would adapt to the place in which it is located.

Throughout the course of day, many functions are required in a home. The needs at night vary from needs during the day. During the day, more living space is required. The sleeping area, at this time, can be compacted and minimized. When night falls, the sleeping area can then open up again. Over
the course of one's lifetime, needs also change. A kinetic house will allow for one home to provide for all the lifetime requirements of its occupants. Residents of this house will no longer have to move when their family outgrows the building, the building will allow for this growth and change. It can be adjusted to fit the necessities of the family, and not force the occupants to look elsewhere when they don't have a space needed to allow for their activities. In general, kinetic architecture allows varying responses over time.

The transitions between outdoor space and indoor space can change based on different configurations of building components. According to the occupants' desires for type of space, or what the environment dictates, the relationship between outdoor and indoor space differentiation can change.

This kinetic residence is appropriate in an urban environment because it can respond to specific city problems and needs. It is in the city that space is tight and valued. Creative solutions to space utilization are extremely needed in the City of Tucson. Land is an expensive component of any city dwelling. You
can make the most out of an unused space or lot in an urban setting, as compared to an open setting.

Downtown Tucson, Arizona has been selected as the location for this kinetic house. Because of the extreme temperatures swings that are indicative of the Sonoran desert, a kinetic building structure can work with the environment and not against it. Because the climate is so much a part of life here, architecture should relate closely to the environment and the natural world. Natural architecture must be adaptable and alterable, like nature itself. The specific site chosen is on top of an existing parking garage within the urban context of Tucson. The parking garage site includes benefits of views of the city and landscape, and allows for both vehicular and pedestrian access to the residence. It also allows for access to sunlight, air, and winds in the urban context.

Kinetic architecture is beneficial because of its flexibility and space saving capabilities. Through the use of modularity, there will be a flexible variety of floor plans that can be easily reconfigured. The goal is to develop a project that demonstrates the potential for kinetic solutions within this specific context.
CHAPTER 2

DEFINITION OF NEEDS
The Need for a Kinetic Home

All too often today, people see their residence as being temporary. People outgrow their homes and instead of being able to transform what they have, they move on to a new place. Many of today's families move every 3 to 5 years. One out of five families move every year. Most move to another location for a better job or more productive career, but others move because their current location no longer suites their needs or lifestyle. A kinetic home can respond to this problem by adapting and growing along with the family. Initially, the home can accommodate space for a single adult, but as a single occupant becomes a couple, and as a couple becomes a family, the home could respond to this change over time, and can add new living space for different living and sleeping arrangements. This type of residence will give homeowners options for change and growth. To provide substantial flexibility in meeting all of the users' needs, kinetic architecture can provide an accommodating and satisfying lifestyle for a wide variety of families and living situations. Residents will take comfort in
Knowing that however the family structure grows or changes, their current home will permit adaptability to fulfill their needs.

Only a small amount of American homes are designed by architects who work with individual clients. Most homes and apartments are designed in advance. The prospective resident is able to choose from alternative plans that often permit only slight modifications. These homes are designed for a typical or ideal family, ignoring many variables in the family and the location. Most American homes are similar; they have kitchens, living rooms, bedrooms and bathrooms. These homes have specialization of function, meaning each room is used only for a particular purpose. A typical home is designed for a generic nuclear family. These types of homes, through their layout and patterning, articulate how a presumed family should live. Homes designed this way severely limit the lifestyle options for many residents.

A kinetic residence may accommodate the non-nuclear family and even the nuclear family in a better way. In a kinetic home, rooms can be responsive to each occupant's needs and desires, whoever the occupants may be. A kinetic
home can accommodate an atypical family structure. Whether the need is for more private, separate sleeping divisions, or for outsized gathering rooms to provide for large groups of people, a kinetic home can adjust to these everyday activities. It can also provide for different lifestyles, as well as for special circumstances such as cocktail parties or for out of town visitors. For instance, if the owner of a kinetic house is an avid traveler, away from home for long periods of time, the house can be closed up and even compacted to provide security and save on energy. Or, if the owner has a hobby, such as dance, they may require a great amount of open space during the day to practice, but at other hours, that open space can be used to entertain friends or it can be converted to a sleeping area at night.

In general, homes in this country have limited regard for environmental factors. Residences that are nearly identical are seen in several locations with different orientations. Usually, occupants just turn on heaters or air conditioners to control the temperature inside. By creating a building that works with its environment, energy costs can be reduced and the air can be cleaner and
Kinetic architecture can greatly enhance living in the Sonoran desert climate. Particularly in areas of extreme climatic changes, such as the desert, people are forced to stay within the walls of their home simply because it is too uncomfortable to be outdoors. Homes in the desert are meant to offer protection from the harsh summer sun, but, as a result, there isn’t much opportunity to enjoy the welcomed winter sun, or views of the landscape. Fixed louvers systems, or calculated overhangs can block the sun in the summer, but can allow winter sun to penetrate the interior. A kinetic solution can shade interior and exterior spaces against the harsh summer sun, can allow residents the chance to experience the warmth of the winter sun, and can also open directly to the outdoors during comfortable summer evenings. There is a dramatic diurnal temperature swing in the Sonoran desert, and kinetic architecture works with this change, and will allow a more comfortable living environment. The natural environment and climate can be more advantageously integrated into the residents’ lifestyles through kinetic architecture.
Description of Needs

In order to utilize a kinetic approach to architecture, design criteria concerning the specific requirements need to be stated. A kinetic building can be physically reconfigured to meet changing needs and conditions. These changing needs are divided into three groupings. Adaptation to environmental needs occurs primarily in response to daily and seasonal cycles, but can also occur randomly. Adaptation for functional needs may primarily respond to daily activity patterns, but can also occur at random and as part of lifecycle adaptations. Adaptive growth and change over time follows the building's life cycle.
Climatic Overview

Tucson is located in the Sonoran Desert in Southern Arizona. Hot and dry conditions dictate adaptations by plants and animals in this arid climate. The area’s mild spring, fall and winter temperatures are part of what makes living in this environment desirable. Even though summer temperatures rise, low humidity makes even extreme high temperatures tolerable.

With an average temperature of 82°F, cooling is a concern for over half the year. Also, solar heating can be beneficial during sometimes of the year, and daylighting can be utilized during all seasons of the year. One of the main characteristics of the desert is its large diurnal temperature swing. During the day the sun delivers a significant amount of heat to the desert. At night the temperature drops. However, the earth retains most of the heat absorbed during the day. This phenomenon can be taken advantage of to passively heat and cool buildings. Because Tucson has some of the clearest skies in the country, protection from the harsh sun is a necessity. A kinetic environmental response is potentially very beneficial for accommodate the changing environment throughout the year.
Environmental Needs

A desert dwelling could use kinetic architecture to respond to the environmental changes of the climate. The configuration of the built form will be environmentally influenced; it will facilitate airflow for heating, cooling, and ventilation. The facade and windows will be environmentally responsive, that is, changing according to light and weather conditions. The facades could potentially be altered at daily and seasonal intervals. Opening up the facade in winter months gives the opportunity to take advantage of views, sunlight, and ventilation. This is something that is not all that common in the Sonoran desert climate now, where west-facing walls are usually left blank and solid. Vertical panels can provide shade for east and west glass but can also become obscured to allow for views and daylighting. The differentiation between outdoor and indoor spaces could be altered based on the desires of the residents. Kinetically, the house can “open up” or “close down” when necessary.
A building should be able to respond to the changes that occur at different times of the year. The temperature is often moderate in the desert climate; meaning that outdoor porches, patios, and terraces can be a well used space if incorporated into the design of a building. During the entire Spring and Fall, and during the winter day and summer night, the natural climate conditions are often comfortable. It is during these times when outdoor spaces are pleasant, and there is little need to regulate the internal temperature conditions.

During cold periods, the environmental objectives would be to minimize heat loss and to optimize use of solar heat gain and internal sources. In the summer, during hot weather, the objective is to avoid heat gain and to utilize shading devices. A properly designed building should take advantage of the benefits of its place, and in the desert, that means responding to the heat loss and coolth gain that occurs at night.

Because it is desirable to save on heating and cooling costs by the simple design of the built form, and because this built form is dictated to change at different types of the year, a moveable wall can offer a solution. A kinetic wall
Adobe is the traditional building material of the southwest. Adobe bricks have a large thermal storage capacity as well as a lengthy time-lag heat transfer. Adobe will offer both shade in the summer morning, and light and views in the winter, and can also provide night-time insulation and security.

The traditional building component in the Southwest has been adobe, mainly because of its high-mass qualities to keep the interior cool and its ability to store heat. The thick earth or masonry walls are able to delay and store the heat that is transmitted in the daytime. This type of construction works exceptionally well in the desert, where there is a large diurnal temperature swing. During the day, heat would work its way into the walls towards the interior. By the time the sun went down and the cool evening began, the flow would reverse itself and work back towards the outside. However, some heat would work its way through the wall and be radiated into the interior space. During winter nights, this is beneficial. In the summertime, the space can be opened and ventilated, thus the heat is moved to the outside. South-facing “sun spaces” also work to passively cool a building. These rooms use glass to capture the heat gained in the daytime and store the heat in tile or concrete floors, or even water drums. The sunspace provides substantial quantities of energy to heat the
Lightweight construction materials are able to allow for direct climate interaction. Through the use of shading elements and cross ventilation, the interior can be kept cool. This type of construction is particularly appropriate where flexibility is required, as the design and layout options are considerable. Lightweight elements can be used for moveable insulation, sunspace systems, screen porches, and other employments that can be operated in a kinetic way to respond to changing climate conditions. Lightweight materials are easily moveable and therefore assist in making architecture kinetic. Lightweight construction – the use of aluminum, steel, and glass - contributes to sustainable architecture, allowing the building materials to be recycled to be used in other ways. In addition, lightweight materials reduce labor requirements, conserve resources, shorten term of works, and lower costs at construction sites.
<table>
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<th>Month</th>
<th>Conditions</th>
<th>Average Temperature</th>
<th>Design Guidelines (Environmental Needs)</th>
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<tr>
<td>Winter Rainy Season</td>
<td>Large fronts that form over the Pacific Ocean are forced eastward by weather circulation patterns in the winter. Large, slow-moving fronts bring rain to the Tucson area during this time. These rains are typically long and gentle, and cloud coverage persists for quite a while, even several days.</td>
<td>January High:64 Low:39 February High:67 Low:41</td>
<td>1- Provide Shelter from rains 2- Allow for natural light to enter building 3- Use Solar Gain for heating when available</td>
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<tr>
<td>(Jan. – Feb.)</td>
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<tr>
<td>Spring</td>
<td>The days are usually warm but nights are still cool. This is the time when desert plants bloom. Good opportunity for views.</td>
<td>March High:72 Low:45 April High:81 Low:50</td>
<td>1- Allow more ventilation to let in air 2- Provide frames for views 3- Create indoor-outdoor spaces 4- Needs to be adaptable for lower load heating and/or cooling depending on specific weather conditions</td>
</tr>
<tr>
<td>(Mar. – Apr.)</td>
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<tr>
<td>Summer</td>
<td>Daytime temperatures are hot and dry. Nights are still relatively cooler. Saguaro cactus begins to bloom - Good opportunity for views.</td>
<td>May High:85 Low:54  June High:99 Low:67</td>
<td>1- Provide sun shading (ramadas, trellis, vegetation, canopies, overhangs, awnings) 2- Cool interior 3- Use nighttime ventilation and/or night sky re-radiation 4- Use thermal mass to store cooler air</td>
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<tr>
<td>(May - June)</td>
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<tr>
<td>Monsoon Summer</td>
<td>Monsoons occur late in the summer. It is during this season that heavy rains help replenish the desert. 46% of Tucson’s annual rainfall is during this summer thunderstorm season. As temperatures reach their peak in the afternoon, moist air is forced upwards forming dark cumulonimbus clouds. The clouds continue to build throughout the afternoon and evening, until they then unleash a great amount of rain. The result is a local thunderstorm that lasts only a matter of minutes. These torrential downpours are intense and can cause flooding.</td>
<td>July High:99 Low:73 August High:96 Low:72</td>
<td>1- Provide rain shelter from these violent thunderstorms 2- Allow views of the heaven-like sky after storms 3- Use cool air for cross ventilation 4- Celebrate qualities of natural desert by providing access and interaction with surroundings 5- Use thermal mass to store cooler air 6- Needs to be adaptable for lower load heating and/or cooling depending on specific weather conditions</td>
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<td>(July – Sept.)</td>
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<tr>
<td>Fall</td>
<td>Humidity begins to leave the area, meaning cooler nights. Days are still hot.</td>
<td>September High:93 Low:68 October High:84 Low:57</td>
<td>1- Sun shading 2- Provide heating at night 3- Use kinetic strategies to solve issues of heating and cooling</td>
</tr>
<tr>
<td>(Sept. – Nov.)</td>
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<tr>
<td>Winter</td>
<td>Cool temperatures in the daytime, the sun is lower in the sky. The nights are cold with rare freezing temperatures possible. Snow is also rare, but can occur. Many plants may drop their leaves.</td>
<td>November High:73 Low:46 December High:64 Low:40</td>
<td>1- Utilize daytime sun to warm spaces 2- Strive for nighttime re-radiation 3- Absorb and store solar energy</td>
</tr>
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Specific Design Strategies to Site Context

The changing altitude of the sun causes climatic conditions in the desert to change throughout the different seasons of the year. The placement of the sun in the sky dictates design guidelines for environmental control. There are environmental requirements that exist in each direction throughout the different seasons of the year. Often these design requirements contradict each other. A kinetic wall structure or a moveable spatial system that changes seasonally and daily can be a solution to this predicament. By allowing the building to be reconfigured, its' organization of spaces can change according to the time of day, the season, or the resident's preferences. The specific configurations can take advantage of both summer and winter benefits. A kinetic residence will echo the ideal of energy efficiency - walls and other building components will behave in ways that stimulate light and ventilation within the home. The placement of openings and windows will allow natural breezes to cool the interior. Moving parts will facilitate passive energy strategies that lend itself to cost-saving resource conservation. By creating spaces that respond to the environment
through the usage of moveable sun shading, outdoor areas can offer refuge in
the desert. Energy efficient strategies can take advantage of the abundant sun.
All throughout the year, sunlight can be diffused to offer constant overhead
lighting, without the glare.

Each area of the residence should have an appropriate response to its
location:
West-facing wall panels are able to open up entirely to the outdoors. In the main living space, the west wall can entirely "disappear" so a connection with the outdoor space is evident. Overhead trellis covers the half of the west facade allowing low winter sunlight to enter the living space while blocking out the high summer sun. Wall panels also swing out providing vertical shading against western sunlight. Outdoor space along the west side gives the residents a view of the street life below, as well as a view of the sunset.
West Elevation Requisites

Traditionally in the desert, it is not a logical environmental approach to orientate the building (a longer surface area) to the west. The western facade is left exposed to the hot afternoon sun in the summer between the time of 3 to 6 pm. In the winter, where sunlight is beneficial to warm the interior, the short side of the building receives the sun during the day between 10am and 2pm, not the longer side.

However, the advantages of a west-orientated building design are many. Windows and glass to the west allow the residents to see views of the Tucson Mountains, and the downtown cityscape itself. It allows the building to passively take advantage of afternoon winter heat gain. But, the best advantage of having openings, windows, or glass walls on the west is being able to view an awe-inspiring southwestern sunset. It is something that is unfortunately not too common in Sonoran desert architecture because of the dreadful thermal heat gain.
Summer

The western elevation needs to be shaded from afternoon sun. Hot afternoon winds come out of the northwest; these winds should be channeled around the house. The west facade needs to open up to allow nighttime cool air to cross ventilate the interior. Protect interior living areas with solid heat-delaying walls. Use window coverings to protect against intense heat.

Winter

Interior space should be allowed to warm up quickly. A west orientation of afternoon and evening functions can benefit from the afternoon sun. Patios and terraces should open to the west and not be shaded. Some shading and glare filtration may be desirable on warmer winter days.

Spring and Fall

Ventilation on the west can facilitate cooling the interior during the day. At night, having the option to either allow the outdoor air to circulate inside, or to close it off from the interior space is desirable. Solar gain and heating on some days or during certain times may be sought-after.
South Elevation Requisites

If the residence was orientated south, the early morning winter sun can enter the interior on its long south facade and can enter this side of the building throughout the day, thus passively heating the interior. This direction also works well in the summer because the building is only minimally exposed to the hot afternoon sun. South-facing glass has its advantages and disadvantages. It is the simplest and least expensive direct solar heating system. It can offer views of both the city and the mountains. It is a good way to admit natural daylight. But during the winter nights, heat loss can be a problem. In the summer, heat gain through the glass is also unfavorable. There are times throughout the course of a day when the residents may want privacy, or may feel the glass results in too much glare. In this instance, a kinetic strategy that would allow south-facing glass the chance to be covered by a sliding wall system when needed would be appropriate. Blinds or louvers can allow more adaptable sun control, though not as much insulation as the sliding glass covering.
A concrete, heavy-mass wall faces the south and radiates heat to the main living space. Glass panels also face the south to provide for a view and for passive heating. Sliding wall coverings are able to cover the glass on the interior. South facing outdoor space is abundant, and vertical wall panels are able to swing out to the exterior spaces to provide shade when needed.
Summer

Walls should be tall to provide shading of exterior spaces. At night, allowing the south facade to open up will help facilitate cooling the interior, as the cooling breezes come from the southeast. Protect interior living areas with solid walls. A horizontal overhang works well in this direction, as the south receives minimal radiation in the summer.

Winter

It is the best location for solar heat gain (which ranges from southeast to southwest.) Sunspaces that can collect and reradiate heat gain are best facing south. Walls should be able to open to the south, as well as to the southeast and southwest to allow penetration of the winter sun. Walls or other building elements that shade exterior living areas are undesirable. Winter winds from the southeast need to be diverted from exterior living spaces. Exterior patios and terraces should be orientated south for maximum solar gain in the winter and should not be shaded.
Spring and Fall

Ventilation can facilitate cooling the interior during the day. Closing the facade up at night will protect against nighttime cooling. Cooling breezes from the southeast can be beneficial, and should be allowed to penetrate the interior. Kinetic elements and systems can allow variation from a heating to a cooling strategy as preferred.
**East Elevation Requisites**

East-facing glass is often subjected to the low-angle summer morning solar radiation. This heats the interior space in the beginning of the day, making it more difficult to keep and maintain a comfortable interior temperature. Moveable vertical and horizontal shading or a solid kinetic wall can help to prevent the sunlight from entering on the east side. In the summer morning, a solid wall will help keep the interior cool and it will save on cooling costs. It is not always necessary to have a solid wall in the east. By having a solid wall, you miss the opportunity for breezes on summer nights to cool the interior through cross ventilation. You lose the chance for the winter rising sun that could help warm the interior instead of by costly electric or gas heating. And you give up the chance for views of the spectacular Rincon Mountains. Eastern light, especially if it is self-shaded, can be particularly benevolent on warm days in the afternoon, where you are able to enjoy the desert without having the direct sun strike you. A beneficial and efficient environmental response can be achieved through the use of kinetic strategies.
Walls pivot to open to outdoor space on the eastern side of the residence. These pivoting walls are glass covered by operable louvers. East facing glass can be covered by sliding interior panels. A northeastern second floor terrace is self-shaded by the building itself.
Winter

Interior space should be allowed to warm up quickly. Allow morning sun to penetrate interior. An east orientation of morning functions can benefit from the morning sun.

Summer

The east side is not as severe as the west due to lower morning temperatures. Sleeping areas in this direction will benefit by having a cooler temperature because the sun is not directly hitting the east during the afternoon and evening. Sleeping areas should allow maximum ventilation. Minimize eastern exposure in the summer using shading elements, such as vegetation, to protect spaces from heat gain. Use window insulation to block intense heat.

Spring and Fall

A southeast patio that has the option to be shaded can be a desirable outdoor area. Windows should be able to control the amount of light admittance.
Parking spaces north of the residence receive shade from the building itself. Outdoor space is accessible from the interior by means of pivoting walls. Glass panels allow for views of the Catalina Mountains in the distance. Aluminum panels cover the steel structure of the building.
North Elevation Requisites

Winter

The north side would be a depressing area to position outdoor patios or terraces since the solar gain is coming from the opposite direction. Insulation is desirable on this elevation.

Summer

In the summer, the northern elevation receives much less direct sun than the east and west elevations. Northeast and northwest areas should provide shading for the building. Outdoor space on the north side of the building can be pleasant if shaded vertically from the west and east. Overhead shading can provide for a pleasant outdoor area in the early morning and later afternoon.

Spring and Fall

Ventilation can help to create a comfortable living environment both at day and night. Windows on this elevation are less detrimental to the unwanted solar heat gain.
Roof Requisites

The roof receives a great amount of solar radiation. The more the roof faces the sky – the more horizontal and less sloped it is – the greater the effect of nighttime re-radiation. Overhangs can be used to shade exterior spaces. Rather than solid overhangs, trellis or ramadas can let the built up heat underneath the overhangs flow out to maintain a cool shaded, space. A calculated fixed louver system can let winter sunlight penetrate to warm the interior, and yet can block out unwanted summer sun.
Floor Requisites

The floor can be used as thermal mass to passively cool or heat the interior of the building. A concrete floor slab has the potential to work well with a low-mass lightweight wall structure. By leaving the concrete exposed, and not covering it with carpet, or other floor coverings, the floor itself can attribute to making the building energy efficient.

Concrete floors throughout the structure work with lightweight vertical building components to passively heat and cool the residence.
Functional Needs

Through the use of kinetic elements, spaces of different values and characteristics can be revealed. Through spatial adaptability, a home can be designed to respond to differing social situations. It can respond to a particular resident’s needs and lifestyle, and it can change as the resident does. Changing family and personal needs dictate various spaces that require different configurations within the architecture. A kinetic home can do just that.

For this design study, the residence will be reflective of place and of the dwellers, and values will be expressed through kinetic architecture. The values of energy efficiency, spatial conservation and adaptability, sustainability, being able to enjoy the outdoor environment, taking advantage of the abundant sun, enhancing the quality of life through design, and the integration of working and living environments will be articulated by kinetic architecture.

The structure of the family, the way the members interact with one another, an individual’s role in the family will all be reflected in the arrangement.
of the home. The value of spatial adaptability will be reflected in kinetic architecture. By creating sliding and moveable partitions, rooms can be multi-functional. The result of this would be the elimination of building costly additions to existing structures. This way a home can be modified, reduced or increased, based on the current residents. You are able to go back, which is not the case with traditional building today. Sustainability - being able to cherish the lasting value that comes from not only building for today, but also for building for the future is what kinetic architecture can offer. The integration of living and working environments can be an easily integrated into a kinetically designed structure. As a home business developed and expands, the structure can kinetically respond to this type of growth. If the business reduces in size, the space not used for working can be used for living. It makes life simpler when the live and work spaces are interchangeable and adjacent. It is a cost and time saving solution, eliminating the cost of fuel and transportation.

People's individual needs are constantly changing and evolving. A kinetic home can evolve with its inhabitants. In a kinetic residence, the public and
private realms can change based on how the residents use the home maintain privacy. A person’s needs for individuality or community might vary from day to day or even from hour to hour. Therefore, the home might be used at one time to express openness and welcome in the outside world to others and shortly thereafter be used to express the need for privacy. Broad cultural standards about the use of homes, such as norms for visiting or entertaining others in one’s home, are less apt to be changeable than individual behavior. It is important to live in a place that reflects what the needs or desires may be at that time.

The occupants’ lifestyle and needs should dictate how their residence is arranged for efficiency. Hobbies require different spaces, whether they are active exercise spaces or quieter, more private spaces.

All homes need to be able to provide for basic functions:

- service area that includes kitchen areas to serve, store, and prepare food
- bathroom area to cleanse and offer retreat
- private area for sleeping and study
Any design element that has only one function is probably a mistake or a missed opportunity. We ought to strive for multiple and diverse functions of each element so we pay once and get many benefits."

- Amory Lovins, co-founder of Rocky Mountain Research and co-author of 'Natural Capitalism'

- gathering space for entertaining
- work space for production and correspondence

These functions can, and often do overlap and merge with one another. Family members with different interests necessitate diverse spaces. These spaces can be achieved through a responsive house.

The flexibility of the interior can allow for different circumstances. In today's home, many adjustments need to be made to accommodate different social needs. For example, overnight guests often impose on those living in the home. Often, it is a pullout couch in the main living space that impedes on the space, and in turn, the inhabitants. Or, families with larger homes may have a guest room, but without frequent visitors, the room often becomes unused and abandoned. With a kinetically designed space, interior and exterior areas can serve many different purposes.

Spaces within the home can also open up to accommodate large groups of people for special occasions. The gathering space can expand to host cocktail
parties or celebrations. The extra expanded space can become available when it is needed, this can save the residents time and money if they entertain often.

A kinetic residence will be a home that can grow and or change with the family. Through the course of a lifetime - with small children, with grown children, and without children - the same home can be used and can perform the function of a well-used and well-loved space. Children impact social circumstances and dictate certain events. As children grow and require more space, so should the home grow along with them. The number of children and the ages of the children do affect what type of space is needed in a home. If a working area is included in a home, this also needs to respond to what is needed at the time. As a small business grows, more space is necessary.

Today, individuals are complex and there is a need for personal choice. A kinetic home will give its residents the opportunity for choice. There are people who psychologically need permanence. This type of architecture offers the individual control, the building can even remain static for long periods of time if the resident preferred. By planning rooms efficiently, so that no awkward
movements are necessary to use it, the occupants will be comfortable. Spaces will adapt to fit their activities, so that a room is large enough to walk through, yet not so large that you have to walk a ways to turn on a television or grab a book off a shelf. People are satisfied by having control over their environment. By exploring multi-use applications and spatial adaptability, a kinetic home could improve the individual lives of its occupants physiologically.
### Daily Cycle

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Problem</th>
<th>Design Guidelines (Functional Needs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>Busy prep time for all residents. Space and equipment needed for preparing and serving breakfast. Work Space needed for residents working at home.</td>
<td>Maximized: Size of Bathroom and Dressing Areas, Kitchen, Work Area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimized: Sleeping Areas, Living Space</td>
</tr>
<tr>
<td>Noon</td>
<td>Living Space, Work Space, Some space needed for preparing lunch.</td>
<td>Required: Work Area, Kitchen, Living Space</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimized: Sleeping Area</td>
</tr>
<tr>
<td>Afternoon</td>
<td>Residents working at home need space to conduct business.</td>
<td>Maximized: Work Area, Living Area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimized: Sleeping Area, Kitchen, Dining Area</td>
</tr>
<tr>
<td>Evening</td>
<td>Space and equipment needed for preparing and serving dinner. Space needed for relaxation, entertaining, and socialization.</td>
<td>Maximized: Kitchen, Dining Area, Living Area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimized: Sleeping Area, Working Space</td>
</tr>
<tr>
<td>Night</td>
<td>Sleeping area required for all residents.</td>
<td>Required: Private, Dark, Quiet Rooms for Sleep</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimized: Living Area, Kitchen, Dining Area, Work Space</td>
</tr>
<tr>
<td><strong>Timeline</strong></td>
<td><strong>Client</strong></td>
<td><strong>Problem</strong></td>
</tr>
<tr>
<td>--------------</td>
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<td>-------------</td>
</tr>
<tr>
<td><strong>Phase I</strong></td>
<td>Single Adult</td>
<td>A residence for a single professional</td>
</tr>
<tr>
<td><strong>Phase II</strong></td>
<td>Couple</td>
<td>Both people work at home, which in this instance means within the chosen rooftop site, one work space is separate, one is located within the home</td>
</tr>
<tr>
<td><strong>Phase III</strong></td>
<td>man, woman, and their two children</td>
<td>Interest in being able to pursue daily activities out of doors as well as indoors as the weather permits. Need to create space for the family and its singular members</td>
</tr>
<tr>
<td><strong>Phase IV</strong></td>
<td>Couple with teen/adult children</td>
<td>Need to create space for both the family as a whole, and also more private spaces for the teenage children</td>
</tr>
<tr>
<td><strong>Phase V</strong></td>
<td>Couple and 1 adult</td>
<td>A separation from the main residence that can accommodate a single independent adult child. This resident should have a reasonably private access to his/her dwelling space as to arrive and receive visitors without unduly disturbing the rest of the family members.</td>
</tr>
<tr>
<td><strong>Phase VI</strong></td>
<td>Elderly parent and adult child</td>
<td>Handicapped Access to all areas of the residence</td>
</tr>
</tbody>
</table>
Adaptive Growth Needs

A kinetic residence can adapt to fit whoever the current occupants are. It can also change with the growth of the residents. A kinetic house can accommodate a single person or an entire family. In this project, the adaptation of the residence will be shown through a family life occupancy cycle. This occupancy cycle is divided into six phases, where there are each different design problems and guidelines that need to be addressed.

Phase I is designed to provide for one adult. This adult is a young, single professional. It is during this phase that the residence is in a fairly minimalist state, for only one resident occupies it, so it is similar to a basic studio apartment. The floor plan shall include flexible space for a living area for entertainment purposes (250 sf,) dining area to eat meals in (100 sf,) sleeping area that can be open to the living space or separated (100 sf,) kitchen for food storage and preparation (16 Lft,) and a bathroom that can be divided through a moveable partition to create a public restroom for visitors and a private bathroom for the
resident’s personal use. It also incorporates storage areas. Traditional closets are not necessary, moveable storage units can work well because they have the ability to be transported to whichever area they are needed in. The square footages given are estimates under normal, everyday use. These areas can minimize and maximize to meet the occupant’s needs and desires. Outdoor space, including a private terrace and a public porch, are also incorporated into the floor plan so as to have the option to conduct daily activities outside if the weather permits.

Phase II is intended for a working couple. Both individuals work at home, meaning separate work space is be incorporated into the site design. One work space is located within the residence and this space adapts to what is needed at the time. The other is a specific work space that has spatial aspects (meeting room, work area, file storage) that employ kinetic strategies. Spatial requirements for the home include an entry arrival space, a living area that can subdivided for different activities (600 sf,) dining space to eat at daily but also formally with guests (200 sf,) kitchen (150 sf,) bedroom (250 sf,) bathroom (50
Kinetic Architecture and its Application to Urban Housing in Tucson

sf), interior work space (100 sf) and a separate work space (300 sf.) The interior spaces of living area, dining area, kitchen, bedroom, and work space each have adjacent or blended outdoor space incorporated into the design, so that the activities that occur in these areas can be conducted inside, outside, or in a space that combines interior and exterior realms. There is also the opportunity to provide space for out of town relatives or large entertaining areas. The bedrooms and bathrooms are the two spaces where privacy becomes a main concern. The rest of the floor plan can allow for freedom of function in the provided space. The kitchen can utilize moveable storage for food and dishes, so that the room can blend into the other areas of living and dining space, as well as outdoor food preparation and serving.

The residents of Phase III include a man, woman, and their two children. Space for the family, as well as its singular members needs to be accommodated for. The home includes an entry space at which to arrive and receive visitors, a living area that can satisfy the likes of all residents (600 sf,) dining area (200 sf,) kitchen (150 sf,) master bedroom (250 sf,) two child’s rooms (150 sf each,)
bathrooms that can be used for guests and for private use, (min. 40 sf each,) an interior work space (100 sf) and a separate work space (300 sf.) The plan is adaptable for the children's needs as well. The children's bedrooms offer flexibility - allowing them to have a combined play space in the daytime, and have separate spaces for privacy in studying and for sleep at night. Outdoor spaces are also incorporated into the plan, and a safe outdoor play space for the children is included as well.

Phase IV is designed for a couple with two teen/young adult children. More private areas for the teenage children are required, but shared space for all family members is needed. Regular daily space is needed for a living area (600 sf,) dining area (250 sf,) kitchen (150 sf,) master bedroom (250 sf,) two teen's rooms (250 sf each,) bathrooms that can be used for guests and for private use (min. 40 sf each,) library (250 sf) and a workspace (300 sf.) Outdoor space, and the division of spaces will create privacy and harmony for the residents.

Phase V entails residence for a couple with one adult. The adult has a space that is separated from the main residence. This resident has a reasonably
private access to his/her dwelling space so as to arrive and receive visitors without disturbing the rest of the family members. For the couple, the residence includes an entry arrival space, a living area (600 sf,) dining space (200 sf,) kitchen (150 sf,) bedroom (250 sf,) and public/private bathrooms (40 sf.) The independent adult should have space that includes a living space (200 sf,) dining area (100 sf,) sleeping area (100 sf,) kitchen (16 Lft,) and a bathroom (40 sf.) The space designated for the independent adult includes a private outdoor area, although outdoor space for all the residents is provided for.

The final phase, Phase VI, is to accommodate an elderly parent and an adult child. In this phase, handicapped access to all areas of the residence is required. The two individuals will be sharing the main space, with only separate sleeping areas if needed. The residence shall include a living area (400 sf,) dining space (200 sf,) two sleeping spaces (200 sf,) kitchen (150 sf,) and accessible bathrooms. Outdoor space is included into the design. The flexibility of the floor plan allows for ease of access and use.
These six phases comprise one lifetime cycle in a kinetic residence. The spatial requirements are guidelines to design by, and are flexible and adaptable to the resident’s needs. Outdoor areas are to be included in the residence during each phase. The overlapping of these stages is possible, as expansion spaces can be added at any time in the cycle. The building life cycle can be repeated, as the beginning stage of the cycle is similar to the final stage of the cycle. The process is free to start all over again in a repetitive motion, allowing for differences in user needs throughout.
CHAPTER 3

TIME, GROWTH, & MOTION
Movement – Relationship to Nature

Some of the systems that occur naturally in animals and plants can be the basis for kinetic systems. The same movement systems can be applied to make architecture kinetic.

An example is the motion of flight in birds. Everything about a bird is made for flight. In order to understand the inherent flight of birds, the structure of a bird should be analyzed. Feathers are light but very strong, they are flexible but very tough. The internal structure is adapted for flight - the biggest muscles a bird has are its flight muscles and the minimal bones they have are hard but thin. The structure of the wings allows for variety in flight and the wings itself take advantage of the air pressure and movement.

There exists interdependence in an ecosystem, where numerous beings relate and respond to each other. So too, can a kinetic dwelling - each building and design component can relate to the occupants and the environment.
Motion – Change – and Process

There are many examples of ways in which the human body adapts for what it needs. For comfort, as well as for its own defensive protection, components of the body behave in ways that allow the body to adapt and respond to its surroundings. One instance is the human eye. The retina of the eye works best at a certain intensity of illumination – and the body changes to maintain this level. In bright light, the nervous system contracts the pupil, letting in a limited amount of light. Therefore, the quantity of light entering the pupil is always within limits that we can handle. Living organisms perceive information through the senses. The senses serve the organism by obtaining information about the environment it needs to survive. Living organisms react to external as well as internal forces.

Evolution teaches us that man has evolved from earlier forms of life on earth. Fossil evidence shows how the primate skull has grown to allow increased brain capacity. The steps from baboon to chimpanzee to human can be seen as
a geometric transformation of a grid mapped over the skeleton. It is as living matter itself is a pliable medium.

Architecture has always had a relationship to the human body. The proportioning system of our built environment has a direct link to human scale. Doorways and ceiling heights have been established relative to human size.

Nature is a living process that goes through cycles and seasons of change. Natural light is never fixed; light and shade change as the sun moves through the sky during the earth’s daily rotation, as the seasons change the angle of the sun’s rays, and as we migrate from one latitude to another. The perception of light brings the awareness of the cycles of change. A kinetic building can reveal this transformation and can relate to nature in that it, too, can experience a process of change and growth.
Adaptation - The Concept of a Living Building

Responding to What it Needs

The way living things respond to stimulus parallels the way a kinetic building can respond to different activators. Plants and animals in the desert climate of Tucson, Arizona, have adapted to water and temperature extremes. Desert plants have a means of storing and conserving water. They often have few or no leaves, which reduces transpiration (loss of water to the air.) Cacti, an adaptation of the rose family, are among the most drought-resistant plants on the planet due to their absence of leaves, ability to store water in their stems, spines for shade and waxy skin to seal in moisture. Other desert plants have extremely long roots that reach down into the earth, allowing them access to the water table.

Animals that live in the desert have adapted to their environment. Animals in the desert must survive intense heat, searing sun, and minimal water. Some
animals never drink, but get their water from seeds, others adapt by spending most of the day underground and out of the hot sun. Other animals have developed salt glands, a physical adaptation that allows the secretion of salt without the loss of water. These are just a few examples of biological adaptations.

A dwelling in this location can also adapt through the use of adjusting and responsive architecture. When the internal air temperature is too warm, openings in the walls can allow for natural ventilation to cool the interior. As the sun becomes too bright and causes too much glare to perform daily functions in, shading devices can filter the light. If the nighttime winter temperature gets too cold, the heat collected by the building materials during the day can redistribute the heat into the interior to warm the space at night. These are just a few examples of the resourceful variety of adaptations a kinetic residence can use to endure in the desert as well.
Time Cycle

Kinetic Architecture can change based on time cycles. Time implies change and growth. To study how and why a kinetic architecture could change, a residence will be tested through different rotations of time. At each stage of the cycle, there will be a manipulation of the structure to respond to what the given needs are at that moment. Analysis will be studied under three time sequences to get an understanding of why and how a singular residence can adapt. Changes take place under a daily cycle, a seasonal cycle, and a lifetime cycle.
Daily Cycle

The residents of the house go through a series of daily rituals that are maintained throughout all seasons and stages of life. They are coordinated with the sun throughout the day. The daily cycle is based on five continuous days in a weekly cycle. Throughout the course of a day, zones of public, semi-public, private, and semi-private space are required. Kinetic elements can help to define and isolate these zones within the different areas of the home.

Morning

The morning is a time of awakening for the residents of the house. This time of the day begins the active, lively time of the cycle. It is a time of both cleansing and preparation for the day ahead. The kitchen is used to prepare and serve breakfast and maybe even to prepare lunch. The kitchen area can come apart to reveal a workstation for food preparation. A kitchen work area and surface space will be utilized at this time. Access to refrigeration and food
Through the use of kinetic features, this space is able to perform functionally and aesthetically. The upstairs bedrooms can take on many configurations and in the kitchen, the counter workstations and an island pull apart to reveal chairs for dining.

Case Study: Norton Apartment
Maya Lin, 1999.

Storage is necessary. Dining space is also necessary, although it does not need to be a formal dining room, it can be stools around a counter top. Morning meals are usually quick and easy on the weekdays. At this time of the day, the sleeping area can be compacted and minimized since it will not be used again till the end of the cycle. The living areas may open up and permit usage. On the weekends, mornings in the home will usually be longer and more relaxed, less rushed than on the weekday.

Bathrooms and dressing rooms play an important role in the morning routine. Separation of activities within would save time during this demanding time and will benefit the residents. Sliding and moveable divisions in the bathrooms and dressing rooms can create separate spaces for the users. The bathing, washing, and toilet areas can be used simultaneously by having compartmentalized areas. This way, one family member could use the sink while another one uses the shower. When the bathroom is not being heavily used, it can be joined together again. But a kinetic strategy would save time and space. No longer would you need to wait to use the toilet while another resident is...
The bathroom is also responsive to occupant’s needs by having the option for an open bath or a subdivided bath for separate public and private use. Occupying the bathroom by taking a shower, and not by using the toilet. Moveable bathroom partitions will give residents privacy while being able to use the same area. The solution will save time and space.

The one adult works within home, so the work space will also be utilized in the morning. The other residents leave the home to go to school and work, and now the home can compact itself to save on energy costs and can free up space on its site. It can do this by using sliding and pivoting walls that can essentially “shut down” the residence.

Noon

At noon, the residents may either come home for a lunch break or may still be away at school or the office. It may be only the kitchen and dining areas that are being used at this time of day. These areas can be screened from the work area so that both can be used at the same time.

Afternoon

In the afternoon, those residents that work at home require space to work and conduct business. Client interaction within the space should be considered.
Therefore, this area has to include both public and private space. A work space needs to provide for many functions, it can potentially be used as both a workshop and an office. This area needs to include space for public reception and client management. Storage is also another consideration. Storage carts or units that are on wheels can be transported from one area of the residence to the next. Moveable subdivisions and partitions can be used throughout the day depending on what's needed. For example, the bathroom can subdivide to create a public restroom to be used by guests, and a more private bathroom to be used only by residents. Kitchen and living areas may be screened off from workspace to create a private and public separation of spaces. The office can be best utilized for a workshop, but for relations with the public, a screening device can divide the space and the area can now serve as a meeting room.

School children return from school and require living space to play and study space to do homework. If the children have a designated area of the residence which is all their own, there becomes a good opportunity for kinetic design. The children can play together in an open area to encourage
socialization, but for study and sleep, subdivisions, that create a space for each child, will offer privacy and quietness. Pivoting wall systems can offer children the opportunity for togetherness and for solitude.

Later in the afternoon, the kitchen becomes important again to prepare dinner. Counter space will be utilized, as well as convenient food storage and refrigeration space. Most of the year, the outdoor kitchen area can be used to prepare meals, grill and serve the food. There will be occasions in which a greater kitchen space is needed to prepare meals for a large group. A dining area is required for the family meal. It is at this time where the table space accommodating all members of the family is needed for eating. The dining room also has different levels of formality depending on who the guests are and what the occasion is. The connection to the kitchen and how open it is from the service kitchen area can determine this formality. Dining is especially pleasant outdoors.

**Evening**

Evening time involves the living space to be available for family conversations and entertainment purposes. Entertainment, relaxation,
socialization, and recreation are all activities that will be done in this area. The living room can also be seen as a space for individual activities such as reading or hobbies and projects. On some occasions, the living area should be a totally separated entity from the dining room, but there are other instances where the two rooms should blend as one. A moveable screen can offer the opportunity for both. Both spaces should have the opportunity to open up to the outdoors to enjoy the warm temperatures of the region when it is permitted.

**Night**

Night suggests that the sleeping area become the focal point of the house. Bedroom divisions can organize space and can allow family members to sleep in separate rooms. Bedrooms can subdivide at any time to make accommodations for out of town guests. In mild temperatures, sleeping outdoors can offer an enjoyable rest. The kitchen, living, and dining areas can all be minimized for their lack of use.
Life Cycle

The life cycle describes the changes that occur over the course of a lifetime. This explains the life of a resident in the house, and can show the relationship of how kinetic architecture can change and adapt along with the occupant. The life cycle is also the building life cycle – it demonstrates the possibilities of an adaptable residence for growth over time. This lifetime cycle is investigated through six phases of life. The first phase has the occupant of a single adult. This single adult is a young, single professional. The home should be convenient and efficient. The rooftop site offers the opportunity for the residents and clients, to live, park and work in the same place to conserve time, money, and space. The second phase is designed for a couple. Both people work at home, so consideration needs to be taken to design separate work spaces that get incorporated into the site, and even the house itself. Living space needs to increase to accommodate two adults now. Phase three includes space for a man, woman, and their two children. During this phase, space needs to be created for both the family as a whole and also for its singular members.
PHASE I
SPACE INTENDED FOR: - 1 ADULT

This is the initial phase of the building cycle. Interior and exterior spaces are organized around a central core that holds plumbing and utility needs for the kitchen and bathroom. It is from this core that the house branches out into the site. Living and dining spaces are able to open to the exterior. Wall panels that pivot and swing outwards permit this to happen.

PHASE II
SPACE INTENDED FOR: - 2 ADULTS

This phase involves a live-work environment. The residents are able to park, live, and work all in one location to save on time, costs, and fuel. The independent workspace is located on the northwest side of the site, adjacent to the parking level below, so that clients and employees can easily access the office. Both work spaces are also able to open up to the outdoor terraces and can establish a connection with the central living space.

PHASE III
SPACE INTENDED FOR: - 2 ADULTS - 2 CHILDREN

Both exterior and interior spaces have variation between public, family, and private zones. This allows greater use efficiency. The second floor cantilevers to the north, providing shade to parking below. The children's rooms are able to join together for play by means of interior moveable wall partitions, but can also be divided for private sleeping areas at night. All daily functions - cooking, dining, sleeping, living - can be conducted outdoors as well as indoors.
As an active family, there is an interest in being able to pursue daily activities out of doors as well as indoors as the weather permits. The activities of sleeping, living, dining, and working can all be conducted outdoors in different circumstances. The fourth phase includes space for a couple and their teenage children. This phase also involves creating space for the whole family, as well as more private space for the teenage children. The fifth phase is intended to provide a residence for a couple and one adult child. There should be a separation from the main residence that accommodates a single independent adult child. This resident should have reasonably private access to his/her dwelling space as to arrive and receive visitors without unduly disturbing the rest of the family members. The last phase of the cycle involves providing residence for one elderly parent and one adult child. In this phase, the home should adapt to provide handicapped access to all areas of the residence.

This sequence of stages is a method to show how kinetic architecture can change throughout the course of one’s life. Families grow and change. No longer will a different residence at a different location be required to fulfill the needs of one family.
Seasonal Cycle

The seasons of the year have a large impact on the configuration of the building. The use of kinetic building elements can respond to the sun and the temperature and can save on energy costs.

In the winter, days are comfortable and outdoor spaces that receive sunlight are desirable. A sunny patio or terrace can be an enjoyable place to spend the winter days. Advantage should be taken to the winter sunshine both for the direct sun penetration through windows and openings, and its warming effect, and for the psychologically pleasing effect. During this time, solar heat gain and storage is needed to keep the occupants warm at night. Night temperatures in winter are cold, and nighttime closure and insulation can keep and reuse the warm air collected during the sunlight hours. The building components should reflect the sun’s position; a kinetic solution that is correlated with the sun would be beneficial to control the interior temperature. In the morning, with the sun being in the low east, solar gain and thermal mass are needed. A thermal storage water wall that uses water held in tubes, can collect
PHASE IV
SPACE INTENDED FOR:
- 2 ADULTS
- 2 TEEN CHILDREN

THE RESIDENCE ALLOWS FOR MORE PRIVACY AMONG FAMILY MEMBERS. THE CHILDREN'S ROOMS ARE NOW SEPARATED. LARGE OPEN SPACES WHERE ALL FAMILY MEMBERS CAN EXIST TOGETHER ARE STILL MAINTAINED IN THIS PHASE. THE MAIN LIVING SPACE IS ON THE WEST SIDE OF THE HOUSE; FROM HERE THE RESIDENTS ARE ABLE TO VIEW THE SUNSET. BY HAVING A WEST-FACING LIVING AREA, THE RESIDENTS ARE ABLE TO REGULATE AND OFFER SECURITY TO THE STREET BELOW.

PHASE V
SPACE INTENDED FOR:
- 2 ADULTS
- 1 INDEPENDENT ADULT FAMILY MEMBER

AN ADULT FAMILY MEMBER IS INTENDED TO LIVE IN THE RESIDENCE. ALTHOUGH THERE IS A PRIVATE ENTRANCE TO HIS LIVING SPACE ON THE SECOND FLOOR. THIS IS SO THE FAMILY MEMBER CAN ENTER AND RECEIVE VISITORS WITHOUT DISRUPTING THE OTHER FAMILY MEMBERS. OUTDOOR SPACES OFF THE LIVING, SLEEPING, AND DINING AREAS ARE INCORPORATED INTO THE SECOND FLOOR PLAN. ONE WORK SPACE IS DESIGNATED IN THIS PHASE.

PHASE VI
SPACE INTENDED FOR:
- ELDERLY PARENT
- ADULT CHILD

AN ELDERLY ADULT REQUIRES HANDICAPPED ACCESS IS NECESSARY THROUGHOUT THE RESIDENCE. SLEEPING AREAS CAN BE JOINED AS ONE, OR SEPARATED. AS IN ALL PHASES, THE BATHROOM HAS A MOVEABLE PARTITION WITHIN IT, SO AS TO SEPARATE PUBLIC AND PRIVATE AREAS. THERE IS A WASHROOM FOR VISITORS, AND A BATHING AREA THAT CAN BE SHUT OFF FROM THE PUBLIC. FROM THIS PHASE, THE BUILDING CYCLE IS ABLE TO REPEAT ITSELF, ADAPTING TO THE NEEDS OF THE RESIDENTS AND THE ENVIRONMENT.
Thermal mass walls are able to collect and store energy to be used for heating and cooling. This method is especially beneficial in the Sonoran desert climate because of the large diurnal temperature swing. The heat as the sun hits it. Water tubes can also be used as a summer, as they are capable of accepting and storing “coolth.” In the summer, the tubes absorb unwanted internal heat, thereby cooling the interior. These water drums have the potential to be moved to where they are needed. When not needed, the water tubes can be emptied and used to water the vegetation on the site. The heat is then transmitted through the tube and warms the interior several hours later. They can slide or move away from the perimeter into the interior to free up views and can permit outdoor space to connect. Throughout the winter day in the north where the sun can hit it directly, a thermal mass wall can contribute to heating the interior. In the afternoon, a time lag wall in the west and east can help collect heat and direct it to the interior. Thermal mass can be found in the floor, or in benches and low walls. Exterior insulation will help to maintain the gathered heat and can keep it inside the residence where it will be used to heat the home at night. The low winter sun can allow direct heat gain through windows with exterior overhangs. Moveable blinds or operable shutters can regulate light and shade. Sunspaces can also permit the sun to enter the interior. There is the
The geometry of the Walker Guest House adapts for functional needs.

Case Study: Walker Guest House
Paul Rudolph, 1952.

This house features a series of panels that pivot on the exterior of the structure. The panels act as an enclosure wall to offer protection and privacy. They are then able to open up to allow for light and ventilation to enter the building. When opened up, these panels act as a cost effective and energy efficient device for shading both the interior of the building and the open exterior patio area.

potential for the sunspace to adapt to become a screened porch or even an entire outdoor space over the building cycle.

The spring season brings warmer temperatures, and different climate conditions that need to be addressed through the architecture. Both the spring days and nights are relatively comfortable. Modest heating and cooling is all that is needed. In the morning, an eastern and southern mass wall will be beneficial, and depending on what is required, solar gain or solar shading can be used in the south. In the afternoon, the west side receives the light and also will utilize either solar gain or shading. Natural ventilation throughout the day and especially at night, will keep the interior at a comfortable temperature. By insulating and ventilating the northern side of the house, you can naturally and efficiently heat and cool the residence. That is why a kinetic – an easily operable and changeable system - can be a simple solution to heating and cooling a building. These requirements can be addressed with a moveable wall, floor, and roof system that can control light, shade, and ventilation.
The fall season is similar to spring; it is a moderate and generally comfortable time of the year. Both minimal heating and cooling may be required, but with a kinetic building that reacts to the sun, the home can be temperature controlled without using costly energy consuming methods.

The summer in Tucson is a time when shading and cooling are top priorities. Nighttime ventilation is desired. The summer sun is higher and it is important to prevent direct heat gain into the home in the daytime. Insulation on all sides of the building in the morning and in the afternoon will help keep interior temperatures cool. At night, air from all directions will help to ventilate and cool the home. However, the elimination of ventilation in the hot hours of the day can be necessary in order to minimize the heating of the interior.

Balanced day lighting and control of light in different areas of the home is also a concern that kinetic architecture can address. Operable louvers or shading devices can easily shade when necessary.

The use of landscaping elements can be beneficial to a comfortable living in the desert. Trees, shrubs, groundcovers, vines, trellis and turf can provide
Trees and vegetation play an important role in passively cooling the residence.

solar control. The foliage and branches of plants will selectively reflect, absorb, and transmit solar radiation. They can effectively reduce direct and reflected radiation. By absorbing heat, and through evapo-transpiration, there will be cooling effect. Needles and small-leafed plants commonly found in desert landscapes can be very effective at reducing glare from reflective surfaces. Deciduous vegetation is a kinetic element in itself, naturally changing according to the rhythm of the seasons. They can provide beneficial shade in the summer, and can let desirable sunlight shine through in the winter.
SLIDING PANELS ARE ABLE TO COVER GLASS TO FURTHER PROTECT FROM NIGHTTIME DRAFTS

PIVOTING WALL SECTIONS CAN CONTROL LIGHT AND AIR FLOW INTO THE BEDROOMS

SOUTH-FACING OUTDOOR PATIO

OPERABLE ROOF OPENS TO THE SOUTH TO LET LIGHT INTO WORKSPACE

WEST FACADE ALLOWS FOR VIEWS OF SUNSET, MOUNTAINS, AND CITY-LIFE BELOW

SOUTHWEST OUTDOOR LIVING SPACE LETS THE RESIDENTS ENJOY WINTERTIME SUNSHINE

SOUTH-FACING THERMAL MASS WALL

A GLASS WALL ALLOWS HEAT AND LIGHT TO ENTER LIVING SPACE

THERMAL MASS WATER DRUMS

WINTER EVENING SUN

WINTER MORNING SUN
Kinetic Architecture and its Application to Urban Housing in Tucson

SLIDING PANELS ARE ABLE TO COVER GLASS TO FURTHER PROTECT FROM NIGHTTIME DRAFTS

WINDOW PLACEMENT PERMITS CROSS-BREEZES

PIVOTING WALL SECTIONS CAN CONTROL LIGHT AND BREEZES INTO THE BEDROOMS

OUTDOOR SLEEPING AREAS

HOT AFTERNOON WINDS

PLANTERS PROVIDE SHADE FOR PARKING SPACES

WINDOW PLACEMENT PERMITS CROSS-BREEZES

WEST FACADE ALLOWS FOR VIEWS OF SUNSET, MOUNTAINS, AND CITY-LIFE BELOW, AS WELL AS VENTILATION

WALL CAN OPEN TO VENTILATE INTERIOR SPACE

SOUTHWEST OUTDOOR LIVING SPACE

SOUTH-FACING THERMAL MASS WALL

GLASS CAN BE COVERED TO KEEP INTERIOR COOL OR KEPT OPEN TO PERMIT SOLAR GAIN

THERMAL MASS WATER DRUMS

VEGETATION FACILITATES COOLING EFFECT ON OUTDOOR AREAS

COOLING BREEZES

SUNSET

SUNRISE
Kinetic Architecture and its Application to Urban Housing in Tucson

- **NORTHWEST OUTDOOR SLEEPING/SITTING AREA**
- **WINDOW PLACEMENT PERMITS CROSS-BREEZES**
- **PIVOTING WALL SECTIONS CAN CONTROL LIGHT AND BREEZES INTO THE BEDROOMS**
- **OUTDOOR SLEEPING AREAS**

- **PLANTERS PROVIDE SHADE FOR PARKING SPACES**
- **WINDOW PLACEMENT PERMITS CROSS-BREEZES**
- **WEST FACADE ALLOWS FOR VIEWS OF SUNSET, MOUNTAINS, AND CITY-LIFE BELOW, AS WELL AS VENTILATION**
- **OVERHEAD TRELLIS PROVIDES SHADE FOR OUTDOOR LIVING SPACE**
- **WALL CAN OPEN TO VENTILATE INTERIOR**
- **SOUTH-FACING THERMAL MASS WALL GLASS CAN BE COVERED TO KEEP INTERIOR COOL OR KEPT OPEN TO PERMIT SOLAR GAIN**
- **WALL PANELS OPEN TO VENTILATE INTERIOR SPACE AND PROVIDE SHADE FOR EXTERIOR SPACE**
- **VEGETATION FACILITATES COOLING EFFECT ON OUTDOOR AREAS**

- **COOLING BREEZES**

**HOT AFTERNOON WINDS**

**SUMMER EVENING SUN**

**SUMMER MORNING SUN**
Aerial Map of Tucson's Downtown area.

Site Location

A kinetic residence can be seen as ideally located in an urban context, where technology is unfolding. In the city, well-planned and flexibly adaptable space is more of a necessity. At the turn of the twenty-first century, 70 percent of the world's population live in cities. Efficient solutions to space performance are needed more than ever. Kinetic Architecture - that responds to light, climate, and people - is an especially viable approach for urban locations.

The site chosen to build an environmentally responsive and socially sustainable residence is on top of an existing parking structure on the east side of Scott Avenue between Pennington Street and Congress Street in Downtown Tucson, Arizona. The chosen location offers excellent vehicular and pedestrian access to the site. The roof top elevation allows for great views. The facades can open up to the elements and respond to the environment in all four directions, and they will not be hindered by surrounding obstructions. This location can offer superlative opportunities for natural ventilation and can offer
the highest potential in this desert region for the use of natural energies for heating, and especially for summer cooling. By resting on top of this element, there is the opportunity for a live – work residence. Clients can have the access and parking needed to do business with the resident. Eventually, there can be the possibility of retail spaces on the ground level of the garage to further benefit the residents of this area. The location is within the downtown area, which means there is close adjacency to employment centers, shopping, markets, as well as community services such as schools, libraries, and museums.

The existing garage was constructed in 1970, and was intended to rise 13 levels above ground. However, only 9 of these levels were built. Because of this, there is enough structural integrity to support the addition of residential functions on the upper most level. The garage has two stairwells for egress, as well as an elevator. The garage is designed to function as staggered floors, with one way vehicular circulation. Entrance and exit is off of Scott Avenue.
View of the vertical circulation towers on the west side.

The west elevation of the parking garage on Scott Avenue.

West side of Scott Avenue looking north.

West elevation (south-side) of parking garage.
View of the eighth level of the parking garage, looking east.

The approach up to the top level of the garage.

Exit ramp for the parking garage, located on the north side.

Looking south down Scott Avenue from top deck.
Building Response

The work-live residence is incorporated into the top level of the existing parking garage, which is thirty-five feet above street level. Using a four-foot grid module, the actual placement on the site was chosen in response to environmental factors. The placement of the building on the garage, combined with outdoor walls and landscape elements, screens the residence from the public. It is within this created realm that living space is able to flow from indoors to outdoors. The residents have the security and the opportunity to expand their nearly all living activities to the outdoors. Courtyards envelop the residence on all sides. These exterior spaces can be used privately or can be used for larger groups of people. The home office space, that includes work areas for several outside employees, can use some of the exterior space in conjunction with the residence for business-related use. The outdoor space has the option to be broken down into different zones, and it can also flow freely as one open park.

The public pedestrian approach is through the stair or elevator tower. After a vertical accent into the sky, visitors arrive at an outdoor space that
includes a panoramic view of the city and mountains beyond. The vehicular approach takes visitors through a dark garage till alas they arrive at the top, witnessing a place that recovers the once-open space of built-up area of the city. The outdoor areas face different directions, therefore receiving different levels of sunlight. In the winter, these patios are a warm and welcome locale. However, in the summer the patios can be shaded by means of kinetic building components. Landscaping beds contribute to creating useable outdoor areas. They define spaces and facilitate shading and cooling of the courtyards. Overhead trellis covers the patio adjacent to the living room and continues to grow down the front of the parking garage, giving passersby below a glimpse of what's above.

Private parking spaces for the residents and their guests are designated. The building and landscaping self shades additional parking spaces on the parking deck below. The office space is easily accessible from both pedestrian and vehicular circulation routes.
Growth in the building involves six stages of additional space that satisfies the need of family expansion. The residence goes up to two stories high, further enabling the opportunity for views, passive cooling, and self-shading. Sleeping areas offer multiple configurations for children or guests. The furniture and walls are moveable, creating greater flexibility to accommodate varying functional requirements.
PHASE I

PHASE II

PHASE III

PHASE IV

PHASE V

PHASE VI
## Objectives of Adaptation for Functional Needs

<table>
<thead>
<tr>
<th>Problem</th>
<th>Implement Kinetic Strategy</th>
<th>Result</th>
</tr>
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<tbody>
<tr>
<td><strong>Bathroom</strong></td>
<td>Time is wasted because one resident may be using the bathroom by taking a shower. During this time, no one else can use the bathroom to use the sink or toilet.</td>
<td>A moveable, compartmentalized bathroom allows a large bathroom to divide into separate functions when needed. Someone taking a shower can allow another resident to use the sink by moving partitions within the bathroom. The bathroom allows the use of a shower, toilet, and a sink at the same time, offering privacy to all occupants. It can then join together as one space when the demand is not there.</td>
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<tr>
<td><strong>Office</strong></td>
<td>As the business grows, and the current workspace becomes too small and inefficient, constant relocation consumes time and money.</td>
<td>The workspace is able to expand as the business grows. Flexible interior allows workspaces to take on other functions as necessary, such as a client meeting area or a file storage space.</td>
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<tr>
<td><strong>Dining</strong></td>
<td>Current dining rooms are either too formal, too informal, or they are not easily accessible - because of this, they are rarely used.</td>
<td>A dining area that can open up to the living space for formality, open up to the kitchen for informality, open to the exterior terrace, or can be totally screened off, will be used more by residents. Screens or partitions that can easily slide to divide or join areas will give the dining room universal appeal.</td>
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<tr>
<td><strong>Living</strong></td>
<td>Living rooms are a commonly used area by all family members. This often leads to disagreements in what the current function of the room is. Is it a quiet retreat to read in, or is it a loud and lively theater?</td>
<td>By creating moveable dividers in the living room, you are able to accommodate all residents by allowing multiple functions to occur simultaneously, and, since the walls are moveable, you are able to have a grand gathering space for entertaining if needed.</td>
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<tr>
<td><strong>Sleeping</strong></td>
<td>There is no space for out-of-town guests, there exists the need for adaptable children’s rooms for them to play and sleep in.</td>
<td>Pivoting walls can create different configurations of sleeping arrangements, including space for guests and adaptable space for children as they grow.</td>
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<tr>
<td><strong>Kitchen</strong></td>
<td>Appliances attract grease and dust, and take up space. Since it is a service area, often the kitchen is treated as a private area, not allowing for socialization.</td>
<td>Appliance and food &amp; dish storage can be moveable by wheels or by sitting on a platform unit on wheels. They are able to compact themselves to save on space. This can make the area a public space when not being used.</td>
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</tbody>
</table>
Fulfillment of Needs

In response to the environmental precepts previously outlined, a home was designed to satisfy environmental, growth, and flexibility requirements. The building is responsive to the changing environment. The general functional areas of the residence are placed in consideration to what orientation is best suited for what will be taking place in the room. The main living space, that includes living and dining areas, wrap around the center of the house and get light from the south, east, and west. The bathroom, kitchen, and stair core are concentrated towards the center of the house. The bathroom faces the north, and the kitchen and stair are orientated south, and are able to receive abundant light. Interior and exterior spaces are organized around a central core that holds plumbing and utility needs for the bathroom and kitchen. It is from this core that the house branches out into the site.

The living and dining spaces are able to entirely open up to the outdoors. Walls that pivot outward permit this to happen. The main living space is on the
Vines growing off the overhead outdoor trellis

west side of the house; from here the residents are able to view the sunset. Horizontal trellis reaches out from the residence to over the sidewalk below. This allows visibility of the live-and-work space from ground level. By having a west-facing living area, the residents are able to regulate and offer security to the street below. Exterior walls are able to “disappear” as barriers and “reappear” as connectors of exterior and interior space. They adjust to permit the flow of air, movement, and space throughout the house. These walls pivot on an exterior track, and are not opaque. The walls contain a plane of glass that is covered by adjustable louvers on the outside part of the glass. This way, the house can be compacted for different situations, and there still exists the opportunity for views. The living room, which is a double height space, is able to open up to the north terrace where mountain views, as well as observation of the parking deck below, are possible. The living room is also able to open up to two outdoor areas, one that is covered horizontally by the trellis, and vertically by the wall, and another outdoor space that is open to the southern light. These areas can regulate light through vertical “shades” – the exterior walls that are able to swing out to
The master bedroom extends to the outdoors. The living space is connected to the dining area, and together they can expand to the southeastern patio. This space has the opportunity to be shaded from the west and the south, which makes it a desirable afternoon location. This outdoor space is also surrounded by vegetation growing on the east. These shrubs and trees will further facilitate cooling of the area. The kitchen core has access to both the living and dining areas, as well as to its own outdoor cooking area. The bathroom has a moveable partition within it, so as to separate public and private areas. There is a washroom for visitors, and a bathing space that can be shut off from the public.

The sleeping area is concentrated in the northeast area of the residence. This location is ideal for sleeping because the east will receive the least amount of light in the evening, so the room will be cooler. Private outdoor sleeping areas are related to the interior sleeping area. The exterior walls of the bedroom are able to open up onto this outdoor area.

The independent workspace is located on the northwest side of the residence. It is close to the parking level below so that clients and employees
can easily access the office. The office space is able connect to the residence by means of an outdoor terrace. The other office space, which is located within the home, has somewhat private access from the main living space, although it is a part of the interior living space.

In later phases of the building cycle, the second level of the residence is added to accommodate sleeping rooms for the family members. Portions of the bedrooms cantilever over the parking deck below, while providing shaded parking spaces. In a later phase, a private living area for one family member is designated on the second level. Landscaped outdoor spaces are throughout the site, as well as designated private parking and circulation routes.

The building materials are a response to the environmental conditions. A heavy mass wall is located on the south side of the house, providing radiant heat storage. This wall is one of the few static elements that exists through all building stages. The rest of the building is constructed from a steel frame panel system that reflects the industrial nature of the site. White aluminum panels create a sleek look on the exterior, while reflecting more light than a darker
Eight-foot high wall panels sit on an eight-inch slab and are covered in an eight-inch high flat roof system. The panels are able to pivot and swing out of place along an exterior ground track to allow for a connection between spaces. The roof system in the independent work space is able to tilt up to the south to allow for natural light to illuminate the office, but can remain a flat roof in the cold of the winter to prevent heat loss. Because the building is composed of a modular panel system, there is flexibility, ease, and rapidity in the building process.
Hybrid Palo Verde Trees can be used in planters on the site.

Hydroponics and Aeroponics grow plants without dirt, and offer a solution for planting on rooftop sites.

Vegetation is used to provide shade and to define outdoor spaces. Natural desert fauna used in planter boxes can fulfill the environmental needs of the residence. The Hybrid Palo Verde is a tree that can reach up to twenty feet high, and is used in tree boxes. It is native to the deserts of Southern California, Arizona, Baja California and northern Mexico. It is used in this region as a street, patio or garden tree, and in desert gardens and lawns. It is often used in planters and beddings and can be seen in urban parks, streets and parking lots. Because of its inherent characteristics, it can be used on the building site. Other desert plants with low root beds provide shade and work to passively cool outdoor spaces. Hydroponics and Aeroponics can also offer a solution to planting on the site. Aeroponics is a system where a plant's roots are suspended in a lightproof box and misted with hydroponic nutrient solution. Storing and using rainwater to irrigate the vegetation on the site is valuable in a desert climate. With a rooftop site, the possibility for rainwater collection is great. Water that falls on the roof of the residence is able to flow down to irrigate vines on the trellis. Essentially, using low-water desert plants is a cost effective means to vegetation on the site.
In Summary

As illustrated in the drawings, kinetic strategies are able to offer a better living environment for the residents. Both interior and exterior spaces have more potential to satisfy the needs of the user with kinetic architecture. A building that responds to sun, wind, and temperature is appropriate for an environment that is in a constant state of change. Kinetic architecture is applicable for both a residence and an office as shown, and can perhaps be used for additional functions such as retail or commercial use.

<table>
<thead>
<tr>
<th>Kinetic Architecture Precepts</th>
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<tbody>
<tr>
<td><strong>Type</strong></td>
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<tr>
<td><strong>Description</strong></td>
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<td><strong>Cycle</strong></td>
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Site Decision and Design Process

Other site locations were considered before selecting a parking garage rooftop site. The general downtown vicinity of Tucson is an ideal location for a kinetic project. Surrounding retail, cultural, and entertainment establishments already draw people into the downtown area. It is a place that is alive with people and energy and a kinetic residence here can offer people a chance to witness how a responsive building can facilitate and improve their lifestyles. An open lot was considered because one of the benefits of a kinetic residence is being able to open the structure up to the space all around it, in every direction, to take advantage of the environment. By being located in the heart of a city, a single-family residence located in an infill or vacant lot is not considered the most efficient use of space. The street level could be better developed for retail and public uses. A rooftop site can offer an alternative solution, but it does have complications. A main concern for living on top of an existing structure is access and egress to the residence. Most existing structures were not built to account for the additional loads of another structure built on top. Adjacent buildings
This scheme was unsuccessful because the addition of the stairs inhibited the quality of the bedroom. The bathroom access is off the bedroom, which is not appropriate for public use.

Sometimes obstructed views to rooftop sites. Hence, the top of an existing parking garage offers a workable solution for a site.

A single-family residence was chosen to demonstrate kinetic strategies to design issues. This residence can be used as a prototype that can be replicated elsewhere by using the same kinetic architecture precepts. The needs and responses can also be applied to other types of functions such as commercial or retail buildings. With this kinetic residence on the upper level of the parking garage, there is the opportunity for future development of retail spaces on the street level. This would further establish the structure as an interactive, urban space.

The initial diagram was to have a building core to hold utilities, and living spaces expanding out from this core. To have a distinction between public and private spaces was important. Initially, the building was flush against the west garage facade to allow visibility over the street front below. This west side later developed into an outdoor space covered by overhead trellis that serves the same function. Earlier stages of design showed interior paces that were too
The building was set back from the garage front to allow for some outdoor space. Landscaping, rather than distinct outdoor places that can be used are evident in this scheme.

confining; these spaces were not free to be something else. Public and private zones became an issue when the only access to the bathroom was through the master bedroom. An effort was made not to diminish the quality of one space with the addition of growth components. Each living space should be wonderful through all stages of growth and seasonal change. The kinetic components should have a meaning, not simply making a space larger or more compact, but they should respond to seasonal, growth, or functional needs. Establishing useful exterior spaces and using the landscaping to define outdoor "rooms" progressed the design.
Climate

Tucson is located in Southern Arizona in the larger context of the Sonoran Desert. Hot and dry conditions dictate adaptations by plants and animals in this arid climate. At 32°08'N latitude and 110°57'W longitude, Tucson falls in a dry valley surrounded by mountains. The area's mild spring, fall and winter temperatures are part of what makes living in this environment desirable. Even though summer temperatures rise, low humidity makes even extreme high temperatures bearable. In general, less than 12 inches of rain may fall in a year.

The seasons in the Sonoran desert are quite different than those in temperate climates. One way to understand the climate of this desert is to understand the temperature and seasonal differences. The seasons in Tucson can be subdivided into six categories, Winter Rainy Season (January – February), Spring (March – April), Summer (May - June), Monsoon Summer (July – September), Fall (September – November), and Winter (December – January.)
As well as the seasonal climate, there exists a large diurnal temperature swing. Temperatures at night can be drastically lower than temperatures at midday, this difference can be as much as 26°F. Because of this, the interior environment and temperature needs to be regulated to provide for occupant comfort. An understanding of the seasonal differences in this climate can indicate what changes and adjustments need to be made to one's dwelling in the desert.

**Winter Rainy Season (January – February)**

Large fronts that form over the Pacific Ocean are forced eastward by weather circulation patterns in the winter. Large, slow-moving fronts bring rain to the Tucson area during this time. These rains are typically long and gentle, and cloud coverage persists for quite a while, even several days.

In January, average highs are about 64°F. Average lows are around 39°F. January is considered the peak month of the winter wet season. Average precipitation is 0.87 of an inch. It can occasionally snow during January in
Tucson. The record amount of daily snowfall in January was 4.3 inches on January 16, 1987. The number of daylight hours is average 10 hours, 26 minutes. Sunrise normally mid-month is at 7:25 am, sunset at 5:42 pm.

February has an average of 54°F temperatures. Average lows are around 41°F and average highs reach 67°F. The end of the winter rainy season occurs during February. The precipitation averages at 0.70 of an inch. Snow is also possible to occur in February. The number of daylight hours increases throughout the month. In the beginning of the month, daylight is 10 hours and 36 minutes, sunrise at 7:18 am and sunset at 5:58 pm. At the end of the month, the daylight hours increase to 11 hours, 29 minutes with sunrise at 6:52 am and sunset at 6:20 pm.

RESULT: Temperatures are cold, long periods of cloud coverage are likely

DESIGN PRECEPT: 1- Provide shelter from the rain
2- Allow for natural light to enter the building
3- Use solar gain when available/necessary
Spring (March - April)

The days are usually warm but the nights are still cool. This is the time when desert plants bloom. Birds migrate through the area and other animals begin to breed.

March averages in at 59°F. Average highs are 72°F and lows are 45°F. March is the beginning of the spring growing season, but some outlying areas may experience lower temperatures and even a deep freeze. Normal rainfall is 0.72 of an inch. The average number of daylight hours is 11 hours 58 minutes. Sunrise occurs at 6:34am and sunset at 6:31pm on the ides of March.

April is a comfortable month having an average temperature of 66°F. Highs in April reach 81°F and lows are at 50°F. April begins the dry season so the normal rainfall is 0.3 of an inch. The number of daylight hours increases throughout the month from 12 hours, 31 minutes on the 1st to 13 hours, 25 minutes on the 30th. In the middle of the month, sunrise occurs at 5:55am and sunset occurs at 6:53pm.
RESULT: desert shrubs, trees, and wildflowers bloom and take on beautiful colors. Air is warmer. Frequent Comfortable Outdoor Conditions. Ideal spaces for indoor-outdoor living.

DESIGN PRECEPT:  
1- Allow more ventilation to encourage air flow  
2- Provide frames for views  
3- Create indoor-outdoor spaces

Summer (May – June)

Daytime temperatures are hot and dry. Nights are still relatively cooler. Saguaro cactus begins to bloom. Bats return for pollination.

The month of May begins with average highs of 85°F and average lows at 54°F and ends with average highs of 95°F and average lows at 63°F. The monthly average temperature is 74°F. May is the driest month in Tucson; the normal rainfall is only 0.18 of an inch. The number of daylight hours is 13 hours 49 minutes. The sun rises at 5:26am and sets at 7:15pm on average.

June has an average temperature of 84°F, with highs at 99°F and lows at 67°F. The Tucson all time high temperature was 117°F on June 26, 1990. June
is the second driest month. The rainfall average is 0.20 of an inch. In the middle of June, the sun rises at 5:17am and set at 7:32pm, an average of 14 hours, 9 minutes of daylight. The sun reaches its northern most latitude at the start of summer, usually on the 20th. In Tucson, the sun reaches 23.4 degrees North over the Tropic of Capricorn.

RESULT: Hot temperatures, Strong sun

DESIGN PRECEPT:

1- Provide sun shading devices (ramadas, trellis, vegetation, canopies, overhangs, awnings)

2- Cool interior and/or exterior areas

3- Use nighttime ventilation and/or night sky re-radiation

4- Direct cooling to specific areas during their time of use.
Monsoon Season (July – September)

Monsoons occur late in the summer, and can actually make for a spectacular sight. It is during this season that heavy rains help replenish the desert. In fact, 46% of Tucson’s annual rainfall is during this summer thunderstorm season.

In the summer, as land temperatures rise, moisture is forced northwest from the Gulf of Mexico and the Gulf of California. As temperatures reach their peak in the afternoon, moist air is forced upwards forming dark cumulonimbus clouds. The clouds continue to build throughout the afternoon and evening, until they then unleash a great amount of rain. The result is a local thunderstorm that lasts only a matter of minutes. These torrential downpours are intense and can cause flooding. They are occasionally violent thunderstorms and can be dangerous. But most Tucsonians welcome them as a splendid sight to observe and photograph.

The month of July has an average of 87°F. High temperatures are 99°F and low temperatures fall to 73°F. The beginning of the summer monsoon season increases the humidity in the air, making the hot temperatures slightly
less comfortable. Precipitation greatly increases during the month of July. Average rainfall is 2.37 inches. The number of daylight hours decreases during the month. There are 14 hours, 13 minutes of daylight on the 1st with a sunrise at 5:21am and a sunset at 7:34pm. On the 31st of July, there are 13 hours, 44 minutes of daylight, sunrise at 5:38am and sunset at 7:22pm.

August has an average temperature of 85°F. High reach 96°F and lows are at 72°F. The monsoon season continues into August and has even higher humidity levels than July does. The normal rainfall for the month is 2.19 inches. In mid-August, sunrise is at 5:48am and sunset at 7:08pm, a total of 13 hours, 20 minutes of daylight hours.

The month of September has an average temperature of 80°F in Tucson. Average high temperatures are 93°F and average lows fall to 68°F. Around mid-month, the monsoon season dwindles, ending the most abundant rainy season. Normal rainfall for the month is 1.67 inches, however the area is susceptible to heavy rainfall during this month. The number of daylight hours decreases
throughout the month, with a loss of 55 minutes. At mid-month the sunrises at 6:07am and sets at 6:29pm, a total of 12 hours, 22 minutes.

RESULT: The resulting water runs off into streets and replenishes the parched desert landscape. Monsoons cool of the desert.

DESIGN PRECEPT:
1- Provide shelter during the violent thunderstorms
2- Allow views of the awe-inspiring sky after storms
3- Use cool air for cross ventilation
4- Celebrate qualities of natural desert by providing access and interaction with surroundings

Fall (September – November)

Humidity begins to leave the area, meaning cooler nights. Days are still hot.

October’s temperature is normally 70°F, with an average high of 84°F and a low of 57°F. Monthly rainfall is 1.06 inches, and Tucson is again susceptible to
Like the life cycle and seasonal cycle of any living thing, kinetic architecture is able to respond to the cycle of the inhabitants.

Heavy rains during this month. In mid-October, there is an average of 11 hours, 24 minutes of daylight, sunrise at 6:27am and sunset at 5:51pm.

November averages a comfortable 60°F. Average highs reach 73°F and lows fall to 46°F. The average precipitation is 0.70 of an inch. Light snow has been known to fall on Tucson. The average number of daylight hours is 10 hours, 33 minutes. In mid-November, sunrise occurs at 6:53am and sets at 5:24pm.

RESULT: cooler night temperatures, but hot sunny days

DESIGN PRECEPT: 1- Sun shading
2- Provide heating at night
3- Use kinetic strategies to solve issues of heating and cooling
Winter (December – January)

Cool temperatures in the daytime, the sun is lower in the sky. The nights are cold with rare freezing temperatures possible. Snow is also rare, but not unheard of. Many plants may drop their leaves.

December has a normal temperature of 52°F. High temperatures go up to 64°F and lows 40°F. A deep freeze is likely during this month. The monthly rainfall average is 1.07 inches. The most snow recorded for December was on December 8th, 1971, when 6.8 inches fell on Tucson. In mid-month, there is 10 hours, 9 minutes of daylight. Sunrise occurs at 7:17am and sunset occurs at 5:21pm. Around the 20th of the month, the sun reaches its southern most latitude, which is 23.4 degrees South over the Tropic of Cancer.

RESULT: Cold Temperatures, need for heating

DESIGN PRECEPT: 1- Utilize daytime sun to warm spaces
2- Strive for nighttime re-radiation through thermal mass
Diurnal Temperature Swing

The drastic diurnal temperature swing – the temperature difference that occurs on a daily basis - is unique to the desert climate. There is the potential to advantageously interact with it, especially by using kinetic architecture. Heat radiated during the day can be stored and then utilized at night.
Summary

With an average temperature of 82°F, cooling is a concern for over half the year. Also, solar heating can be beneficial during sometimes of the year, and daylighting can be utilized during all seasons of the year. Because Tucson has some of the clearest skies in the country, protection from the harsh sun is a necessity. Based on the design precepts previously outlined, a kinetic environmental response is potentially very beneficial for accommodate the changing environment throughout the year. Kinetic architecture is a solution for working with the environment, not against it.
Tucson, Arizona Temperature Data

<table>
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<th></th>
<th>Jan</th>
<th>Feb</th>
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<th>Apr</th>
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Source: The Weather Channel Enterprises, Inc.

Kinetic Architecture can respond to the changing sun patterns and seasonal temperatures to provide a comfortable living environment for the residents.
Kinetic architecture can allow for framing views, whereas traditional desert architecture limits openings in the building envelope.

Views

Tucson is located in a valley surrounded by mountains on all sides. The spectacular mountain ranges provide for a magnificent view from nearly anywhere in the city. The valley land of Tucson is generally flat or gently rolling.

The Santa Catalina Mountains border the north-northeast side of Tucson. Their elevations go up to 10,000 feet above sea level. They stretch about 20 miles across east to west. The Rincon Mountains border the east side and have an elevation up to 7,000 feet. To the west side are the Tucson Mountains, which have an elevation of 11,000 feet. Included in this mountain range is Sentinel Peak, known as "A" Mountain, at which Tucson was first settled at the base of. Approximately 30 miles to the South of Tucson are the Santa Rita Mountains, which also have an elevation rising to 11,000 above sea level. Besides the natural views, there are also brilliant views of the Tucson cityscape.
## Case Study Analysis

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<th>Protection from Weather</th>
<th>Japanese Architecture</th>
<th>Transformable House</th>
<th>Norton Apartment</th>
<th>Walker Guest House</th>
<th>Phoenix Central Library</th>
<th>Milwaukee Art Museum</th>
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<tbody>
<tr>
<td>Amado Screens</td>
<td>exterior shell closes</td>
<td>n/a</td>
<td>wooden panels</td>
<td>operable fins</td>
<td>lowering of brise-soleil</td>
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</tbody>
</table>

| Flexibility in Floor Plan | curtains, folding partitions, screens, and minimal furniture | moveable walls and enclosures | moveable walls and foldable components | versatile indoor-outdoor spaces | plan based on modular grid | n/a |

| Structure | wooden structural system with bamboo grid | wood frame | steel framing | wooden structural system | concrete | steel cables support deck |

| Control of Light | transparent shoji screens, moveable exterior partitions | opening of exterior shell, building raised on stone plinth | openings in sections of walls to allow for light flow | opening of wooden panel system | louvers and vertical shade sails | moveable brise-soleil |

| Kinetic Movement | sliding | sliding, pivoting, swinging | pivoting and gliding | pivoting | pivoting louvers | raising & lowering of fins |

| Functional Use | residential | residential - part time | residential | residential - part time | civic building | civic building |

| Context | rural countryside | rural | urban | rural seaside | urban | urban |

| Climate | temperate | temperate | temperate | semi-tropical | desert | temperate |

Japanese Housing and Pavilions

Beginning as early as the 8th Century

This case study has been considered to understand how kinetics and moveable components were applied to architecture in a historical setting. The Japanese's conviction of flexibility in their homes is a valuable design principle that can be applied to today's residential projects.

PROJECT OVERVIEW

The architecture of housing and pavilions in Japanese was traditionally based on a relationship with nature, design harmony, simplicity, and spatial interpenetration/adaptability. Many residences were constructed based on fundamental ideas of flexibility in the ground plan, a framework structure, a modular system, and an awareness of the materials. An important principle in Japanese architecture is a close connection with nature. This is an explanation
Shoji Screens are the exterior sliding screens that usually lead to a veranda area. These screens consist of white opaque paper, fixed to a wooden lattice frame.

as to why they designed the openings of walls and extensions of exterior balconies, where indoor and outdoor spaces merged.

The architecture of Japan was largely dictated by the climate. Summers in Japan are usually long, hot and humid, and their architecture reflects this. The traditional Japanese homes were raised so that air could circulate around it. The material of construction was generally wood, because of its thermal characteristics and its flexibility. Light and shadows, as well, play an important role in the Japanese home.

Shoji screens were invented as slide-away translucent screens to let light into the Japanese home, while opening up obstructions to the outside. Made of either cedar, bamboo, or paper, these screens allowed for flexibility within the home. When closed, they acted as walls, when open, they allow two spaces to flow together. Fusuma panels were lightweight sliding panels that offered total flexibility in the floor plan so that the average Japanese house was able to accommodate large gatherings of people.

Amado screens offered more security and protection and covered the shoji screens at night. Amado screens were stored within the walls and slid back
Tatami mats have many functions. The tatami's straw inner-core is squashed tight and full of air. This makes it very effective at absorbing heat. A tatami mat can also absorb 500cc of water from the air. And if the atmosphere is dry, the water will naturally evaporate. Tatami is made of soft reed and according to traditional Chinese medicine it calms the spirit and the natural smell will relax the body and soothe the mind.

and forth. Extra wide overhangs also offered protection for the shoji screens against the weather and its elements. The engawa was a porch that had shutter-like panels on it, and the position of these shutters indicated where the focus of the house was at a given time. When they were open, the emphasis was on the inside of the home, and when they were closed, the emphasis was on the outside.

Since it was customary to sit on the floor, no furniture was needed. These rooms were used for various functions - eating, sleeping, sitting, and entertaining. Bedding, cushions, and short tables were stored in nearby closets and were brought out as needed. The minimal furniture the Japanese house did have were low tables and chests. They were portable and were designed to be easily moveable. This was done because each room served several functions.

Because harmony was an important element, the Japanese used a modular grid system in their construction. This grid system is based upon the tatami mat, which was a mat set on a compacted straw mattress. Tatami mats were roughly three feet by six feet. The tatami became a system of measurement and since all the tatami mats were the same dimension, a
Fusuma panels were large interior sliding screens. They were covered with heavy paper and sometimes painted. The function of these screens was to partition the space within a room, as well as to partition the room itself.

Proportion for construction was defined. The mats were the ideal flooring because you were able to walk on them, yet they were soft enough to sleep on.

The first residential pavilions at the beginning of the 8th century were composed of one large room with multiple uses. Later the addition of other multi-functional rooms was added, with the separation between rooms being moveable partitions. The living area was divided by the use of folding partitions, screens, and minimal furniture. All of these elements would be able to move according to circumstances. Eventually there became a breakup of internal space, but this division was done with minimal sliding partitions and it was done as to maintain a connection with the outside. The construction of the Japanese house was designed so that the structure could move with the wind. Their bracing system allowed for bending, not breakage. A grid of bamboo provides the support for the structure. The interior walls only act as temporary dividers, they do not offer structural support. No nails are used in traditional Japanese home construction. Joint systems were developed so that the house could be flexible.
OBJECTIVE

The objective of Japanese architecture was based on guiding principles. These principles were flexibility of ground plan, framework structure, modular system, and an awareness of materials. They always intended to maintain a close relationship with nature in their living, and to live in harmony through simplicity and spatial freedom.

TECHNIQUE

Different parts of a traditional Japanese pavilion were marked only by mobile elements whose arrangement varied according to circumstances. Opening walls and external balconies provide both external and internal spaces. Shoji screens let light penetrate and created divisions in space. Curtains, folding partitions, screens, and minimal furniture varied the living area. All of these elements could be moved according to circumstances.
The interior and exterior space of a Japanese Home blend together.
Sliding screens create spatial adaptability.

Sunken kitchen of a Japanese home.

Spaces can open up to accommodate large gatherings.
The structure and layout of a traditional Japanese home allows for flexibility in floor plan.
This case study has been investigated to develop an understanding of how a residence is able to reconfigure itself to adapt for social needs. Spatially, the building takes on a new form by manipulating exterior surfaces.

PROJECT OVERVIEW

As a single-family residence situated in the middle of a quiet, wooded area, this house adapts and changes according to the actions of its inhabitants. Used primarily as a summer vacation home for city dwellers, the house is able to shut down and open up when the residents come and go. It does this so as to adapt - to make it energy efficient and to create various spatial solutions. The exterior surfaces are able to move; they slide, pivot, and swing. They move
across and from the house both vertically and horizontally. This exterior shell creates interesting configurations, lets light and ventilation in, and makes the house come alive. Balconies are able to extend when the house is “opened up.” The defining lines between outdoor and indoor space are indistinct when the occupants use the house, the residence really allows for the interaction of spaces when it is activated. To utilize natural light, the house sits upon a raised stone platform. When the residents leave, it is able to close up into an efficient cube. It sits minimally on its lot, not imposing on anything when it is not being used. The kinetic elements of this house are essentially the moving parts of its exterior; these parts allow the contained living functions within to spill out onto the landscape. It adapts for social functions to allow the house to accommodate any number of people. The house efficiently shuts itself down when not being used.

OBJECTIVE

The objective of this project was to create various spatial and visual solutions to activate the house. The intent was to create an adaptable residence
that can shut down when not being used, to minimize its impact on its surroundings, and to conserve energy by reducing heating and cooling costs. But when the residents did use the building, the architects intended the space to "open up" and "come alive." The objective was for the floor plan to expand to accommodate different social situations.

TECHNIQUE

Through the reorganization of surfaces, the building is able to adapt.

Through the movement of exterior surfaces, the building envelope comes apart. Portions of the facade slide, pivot, and swing at different positions to allow for the interior to expand spatially.
Kinetic Architecture and its Application to Urban Housing in Tucson
Used primarily as a summer vacation home for city dwellers, the house is able to shut down and open up when the residents come and go.
Norton Apartment

Maya Lin

New York City

1999

This case study was chosen because this residence is internally focused and flexible. The building is able to change with the moment. For these reasons, it demands a careful exploration.

PROJECT OVERVIEW

A residence for a married couple and their two children, this apartment takes best advantage of an undersized, dark space in New York City. Although only 2 stories, the architect, Maya Lin, uses kinetic features to further maximize the square footage. Originally, the space was 2,300 square foot and partially below ground. Views and ventilation were a problem that needed to be dealt with. Through the use of moving elements, the residence is designed to keep up
with the change of its inhabitants. It can be transformed to provide accommodations for various social configurations – for when their children are young and at home and when they grow older, and live on their own. Features include sliding and rotating panels that can divide or join rooms. The entire apartment fits together like a puzzle.

The influence of Japanese architecture is apparent. Throughout the residence, panel systems resemble the shoji screens found in Japanese homes. Panels throughout the home pivot and slide to create different arrangements of divisions and rooms.

The details of the apartment are suggestive and evocative of movement, flexibility, and bendability. The staircase appears to be a folding piece of paper or fabric. Portions of walls are able to pivot and revolve to open up spaces and allow for views.

In the sleeping area, numerous configurations in a wall partition can change on a track and divide one bedroom into two separate bedrooms. It is in the same way that a master bathroom can transform into two disconnected
bathrooms. In the master bedroom, a study area can compactly fold away into the wall. And in the kitchen, the counter workstations and an island pull apart to reveal chairs for dining. Sycamore panels glide across planes in the kitchen, they conceal appliances such as the refrigerator and washer and dryer. When closed, they give the room a clean and minimalist look. The dining room table appears as an unobtrusive solid volume, not giving hint to what it is concealing. Other furniture was designed by the architect and is built on wheels for easy transport from one room to another.

OBJECTIVE

The objective of this project was to maximize the little space there was in a small apartment. It is meant to satisfy the needs of the inhabitants, whoever or whatever they may be.
TECHNIQUE

Through the use of moveable kinetic elements, the apartment was able to take on more functional special needs. Without the use of any exceptional mechanical devices, the apartment is able to transform internally.
The components that make up the kitchen pull apart and then can be neatly compacted.
1. Living
2. Kitchen/dining
3. Master bedroom
4. Bedroom
5. Skylight
The stairs appear to be a dynamic, folding element to the apartment.

The apartment uses kinetic architecture to create different spatial arrangements.
Walker Guest House

Paul Rudolph

Sanibel Island, Florida

1952

This case study has been investigated to develop an understanding of how a residence is able to reconfigure itself to adapt to environmental conditions.

PROJECT OVERVIEW

This guesthouse, located in the rural seaside area in a semi-tropical climate, utilizes a single design concept to perform numerous functions.

Kinetically, this house features a series of panels that pivot on the exterior of the structure. The panels perform different tasks based on what is deemed necessary at the moment. They act as an enclosure wall to offer protection and privacy. They are then able to open up to allow for light and ventilation to enter the building. When opened up, these panels act as a cost effective and energy
efficient device for shading both the interior of the building and the open exterior patio area. More importantly, these panels offer storm protection during the hurricane season. There are three bays on each side of the guesthouse; two of these bays are pivoting panels and the third bay is fixed glass. The effects of these changing wall systems create varying atmospheric effects for the residents.

OBJECTIVE

To develop a system that can close to offer privacy, security, and protection from the weather conditions. The system should then be able to open up to let the light, ventilation, and views into the interior of the structure.

TECHNIQUE

The response was pivoting panels on the exterior of the structure. Easily, these wooden flaps could satisfy the needs of the residents.
The Walker Guest House opens to the surrounding landscape.
Kinetic Architecture and its Application to Urban Housing in Tucson

Plan

wood flaps

Living

Bedroom

Dining

Kitchen

Scale 0 5 10

north
Phoenix Central Library
Will Bruder/DWL Architects
Phoenix, Arizona
1995

This case study is important because it is an example of a flexible, energy efficient space in a local context. The climate issues are relatively the same as in Tucson. The building uses kinetic energy strategies and a complex solar control system.

PROJECT OVERVIEW

Located in Phoenix, Arizona, the library is a response to the harsh desert climate in which it is located. The Phoenix Central Public Library opened in June 1995 and replaced an older one. The building consists of five floors and made from a precast concrete structure. The East and West sides are clad with perforated metal. Cooling is the major concern for the library. The building is a
square cube, and the mechanical rooms are on either sides of the cube. The north and south facades have floor to ceiling glass. Green insulating glass with an 85% low-e coating is used throughout the library. The east and west facades are solid, composed of 12 inch thick concrete. The east and west glazing systems had a unique design in that they used a perforated copper sheet to reduce the solar impact that is normally associated with east and west glazing. The task was to estimate the heat transfer coefficients of these areas. The building is cooled by a complex ventilation system involving 600 ton cooling towers.

There are different kinetic features applied to the structure. They include louvers on the south facade and louvers on skylights. The aluminum louvers are computer-controlled; the system tracks the path of the sun and adjusts accordingly. The building utilizes solar daylighting to conserve energy. The louvers are able to open and close to offer solar protection. The louvers are motorized and computer controlled to position them to block direct beam solar radiation and allow for natural lighting. On the north side of building, there are
external vertical shade "sails" to prevent north-west and north-east solar heat gain in the summer when the sun's azimuth angle is in the northern direction. They diffuse the light entering the building, which reduces glare for the occupants. The are twenty four panels that are seventy five feet long, and they are made out of a polyester/PVC shade cloth. Light plays an important role inside the library as well; reflections off the glass-enclosed stairwell are cast into the central space. Light is a dynamic element to the building. The library was designed to be a flexible space, set up on a square grid based on the library stack modules.

OBJECTIVE

To create an energy efficient building that is responsive to the harsh desert environment in which it sits.
TECHNIQUE

The building uses moveable louvers to respond to the desert climate. The louvers on the south side are computer-controlled and can regulate the amount of light that enters the library.
The north facade has operable vertical louvers to control sunlight.
South Facade
Closeup of operable sun shades.
Milwaukee Art Museum

Santiago Calatrava

Milwaukee, Wisconsin

2001

This precedent study has been examined to develop an understanding of how a moveable sunshade can be applied to a building in response to the changing sun to allow light and air to penetrate the structure.

PROJECT OVERVIEW

Santiago Calatrava, an architect known around the world for his kinetic sculptures and buildings, was commissioned to design his first building in the United States - an expansion for Milwaukee's Art Museum. This museum addition includes a dramatic new entryway, more exhibition space, an auditorium and better access for both cars and pedestrians. But most importantly, the addition features a moveable sunshade that creates dramatic configurations
based on the direction of the sun. The main space is a large gathering space that is enclosed by a transparent structure. Covering this transparency is a light controlled sunscreen that can be raised and lowered - a kinetic brise-soleil. This brise-soleil not only responds to the sun, but it is also a response to its site – the building sits on the edge of Lake Michigan, with also has an ever-changing landscape. Calatrava's building does not obstruct views of the lake. The building exhibits nautical imagery throughout – sails, birds in flight, masts.

The glass enclosed gathering space is 90 feet in height. The brise-soleil that covers it is composed on 72 steel fins, and it is raised and lowered to control both temperature and light into the building. With fins range in length from 26 feet to 105 feet, the brise-soleil wingspan spreads 217 feet at its widest point, and weights 90 tons. Hydraulic motors are responsible for the movement of the fins. A tall, thin post leans backward at an angle with steel cables extending to support the deck. The material used to construct this sunshade was intended to be carbon fiber, but steel was used instead as a cost effective and timesaving alternative.
The brise-soleil takes about four minutes to transform from its closed to open position. It is able to close automatically if wind sensors detect wind speeds that surpass 24 miles per hour.

On the inside, concrete ceiling beams are exposed in the exhibition space. Moveable wall dividers are low to create the feeling of openness in the museum, yet they mark separation in the exhibits. Arching concrete ribs flank the gallery spaces. The ribs are grounded in steel joints.

The building gives Milwaukee a striking landmark while demonstrating a harmony between sculpture and structure.

OBJECTIVE

The building was intended to have an adaptable enclosure space that can adjust to control the light in the space contained, and also to control the temperature inside the space through the use of light and air flow from the exterior.
TECHNIQUE

The response was a Burke Brise-Soleil that can be raised and lowered to adjust the conditions within the building. The fins of the brise-soleil are attached to rotating spines.
The main space is a large gathering space that is enclosed by a transparent structure. Covering this transparency is a light controlled sunscreen that can be raised and lowered - a kinetic brise-soleil.
Working Bibliography


The Pinwheel Beach House, the first house by the author, has provided insight into ways building components can kinetically open up to perform other functions. The house incorporates simplicity with moveable wall systems. These walls respond to changing views, breezes, and sunlight.


This book includes several works by the architect, Santiago Calatrava, an architect known for his designs in kinetic buildings, bridges, and other structures. In this reference, insightful information can be found - specifically the “De Sede” moveable exhibition pavilion. Included were a plan, section, and elevations. What makes these drawings valuable is that they are drawn with given dimensions and a scale. It is useful to have accurate drawings like these to begin on designing a project on kinetic architecture.


Mechanical devices are the main topic of this book. This is important to the research because understanding of how to make the building physically transform is essential to designing moveable buildings. This resource can be used to obtain information on different mechanical movements and systems.
Library Call No. (science) TJ181.C399 1991

This is a collection of papers from several authors that discuss desert housing. Energy conservation and passive solar techniques are also explained. Particularly useful is the paper entitled, "Landscape Architecture for Arid Zones," which explains how vegetation can be used to benefit residences in the desert. Solar orientation and sun-shading techniques are also examined. It is useful to learn what techniques have been used in the past that be expanded on for the future.

Library Call No. (archit) NA.2542.A7.c.3


This source contains an in depth look at the kinetic structures and pavilions of Frei Otto. Several examples are given, as well as the details of the construction of his kinetic structures.

Library Call No. (archit) TA663 D73 c.2


A lecture given by Glenn Murcutt on the 2nd of April, 2002 at the University of Arizona, discussed the ways a residence can be responsive to its environment through its use of materials and characteristics of the site. The book features the Marie Short house, which uses pivoting doors to connect two parallel pavilions. The outdoor realm is able to connect to the interior, and it is evident in the book's photographs. Expansion, shown through floor plans, is also illustrated in the book.

ISBN 0714842192


This academic paper attempts to develop a means to enhance the performance of kinetic architecture. It goes further to discuss responsive spatial adaptability. It explores multi-use applications. This resource differs from others in that it talks about how a building could respond to different social configurations.

http://kdg.mit.edu/Projects/pap05.html
This academic paper also wants to further the development of kinetic architecture. It sees these kinetic systems as an integral component of a larger system. It mentions that the groundwork for kinetic architecture is science-based and focuses on structural engineering. This appears to be one of the most current sources on the topic of kinetic architecture.

http://kdg.mit.edu/Projects/pap02.html

This thesis was done by someone who has devoted his much of his architectural career to developing kinetic architecture systems. Therefore, it provides a knowledgeable account of kinetics in architecture. This source differs from the rest because he examines using CAD technologies to develop this architecture. CAD sets up a smooth environment to begin solving the problems of moveable architecture. The thesis goes further into designing on a computer to develop hierarchical data layers to best understand architecture that has the potential to be constantly changing. Several other works site this thesis as a reference.


This paper talks about space saving elements that be incorporated into a building's design. It explains the requirements and benefits of deployable building systems. It discusses the benefits of such systems, including material use and reuse and public health benefits. Within a single story dwelling, it can be possible to double its height and flexibility. This concept has been tested in relation to the cost, manufacturing, and erection of the deployable structure.

http://kdg.mit.edu/Projects/pap04.html

This paper is focused on creating spaces and objects that can physically re-configure themselves to meet changing needs. It includes helpful diagrams on kinetic typologies in architecture. This resource provides a general outline of the different relationships to kinetic buildings. It breaks down the topic of kinetic architecture into several categories and sub-categories, which is useful in understanding.

http://kdg.mit.edu/Projects/pap01.html


This book discusses different movement systems that occur in the lifecycle of humans, animals, and plants. It deals a lot with biological movement systems such as flight and swimming. This reference assists in the research in that it gives reason to relate back to the basis for movement and it shows the correlation between human movement and architectural movement. This book also highlights the structure that makes up human and plant cells. The author discusses the operation of both living organisms and machines. It looks at movement from a different point of view. Altogether, this helps to form a more objective, well informed theory to kinetic architecture.

Library Call No. (archit) 591.1 H572, tS4


This resource describes the historical context of kinetic architecture. The book includes a chapter on non-architectural precedents, such as those found in nature or on maritime vessels. This information can be used to relate the broad topic of kinetics with a more specific movement in architecture. The book also provides diagrammatic sketches, which are basic and simple to understand.

Library Call No. (archit) NA.8480.K76.1995
Although this book focuses on portable structures that actually move from one site location to the next, the diagrammatic series showing the movement are incredibly useful. The book includes a graphic series of movement and the process the structure undergoes during erection and dismantlement. Detailed drawings, as well as clear plans and sectional drawings are also provided.

Library Call No. (archit) NA.8480.K77.1996


This recent article describes how two architects with a group of their students participated in a design-build studio that created a foldable theater. This article is helpful to the research because it is most current and went further into adaptable architecture to discuss foldable furnishings and other objects within the building. It discussed how different elements could perform several functions at different times of the day, or season. Furthermore, the article tells of a current competition project that features a roof to a sculpture garden that folds up to become a billboard or drive-in theater. It is inspirational to read something that talks about adaptable architecture designs that are currently being built and designed.

www.architecturalrecord.com


A room that can be compacted and taken away in a compact box – that is what this article refers to. It is a very unique and interesting approach to portable architecture. The one project that can be looked at further is the Vinyl Milford House. It has cutouts in the room the exact same shape as its furnishings, allowing the furniture to slide into the wall. There is a good possibility that I could further this idea and incorporate it into my own design. The article also featured a good solution to compacting the kitchen. These service rooms appear to be the hardest to adapt and compact, but the pictures and text gave a supportive explanation.

www.architecturalrecord.com

This paper can be a valuable on its list of resources and web links alone. But it also includes the concept of designing a new prototype for sustainable housing. In this prototype is the flexible organization of different functions. It uses an artificial genetic code to build architecture. The concept is unusual and offers a refreshing way to look at kinetic architecture.


The thing that set this book apart from other sources is that it made a comparison to motion pictures. It talked about the different components of a film: the optical, the acoustic, and the kinetic. This is very meaningful to me in my research of kinetic architecture. The author went further to make the comparison of kinetic architecture to art, painting, photography, and sculpture. This book discussed special issues and an organic approach to architecture.


This source differs from others because of its discussion into structural morphology. It discusses membrane structures, tensile structures, deployable structures, thin-shell structures, and hybrid structures. It even features outer space structures. This book has really captured my interest in this subject of designing kinetic buildings. The book features insightful illustrations and also colorful photographs of these structures being built. It was helpful that the process of these structures being constructed was documented so clearly.


This book is a collection of selected projects by Santiago Calatrava. The reason this book is beneficial is because it includes the Kuwaiti Pavilion Expo project. This project is a good precedent for studying kinetics in architecture. Several
photographs of the pavilion are included, as well as a written brief about the project and architectural drawings. From this book, you discover that this project is third in a series of kinetically oriented projects by Calatrava.


This is a resource that provides insight into the growth and form of life—of man, animals, plants. It diagrams the way things grow and the shapes they take on. A mapping of the evolution of man through co-ordinate diagrams is also given in the text.

Library Call No. (archit) QP.84.T4.1971

Yeh, Bryant "Kinetic Wall." Thesis M.S., Massachusetts Institute of Technology, 1996.

This thesis relates very much to research in kinetic architecture. It provides an outline and sets up an organization as to go about examining the topic. It gives supporting testimony to moveable and foldable architecture by exploring folding paper and models. A prototype for a kinetic wall within an architectural space is what the thesis is focused on primarily. The bibliographical sources are extremely valuable.


This resource appears to be the first staple in the field of kinetic architecture. Although it was written over 30 years ago, it still holds important guiding principals for design. It is the resource that most extensively explains why there is a need for adaptable architecture. The book includes a collection of quotations related to area of change and transformation. These quotations can be used throughout my thesis. The book also talks a great deal about mechanics and engineering. It introduces the first buildings to incorporate adaptable mechanical systems into their architecture.

Library Call No. (science) TA.658.2.Z85.1970