Parametric Architecture : Performative/Responsive assembly components

by

Huei Sheng Yu / Carl

Submitted to the Department of Architecture in partial fullfillment of the requirments for the degree of

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Signature of Author [redacted]

Department of Architecture, Computation May, 22 2009

Certified by [redacted]

Takehiko Nagakura
Associate Professor o f Design and Computation
Department of Architecture
Thesis advisor

Acceptrd by [redacted]

Julian Beinart
Chair,Department Comitte on Graduate Students
May, 22 2009

Thesis reader

Terry Knight
Professor of Design and Computation at MIT

Thesis reader

Federico Casalegno
Director of the MIT Mobile Experience Lab and
Associate Director of the MIT Design Laboratory.

Thesis reader

William J. Mitchell,
Professor of Architecture and Media Arts and Sciences at MIT

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Abstract.

Current parametric design generates many possible solutions during modeling and design process, but in the final stage, only allows users to choose one solution to develop. This thesis demonstrates a design strategy for physical parametric design that embeds knowledge from simulation tools and helps parametric design still keep variations after final model. This thesis begins with an introduction of theory and practices of current parametric design and clarifies the connections between its methods and physical parametric design. Then a few new concepts and prototypes are proposed, and physical parametric designs are demonstrated. The thesis presents a series of case studies investigating specific parametric design methods. Their objectives are studying ways to implement variations from parametric design to physical world and to fix parametric design's constraint problem through the use of physical feedback loop. Some cases are related to simulation environment which can be used as a test platform for fabrication or responsive environment design: others are different data access, such as visualization. Together, these physical parametric design projects indicate how to solve the bidirectional constraint in design exploration. Finally, this paper evaluates new possibilities of this design strategy and construction method, and discusses how the physical models impact digital parametric models.

key words: parametric design , Artificial Intelligence Knowledge Base ,Evolution system design, simulation environment.

Thesis Supervisor Takehiko Nagakura

Title Associate Professor o f Design and Computation

Department of Architecture at MIT

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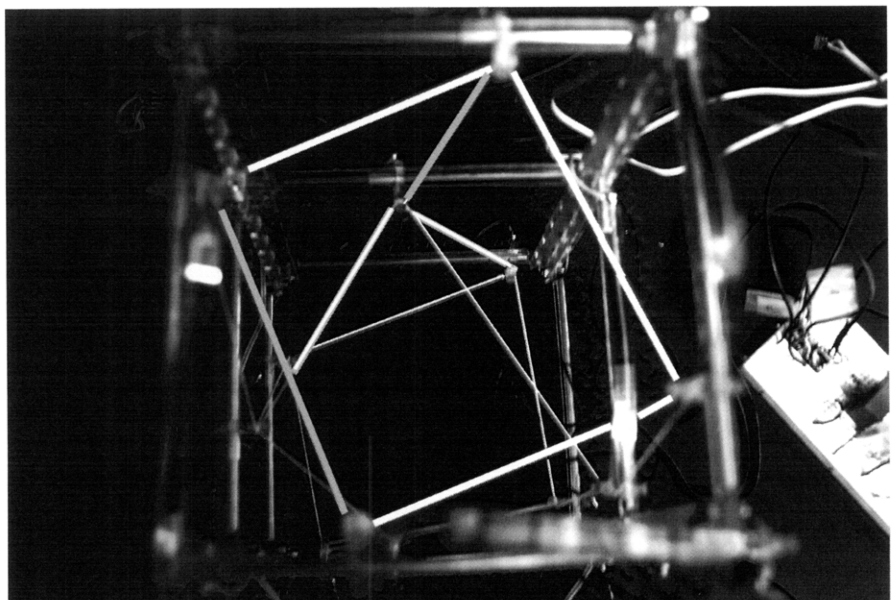
Finally I have to thanks my sister to assist me, my best friend HuiYuan Lim motivate me to finish my thesis , and my parents for raising me to this life with their limitless endeavor

Carl yu 2009



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1.1 Introduction

Parametric design tools have generated wide interest in the design and construction processes for architectural designers. Until now, research in this area has been mostly focused on software approaches to help the architecture industry to deal with documentation, but it lacks any discussion of how to use this methodology to improve our current construction process and how to integrate parametric design systems into current design processes.

Current parametric design generates many possible solutions during modeling and design process, but in the final stage, only allows users to choose one solution to develop. Physical parametric design is a design strategy for parametric design, enables parametric design embedding knowledge from simulation tools to help parametric design still keep varieties after final model. Physical parametric design allows models to keep varieties in physical model ,but also give feedback to the virtual models to improve the design process. In order to keep the variable for physical model for parametric design, physical parametric design integrates knowledge base design , mechanical design, electronic design, so it is a cross field knowledge, but the main focus is on how to help parametric model keep the varieties.

This thesis proposes on the manufacturing process of a physical parametric design method and how to implement parametric design concepts into traditional processes. Finally, this paper will look at different problematic aspects of traditional parametric design methods, and investigate how this new method of physical parametric design can help extend the possibility of architectural parametric design.

1.2 Thesis structure

Introduction
Current parametric design
The dilemma of parametric design
Precedent
Introduction of Experimental works and Design theory
Experiment works
Conclusion

The goal of this thesis is focusing on implmenting parametric design into physical world, enables parametric design keep variations in physical world and feedback loop design aims parametric design fix constraint problem. Initially, i will give an intoduction and current parametric design software in order to provide backgrounds of parametric design and prblems. Therefore precedent works provide relative researches in different fields. The main focus of this theis is on design theory and experimental works to explain the proof-concept of physical parametric design and keep variations in different design methods. Finally, I will give conclusion of this series studies in order to clarify the concept of physical parametric design.

2. Current parametric design usage

2.1 parametric design background

Ideally, parametrical design software is used to capture the concept of three-dimensional design, to generate many variations of shapes or to aid the documentation process.

Branko Kolarevic described parametric design in the following way:"In parametric design, it is the parameters of a particular design that are declared, not its shape. By assigning different values to the parameters, different objects or configurations can be created. Equations can be used to describe the relationships between objects, thus defining an associative geometry — the constituent geometry that is mutually linked.

That way, interdependencies between objects can be established, and objects' behavior defined as transformations. As observed by Burry, 'the ability to define, determine and reconfigure geometrical relationships is of particular value.'"[1]

By automatically generating many possibilities of shapes using generative algorithms to edit relative data enables computers recursively to generate various shapes, so designers can pick one possible shape to further develop their design. These concepts are widely used in scripting softwares.

Another development of parametric design is using three-dimensional modeling software, such as CATIA or Generative Components to build three-dimensional parts , while these parts have constraint relationships among themselves. If one part changes its properties, all parts will automatically update. This parametrical concept is widely applied during the design development phase to help architectural designers to shorten the time of traditional documentation processes.

2.2 Smart Geometry Group with Generative Components

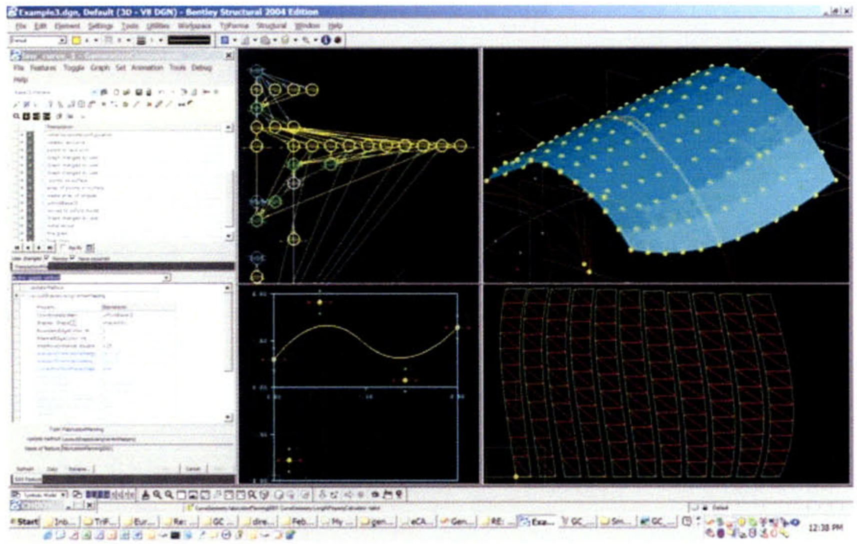


Figure 2-1 Generative Components (image source: http://www.aecmag.com/index.php?option=content&task=view&id=82)

The smart Geometry Group which uses “Generative Components” that was invented by Robert Aish at Bentley Systems consists of founding partners of , KPF , Forster and Partners, and Arup Sport.

Robert Aish described the value of parametric or associative design: ”Design involves both exploration and the resolution of ambiguity. Therefore, it is not sufficient that computational design tools can model a static representation of a design. What is important is that the design tools are able to capture both the underlying design rules from which a range of potential solutions can be explored, and facilitate how this ‘solution space’ can be refined into a suitable candidate for construction… To model not just one solution to this problem, but the design rules that can be used to explore alternative solutions, requires a complex 'graph' of 'associative geometry'."[2]

Generative Components which is based on the concepts of associative design and object-orientation, is constructed in C language. Generative Components allows users to design object (such as basic elements: point, line, face) by giving its specific definition, thus a collection of defined objects provide the ability to control the entity of design through controlling objects. This distinguishing feature enables Generative Components to provide flexible manipulation for designers.

2.3 Digital Project

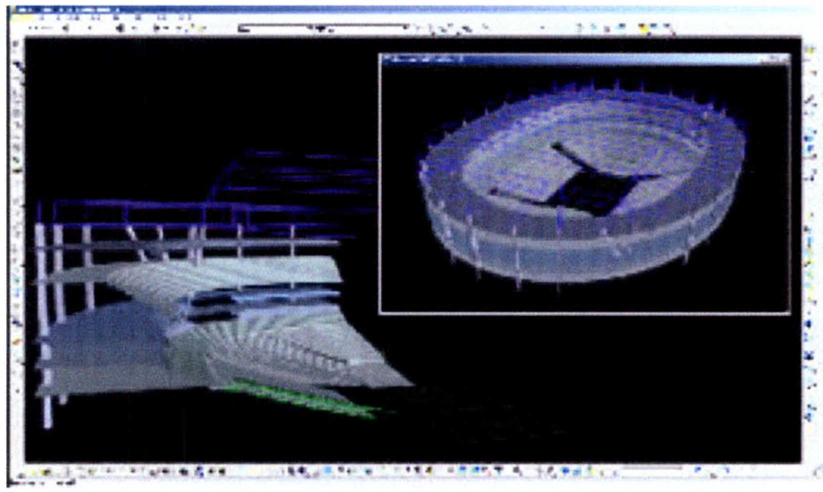


Figure 2-2 Digital project (image source:http://www.gehrytechnologies.com/index.php?option=com_content&task=view&id=50&Itemid=102)

Digital project developed by Gehry Technologies, is an ac-laplation of CATIA for the architectural industry and building customization. Because Digital project occupies vast computer memory resources, initially, Digital project only worked on high performance work stations. Personal computer technology has improved, so Digital project can easily be installed in general PC.. This improvement enables the architectural industry to adopt parametric design to accelerate the construction development process .

Digital project uses Visual Basic in its programming platform, enabling users to develop additional application and scripts, and embeds Uniformat and Mastetformat.(the Classification System for organizing preliminary construction information), enabling users to estimate cost and material uses.

The advantage of Digital project is that it offer many powerful parametric modeling tools and supports many file formats to exchange to other software. It provides a well designed environment to help users to model components first, and assemble those components in complex configurations. Digital project is a useful software for detail developing design process, allowing users to design detail components that have their own definition. This enables user to estimate and analyze their models.

The weakness of Digital project is its user interface; Its steep learning curve in comparison to other modeling softwares. Because users have to define every component, and then assemble large complex models, the final models of digital project are difficult to modify. The design process in Digital project doesn't offer enough flexibility to manipulate, and it takes much time to define every component, therefore it is difficult for users to modify his models once they reach a final stage.

2.4 Grasshopper

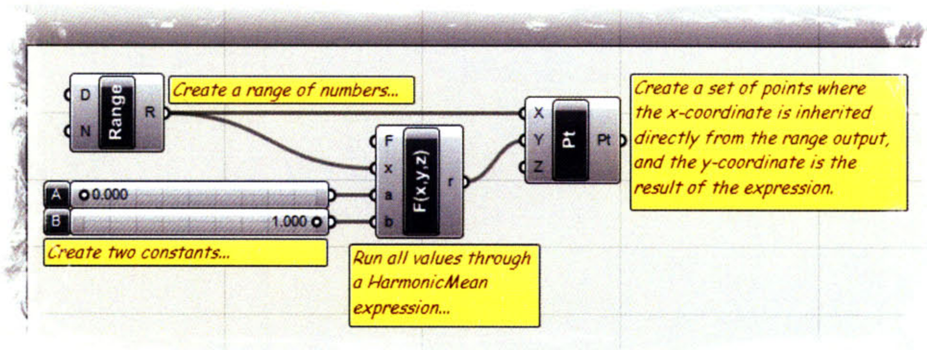


Figure 2-3 Grasshopper (image source:http://en.wiki.mcneel.com/content/upload/images/ExpHis_MultiVariableExpression-ExampleDefinition.png)

Grasshopper which was developed by David Rutten in 2007 is a parametric modeling plug-in for Rhino. It is based on explicit history concept that recorded the modeling process, allowing users to manipulate graphic node to generate parametric models. An advantage of Grasshopper is that users with little programming experience can manipulate graphic nodes to define relationships for each element to generate parametric model.

Each graphic node in Grasshopper is similar to a modeling element which enables users to learn the logic of modeling process to build parametric models. Because it has a flat learning curve and it is until now still freeware, many rhino users begin to learn it rather than using other parametric modeling soft wares. Although Grasshopper is a very new software, it has potential value to become popular parametric modeling platform in the future.

Grasshopper lets users manipulate graphic nodes, and allows users to script in VB.net , C# and python. This scripting portal is used by advanced users to develop free applications for non-programming users to manipulate new functions. Like other parametric soft wares, Grasshopper enables users to use spread sheets to read and export data to control elements. Because Grasshopper is working in Rhino, can be comparison to Genitive Components ,which generates small text file as definition of the models, unlike Digital Project models that turn into large 3d models after its final process.

The weakness of Grasshopper is that it is difficult to assemble many parametric elements. Grasshopper is powerful to generate parametric architectural forms, detail design models, material strategy analyze and to analyze models, but it is very difficult to assemble all predefined elements for entire building design.

3. The dilemma of parametric design

Research tends to point out how parametric design can help improve work-flow, but in the parametric design process, associated relationship between parts have hierarchical constraints, so higher level parts can only be edited with difficulty. Once the user tries to change higher level relationships, the parametric tree breaks down. This kind process makes parametric design become inflexible.

This research will extensively clarify the effects of applying parametric design concepts to physical materials. This way the parametrical design process can be extended as a process and new ways to improve the possibilities of parametric design arise. Beyond traditional design processes. For instance, in traditional parametric design, the constraints between parts make the relationship hierarchical. If designers break down this relationship , the parametric design process fails to update changes. Materials and structures with this newly proposed method can relate to different contexts. The system still enable physical design update changes. The kinetic design and interactive architecture reveals new possibilities of architectural design. It can be argued that kinetic structural designs, digital-fabrication systems and robotic structural designs enable designers to be more creative than through parametric methods and extend the parametric design process.

Figure 3-1 Fix constraint problem in parametric design

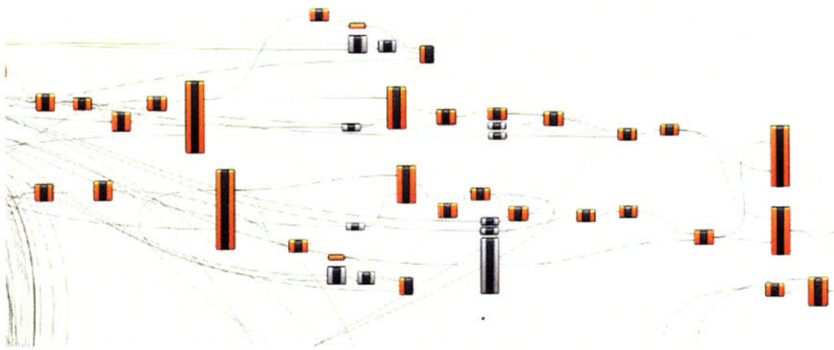
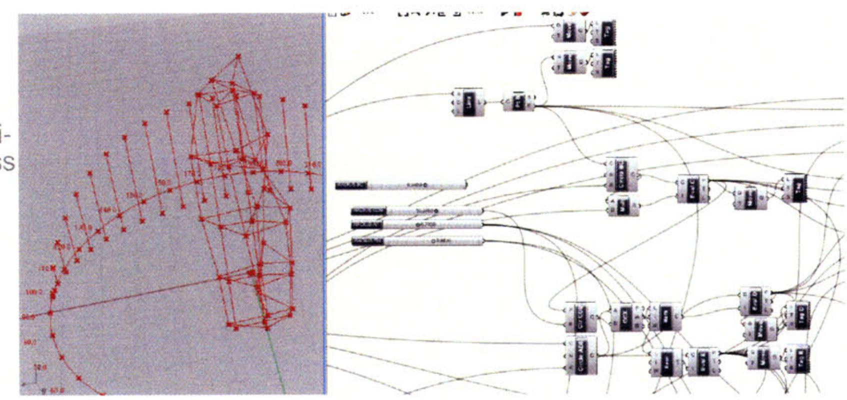


Figure 3-2 Variation possibilities during modeling process



This thesis will focus on integrating parametric design concepts into different software and hardware knowledge beyond the use of software embedding material and structural properties. Although recently many projects explore parametric topics, research on new concepts for parametric design is needed to improve current construction and design processes. In next chapter, this paper will look across disciplines in order to open a new territory for parametric design.

4.Precedent

This chapter demonstrate previous works in different fields includes artificial intelligence, architecture, kinetic structure, and performative design that are related to my research.

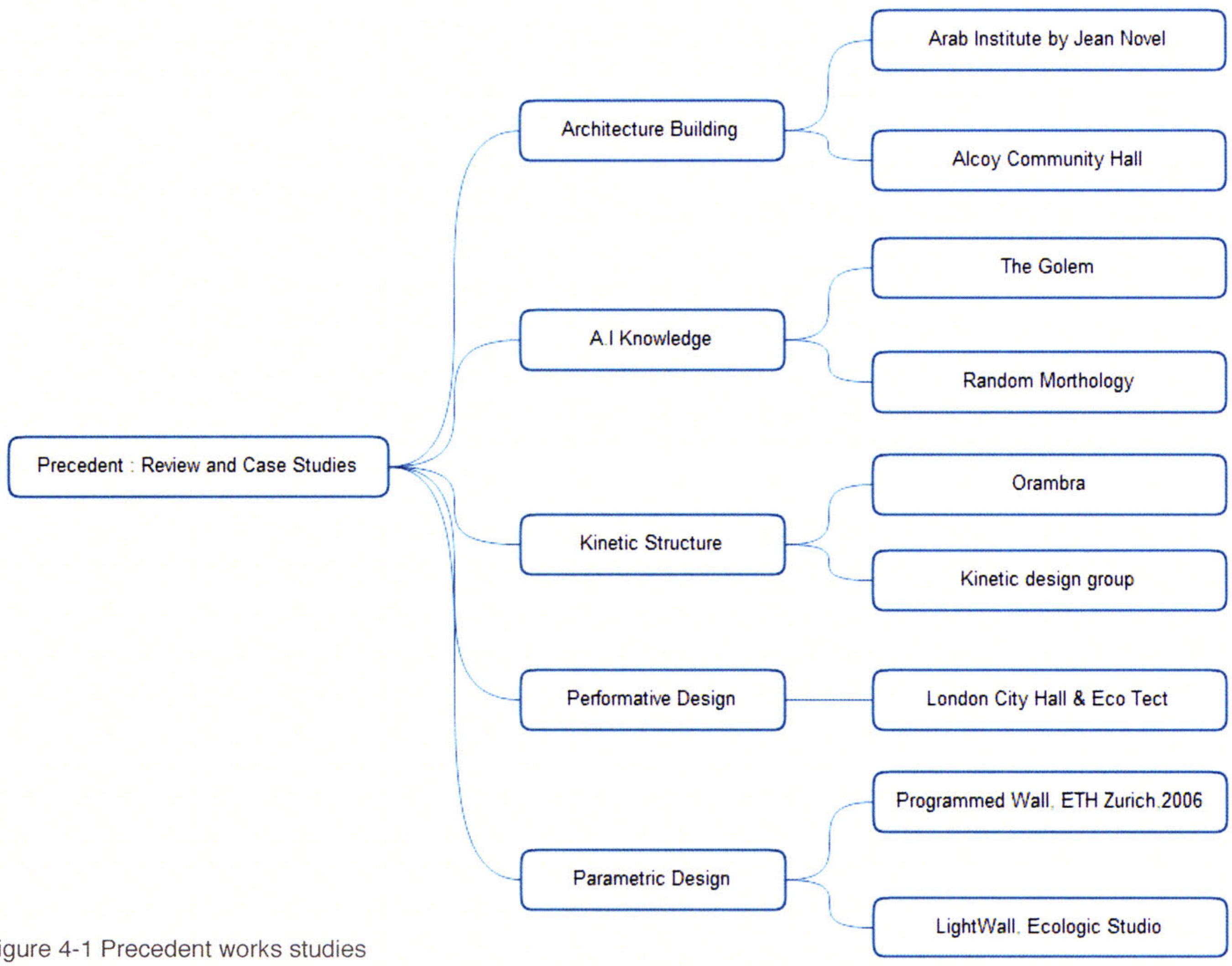


Figure 4-1 Precedent works studies

4.1 Arab Institute by Jean Nouvel

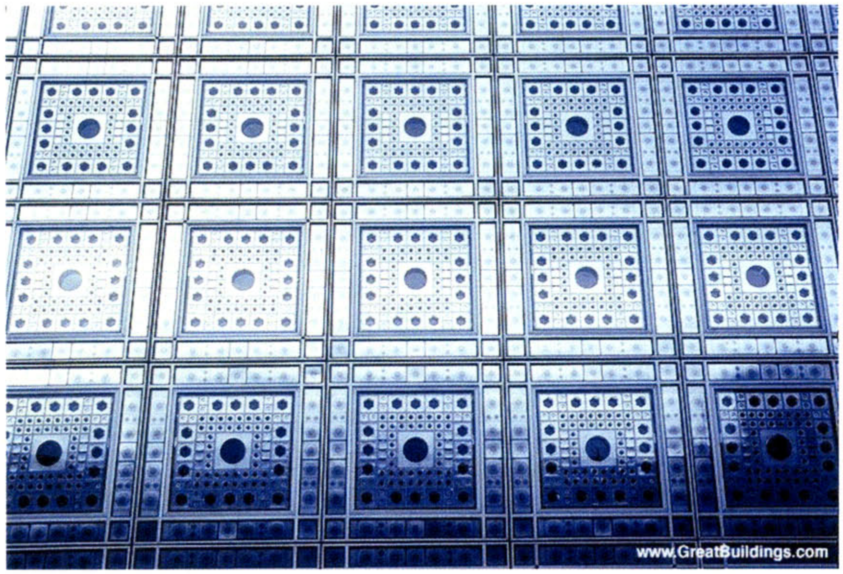


Figure 4-2 Arab Institute by Jean Nouvel images is from http://www.greatbuildings.com/gbc/arab_institute/arab_institute.html

The building which was built in 1988, by Jea n Nouvel is located in center of Paris. The facade of this building purposes an innovative design to filter light by automatic mechanical design. The mechanical design is like camera lens to control the sun light penetration into the interior of the building and each panel is designed patently in Islamic decorative terms. The facade design enables the interior of the building keep the subtle light and enables people inside feels peaceful.

4.2 Aloy Community Hall

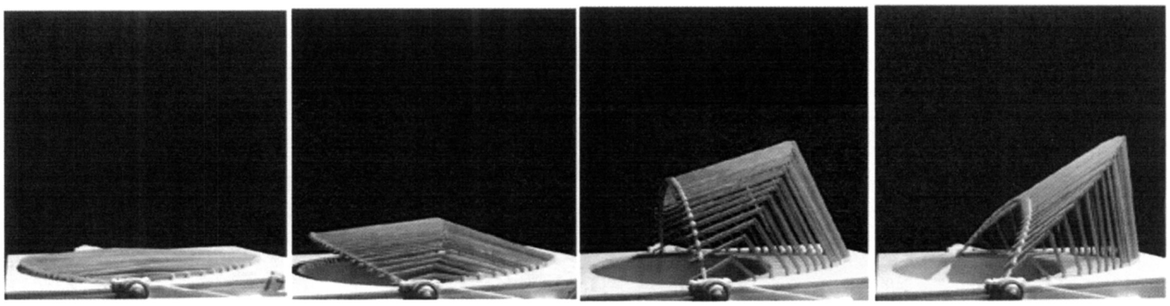


Figure 4-3 Aloy Community Hall

images is from http://www.greatbuildture.com/kdg/index.html

Alcoy Community center was built in span in 1995 by Santiago Calastrava. The purpose of building is designed for civil weddings and exhibition. The structure consits of translucent glass floor pannels and stan less steel frames enables light penetration into the interior of the building and light the structure at night. The structure is designed as a moving open entrance, allowing access the stair in the mid of the building when the roof structure is open at the opposite end. The mechanical design of the roof structure employ moving rod and joint mechanisms to change its shape from horizontal position to vertical position.

4.3 AI knowledge and Robot morphology theory

This research investigates the dynamic possible movement patterns according to signals from sensory information which is based on Brooks 's subsumption architecture(Brooks, 1991)[3][4]:

He believes that robots integrated sensory systems, can experience and interact with their environment.

The motion patterns are derived by the concepts of artificial intelligence, which enable robotic structures to evolve computationally from rhythmic locomotion. Locomotion is a term to describe a common movement of an organism from one place to another place. Locomotion is composed with three major components: sensors, actuators and the connecting control system. Locomotion is based on the CPG network, Central Pattern Generator (Stein et al., 1997[5])which is the creature's essential control pattern that the nervous system from spinal cord produces special control units to send out indispensable signals to the muscles to act movement rather than those signal from brain.

The concept of A.I robots which develop their own behaviors, cope with predefined hardware bodies through the iteration of autonomous processes, enabling the robots to learn how to adapt to the environment where they are situated.

4.4 The Golem (Genetically Organized Lifelike Electro mechanics)

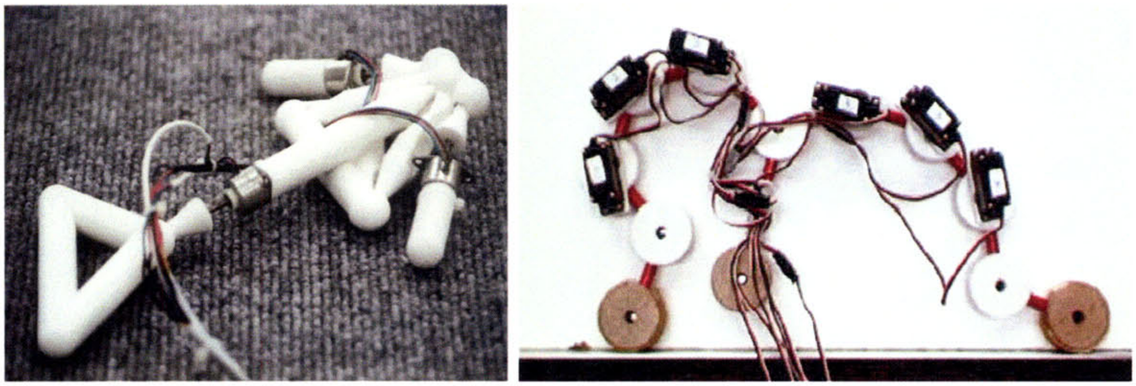


Figure 4-4 Golem (image source : Eva Schindling , Spinal Rhythms, Autonomous Embodied Evolution of a Biomimetic Robot's Rhythmic Motion Behavior)

The Golem (Genetically Organized Lifelike Electro mechanics) project is designed by Lipson and Pollack at 2000. Golem is a simple robotic system which is assembled by a set of bars, linear actuators and artificial neurons and advocates that not only the behaviors of robots should be the essential part of autonomous learning system design, but also the bodies and their manufacturing. The Golem project includes software parts and hardware parts to manufacture. [6] [4]

The Golem uses software to simulate the possibility to manufacture its own body. The software uses variables of weights and threshold parameters to evaluate its random performances to get optimized configurations. The optimized software uses genetic algorithms to produce appropriate fitness and builds new generations by updating some of the building blocks. The software simulates the randomly assembled parts and decides what the optimized fitness is by repeatedly testing its forward locomotion ability.

After 300 to 600 generations of Golem which is artificially evolved, some generations are picked by the designer to be manufactured to test them in a physical environment. The mechanical part of Golem consist of bars that are connected to each other with balls and socket joints. This mechanical design allows Golem to have stable and flexible forms. The ball and socket joint structure is equipped with motors and microcontrollers s during the manufacturing process. The micro controller is loaded with the simulation software which allows Golem to represent the evolved locomotion patterns. This design process improves the possibilities of robot design in terms of the process of rapid prototyping for circuits and mechanical systems for robots. But the disadvantage of Golem is that it is assembled by simple structures which can be done by hand ,rather than a complex structure that should use machines during the manufacturing process. [6] [4]

4.5 Random Morphology Robot project

The Random Morphology Robot project which was designed by Dittrich, in 1998 demonstrates a robot applying evolutionary algorithms to an autonomous learning system, giving robots a simple structure to learn how to adapt to their environment. The purpose of this project was to develop a manipulating system to use a set of mathematical programming operations, such as delay, rotate, degree in order to send signals to different motors and move the structure of the robot quickly in one direction. This evolutionary system evaluated the possible movements for each motor in all joints and generates the best controlling information for itself . The result of this experimental robot illustrated the success of applying Genetic Programming into a complex control program for robots. [7] [4]

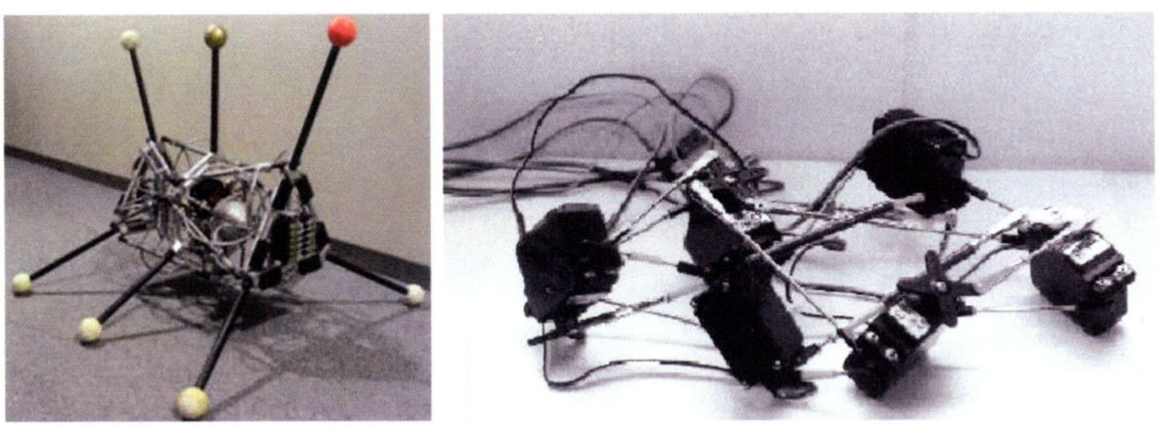


Figure 4-5 (image source : Eva Schindling , Spinal Rhythms, Autonomous Embodied Evolution of a Biomimetic Robot's Rhythmic Motion Behavior)

4.6 Kinetic architecture: orambra

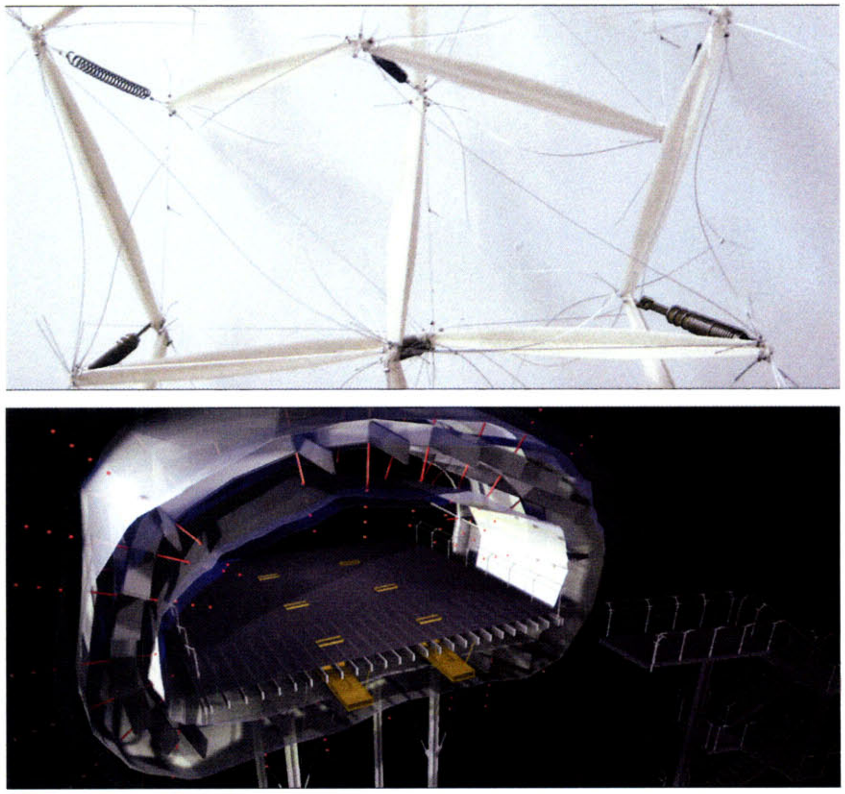


Figure 4-6 Orambra
(image source http://www.orambra.com/)

Orambra ,The Office For Robotic Architectural Media & The Bureau For Responsive Architecture is a small office which is hold by Tristan d'Estree. The main research is working on the kinetic structure design, enabling response the context change, such as weather and human movement.

4.7 Kinetic architecture: Kinetic design group

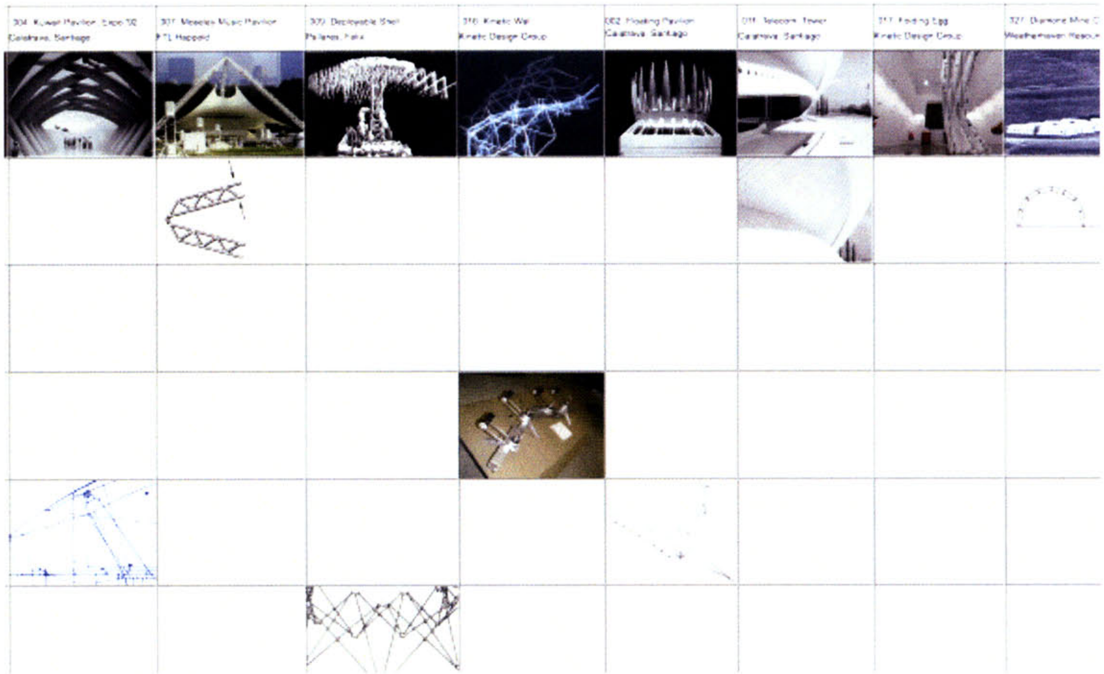


Figure 4-7 MIT Kinetic architecture http://www.robotecture.com/kdg/index.html

Kinetic design group was created by Michael A Fox in 2005. The goal of kinetic design group is trying to find architectural solutions that can demonstrate responsive and intelligently active behaviors with response individual, social and environmental needs.

Kinetic structure use embedding system consists of sensors into the structure, enabling structure response the environment change and also enables designers study different forms in their efficiency analyze, flexibility.

The three key elements of kinetic structure design: structural engineering, embedded system and adaptable architecture. The kinetic system design focus not only on the way of form generation, but also investigates a new way of developing space experience which response dynamic, flexible and constantly changing needs.

4.8 Performative Design

The goal of performative design is trying to find an optimized design solution for building design. It may consists multiple disciplines, such as social, cultural contactual approaches.

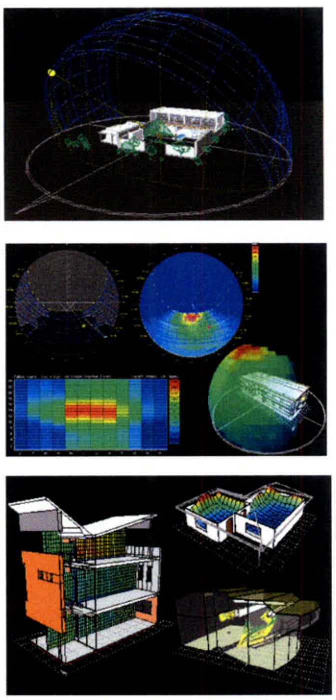


Figure 4-8 performative design http://ecotect.com/products/ecotect/gallery

Recently, many architectural firms use simulation tools to help building become su stainability during design process. They use simulations tools to analyze daylight changes for outside building to investigate the optimal performance for building, such as preliminary building shapes researches in order to get a good building shape in different context.

Through this design strategy for optimized building design , designers enables to design sustainable buildings in some conditions, but after constructing, buildings in different conditions may have unexpected performance.

4.9 The Programmed Wall, ETH Zurich,2006

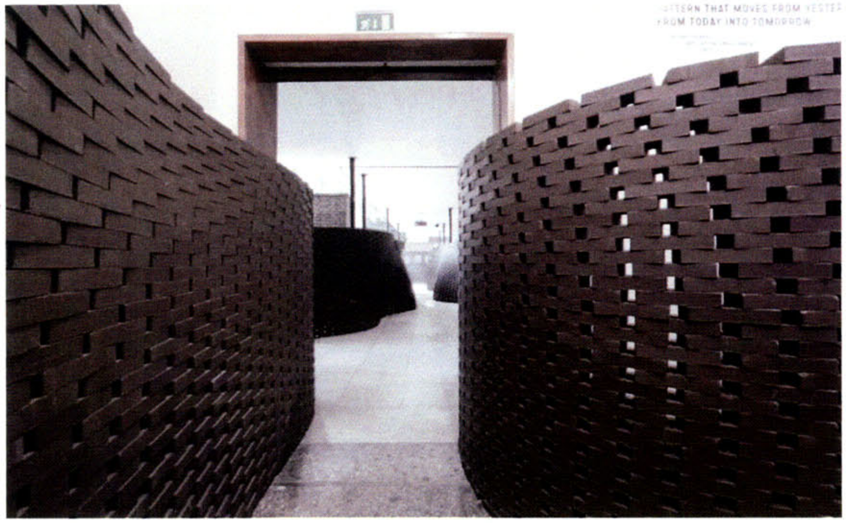


Figure 4-9 (image source : http://www.dfab.arch.ethz.ch/web/e/lehre/84.html)

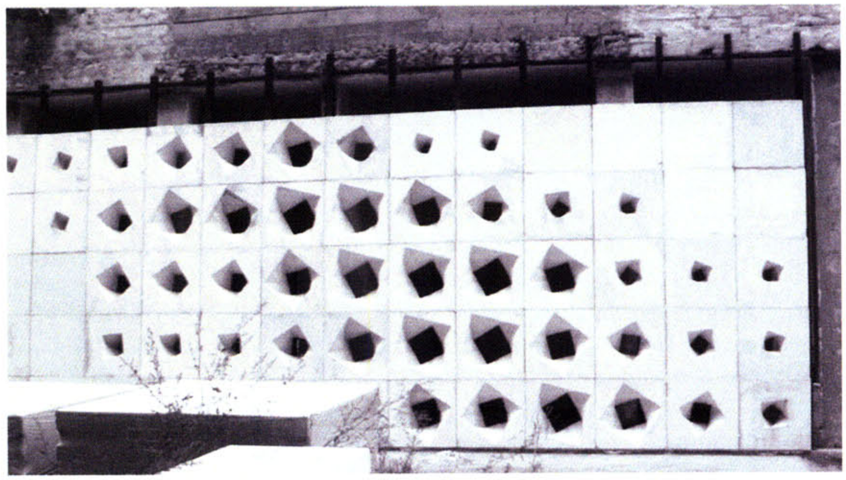
This research project demonstrates the possibility of applying parametric design to a traditional brick wall. The parametric brick design focuses on using a robotic arm to build waving brick wall. The process of the parametric brick design is called additive digital fabrication technique which can be described as a three-dimensional printing process, using robotic arm to put every brick on its precisely pre-defined position. Therefore the material of this design is not limited to bricks, and different kinds of materials, such as wood, concrete.. etc, can be utilized to build complex forms. The beneficial part of this research project is using cheap and traditional materials, such as bricks, wood, concrete blocks and an industrial robotic arm to positions to precise coordinate position, without any measurement reference. [9]

In order to put every brick in its specific position, the researchers developed algorithmic design tools that guide the robotic arm to distribute bricks for their spatial positions according to the logic of algorithmic design tools to put bricks on their spatial position and rotates each brick in space. The algorithmic design tool defines not the shape of the wall, but the constructive sequence of materials, such as using cement as glue then move brick to attach another brick therefore keep this process going to produce an architecture form.

This research was exhibited at the "Explorations exhibition" in Swiss-land in 2008. The design of the programmed wall was assembled by 14,961 individually rotated bricks to form a 100 meter long continuous curve wall. The programmed wall was built on site at the Giardini based on a design of Swiss architect Bruno Giacometti in 1957. The idea of this programmed wall was to build a continuous curved brick wall that becomes an interface, enabling exhibitions in different space. The wall can be automatically re-generated to change form for a group 's need. [9]

4.10 LightWall, EcologicStudio

Figure 4-10 Light wall (image source : http://www.ecologicstudio.com/v2/project.php?mp=0&idcat=3&idsubcat=4&idproj=10)



Lightwall which was designed by EcologicStudio in Italy is a concrete brick system, allows absorb and filter light and heat by open the mid hole from concrete. The concept demonstrates the brick system response the context change. The behavior design which response environment change is embedded in the parametric design software by Generative Components. This project use parametric design to generate different concrete design, then make molds to make different concrete design. But this project shows the variable bricks assemble to a wall, rather than as concept demonstration which interactively responsive context change in real time.

5.Introduction of Experimental works and Design theory

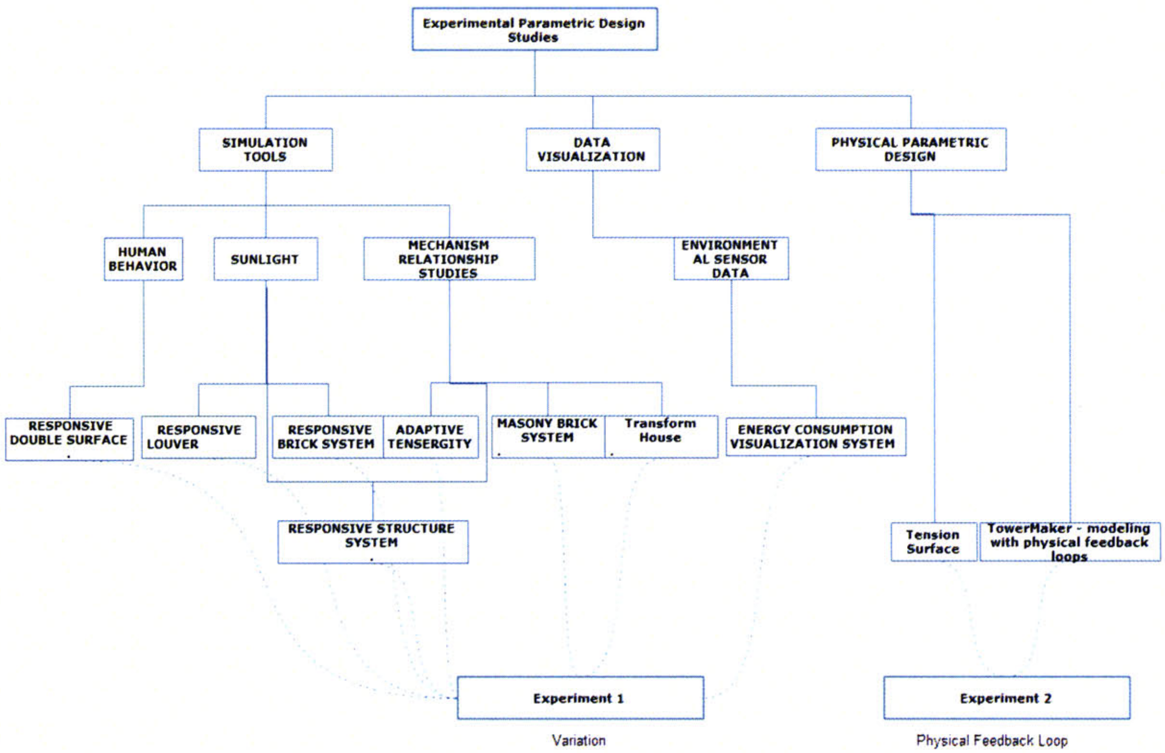


Figure 5-1 Experimental works and category

5.1 Experimental works documentation

This thesis presents ten case studies investigating specific parametric design methods with the objective of study how to implement the variation from parametric design to physical world and the physical feedback loop desigm aims parametric design fix constraint problem. Two are related to simulation environment which can be used as a test platform for fabrication or responsive environment design: Two are different data access, such as implementing environment data to parametric design and generating visualization. Each of the presented studies investigates possible methodology/ solution as alternative research tools.

The experimental studies are based on grasshopper, processing as data visualization and simulation environment. They include three parts: simulation tools, data visualization, and physical parametric design. This thesis will addresses major on physical parametric design and documents the process.

The simulation tools involove three different components, sunlight, human behavior, and mechanism movement. The sunlight simulation is built with PSA algorithm *(http://www.psa.es/sdg/sunpos.htm , Plataforma Solar de Almería Web Server, the European Test Centre for Solar Energy Applications)* to calculate the direction of sunlight in different time, zone, and latitude. The responsive simulation system adapts the responsive component change according to human proximity and behavior. The mechanism simulation tools as a test platform for designer dynamically evaluate the mechanism design.

The data visualization demonstrates the idea of using parametric design as a simulation platform to process sensor data and generate interactive visualization. The system is built up by two stages; The first stage uses parametric design as an evaluation system; The second stage generates visualization. The system reads a spreadsheet, which is generated from the sensor, and then uses algorithms to calculate. Then generates real time heat map. In addition, the system exports data to processing to generate a visual interface for the user.

The visual interface can be applied on mobile phone device as personal energy application to allow users to organize the better daily energy consumption.

The Physical Parametric Design demonstrates the idea of a physical feedback loop design system, enabling designers directly manipulate parametric design and implements the design into the physical model. Then the design output permits designers to manually adjust the design from physical model. The sensor which is embedded in the physical model transmits data from the physical model in order to update design for designers. The Physical Parametric Design is not only aimed to keep variation from parametric design in physical condition, but also enables designer to observe and manipulate the design results then physically update the digital parametric model.

The Physical Parametric Design plays an important role in this thesis, since it explains how to solve the bidirectional constraint in design exploration. To demonstrate the possibilities of parametric design usage, additional case studies are necessary to show how to implement parametric design in alternative way, such as how to convert physical data to parametric design, how simulation environment aims design process, or how to implement variation of parametric design in physical world. The documentation of these knowledge will enable the implementation of physical parametric design to a proof-of-concept.

5.2 Design and flexibility

In 1975, William Mitchell wrote “when the first computer-aided design systems appeared, they reified these well-established design traditions”.[10] He pointed out that a design process needs a flexible and undetermined methodology and an open environment, in order to provide design possibilities on the fly. He also mapped out a line from Aristotle to Lull through the parodies of Swift and Borges to summarize the generative systems for architectural knowledge base design.[11] These researches have brought architectural design into a new era.

This thesis is following several ongoing experimental projects at this moment. The main goal of this paper is trying to develop a new parametric design strategy, allowing users to get physical models which are still keeping the properties of parametric models, allowing a user to change the configuration of a physical model, after manipulating parametric model.

5.3 Congnitive Physchology

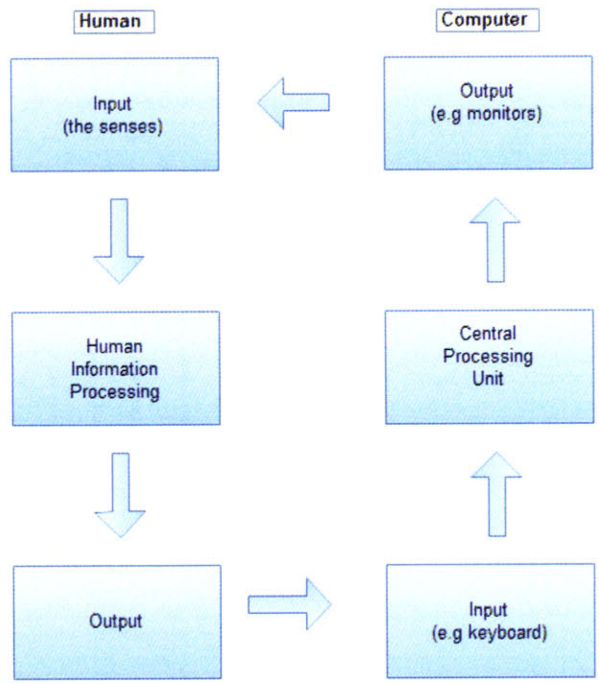


Figure 5-2
The information processing paradigm for cognitive psychology and human information processing
(image is from book :Designing interactive systems pp.100)

In cognitive psychology approach, the human information processing can be simplified into three subsystems:

a sensory input subsystem (seeing , feeling , testing)

a central information processing subsystem (memory, awareness, motivation, attention, affect)

a motor output subsystem (muscle , speech)

This approach is similar as what we categorize the main elements of computers. This diagram above illustrates the information processing which demonstrates strong parallels between the human and computer and the relationship between human and computer which are functionally similar and becomes a closed loop.

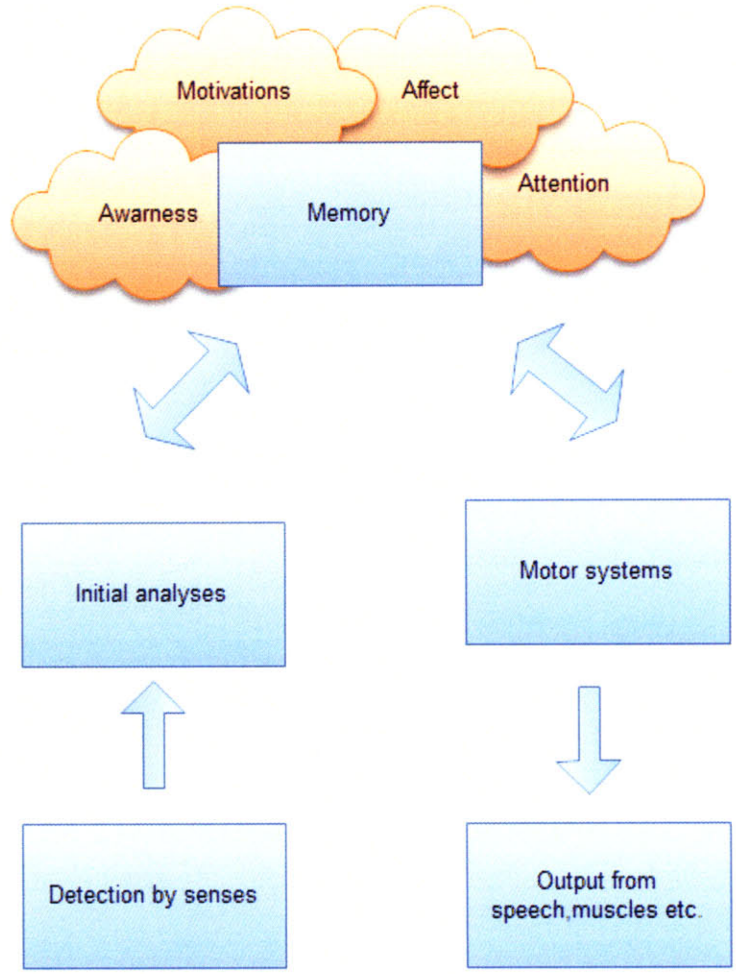


Figure 5-3
The information processing paradigm for cognitive psychology and human information processing
(image is from book :Designing interactive systems pp.101)

The diagram demonstrates the relationship between these subsystems for human and computer. The information from the sensing is analyzed before storing into memory. After information is stored into memory, the clouds (awareness, motivation, affect, attention) helps to make decision to decide if the information should send to motor system to give action output .

5.4 Conceptual design and physical design

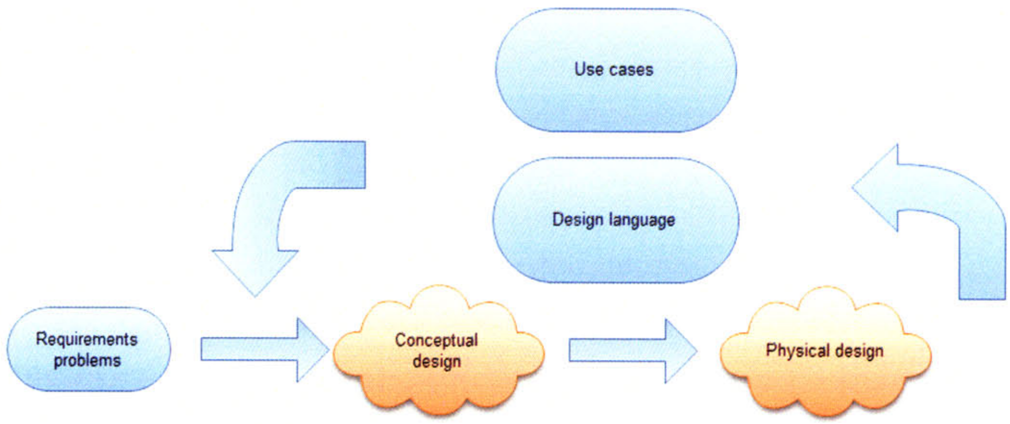


Figure 5-4
Concepture and Physical design

(Image is from book :Designing interactive systems pp.290)

Architectural design process is concerned with problem solving approach, therefore design space for designer to think about how to solve specific problem becomes important.

Conceptual design is focusing on abstract description in the design process, such as the logic, function, representation, but not address on the implementation of physical world, such as how the form, structure supports the function to build. Physical design is more concerned with the relationship between designers and artifacts, such as appearance and behavior of artefacts.

In the design process, conceptual design and physical design doesn't separate each other, but more like a loop for designer literately fix the design description and design decisions, enabling physical design understanding the conceptual level better and conceptual design implement better idea into physical design. A good design system/platform is designed to easily learn from designer and fit designers 'expectation and preferences.

5.5 knowledge-base

A generative algorithm is used for architectural concepts to express certain rules for architectural form to develop, to evolve. Architectural concepts in generative algorithm are described as a series of code scripts of instructions for form-generation. In the previous work, the Golem (Genetically Organized Lifelike Electro mechanics) project used generative algorithms to generate possible forms for robotic body, and embeds the same kind of knowledge base system to help robots evolve and obtain better performance. Because of this reason, if designers not only use generative algorithms for form- generation, bust also embed this kind of genetic language in their architectural design or structural design, architecture can perform better. For example, recently, designers use simulation tools into architectural design, such as Ecotect or CFD to evaluate designed architectural forms in certain conditions in order to make building more sustainable or optimized. But the design only works well for few some predefined conditions. The performance of building doesn't work well in many other conditions. Because of this reason, it is important to have a new design strategy could offer building embed the knowledge from those simulation tools, and the building could evolve itself to get optimized performance in different kind of conditions.

Therefore updating the physical model is an important approach. Recently the “attractor “in parametric modeling plays an important role, allowing users to build the relationship between attractors (such as point, cube) and a surface, Various different types of surface can be archived by only manipulating attractors. The“attractor” can serve as sun, environment or people, and the designer can use this kind of concept for a responsive parametric model. Although this design concept offer parametric design some flexible and undetermined, due to an open environment. After the design is finished and becomes physical model, it is still fixed.

The attractors also can simulate contextual factors. Contextual factors can be simply classified into three categories:
physical context
Social context
Cultural/ Historical context

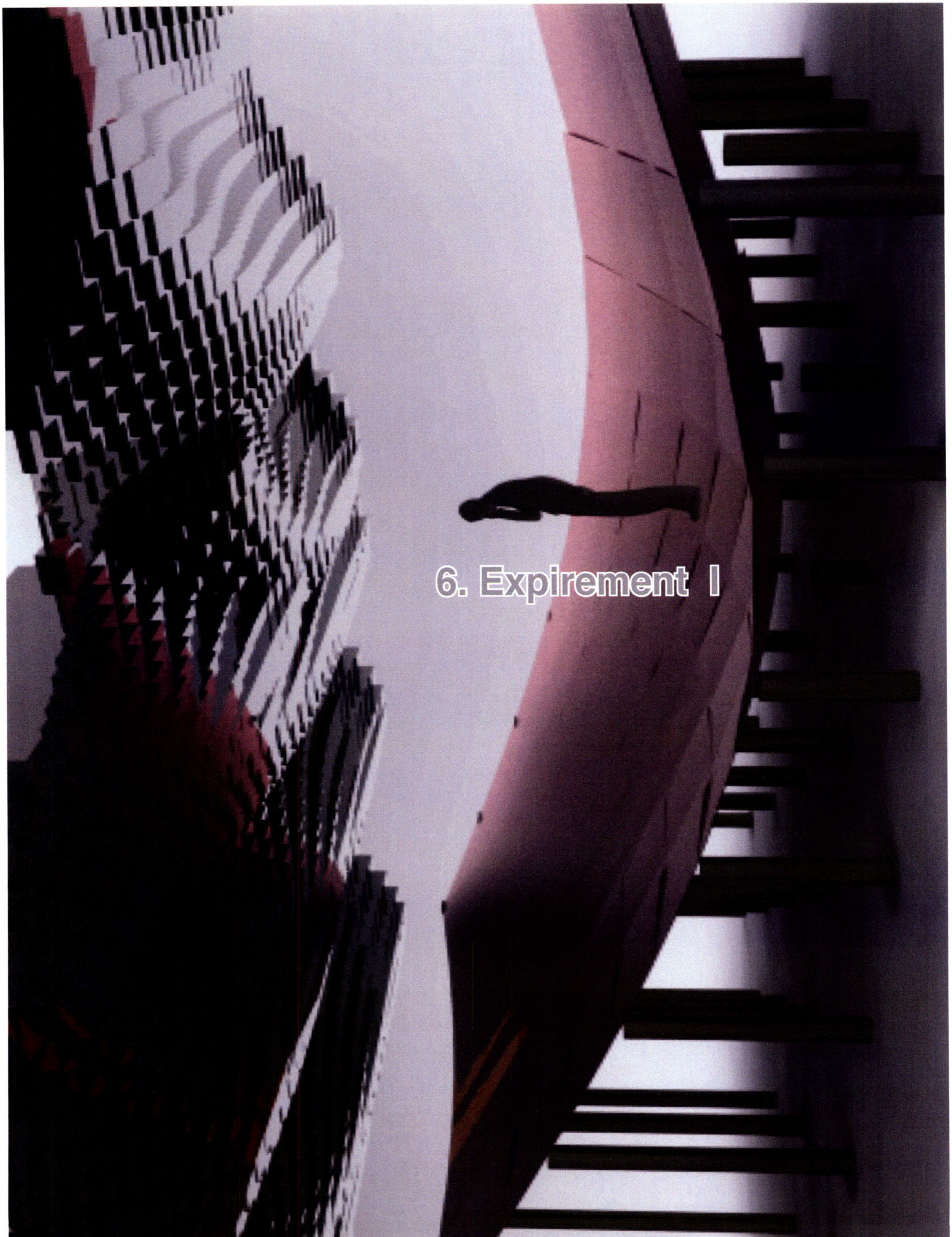
In the last paragraph, the physical context were addressed by using a sun, environment as attractor to generate various different surfaces. A social context consists of how people think and use something and interpret it.

For example, when you watch a movie in a theater with friends or watch it on television with your family, or watched it in a class room. Although you are watching the same thing the experiences are very different.
Facebook, a popular social network utility, allows users to share social events, and pictures and know new friends. Because so many people share and participate in Facebook, it becomes easy to track social contextual information in the virtual world. Many people develop many applications on Facebook in order to entertainment friends or other beneficial purposes.

Social network plays on important role in interactive architecture. For example, many media facade displays dynamic graphic on the facade by LED light,which according the resource from internet or the different context. such as people's movement inside building(Kunsthaus Graz Graz, Austria , Peter Cook). This kind of concept improve the possibilities for users communicate with buildings and environment. we can consider parametric software as a platform for designers to predesign the behavior into parametric model, so that the behavior could extend after building built.

In "the Design of Intelligent Environment article", which was published by Warren Brodey in 1967, he proposed the concept of environments that could become self-organizing, self-evolutionary.[12] We could predict that this social network utility database becomes a great data base for architectural form determination in the future. For example, a user who lives in a small apartment in a city, shares his house energy information online, the house could gradually change its architectural form, in order to get optimized performance in urban environment. Because of this knowledge base system which according the simulation tools is already embedded inside the architectural and structural design, the architectural form can have flexible and undeterminable space to evolve during its learning process to adapt to environmental change.

6. Expirement I



6.1 Simulation tool-Human behavior

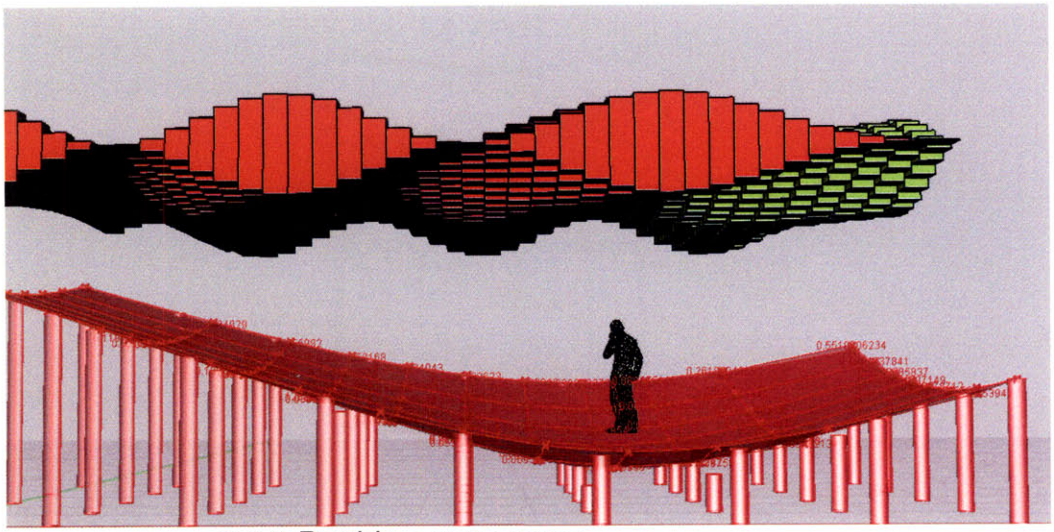


Figure 6-1
Double curve space

6.1.1 Double curve space

The design demonstrates a double curve space which responds to the person's movement. The upper curve represents a collection of cubes which generate sin wave movement and also change color from red to green according to the distance logic between human and cube components.

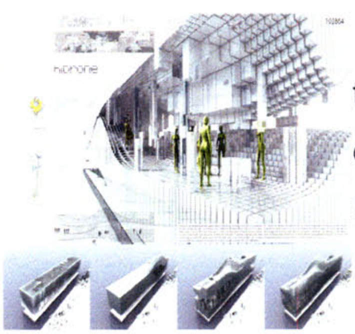


Figure 6-2
urban competition /London 2008/ adaptable architecture gallery on the Thames River (http://www.arquitectum.com/index.php) by Sergio Araya, Orkan Telhan, Duks Koschitz, and Alexandros Tsamis.

This idea has its foundation on the winning competition of urban competition /London 2008/ adaptable architecture gallery on the *Thames River (http://www.arquitectum.com/index.php) by Sergio Araya, Orkan Telhan, Duks Koschitz, and Alexandros Tsamis.*

The cube components are reconfigurable to open and close by operating filling and releasing water recycled from Thames River. When opened, the building becomes a occupied space for gallery use; when closed, the building becomes a large 3d screen.

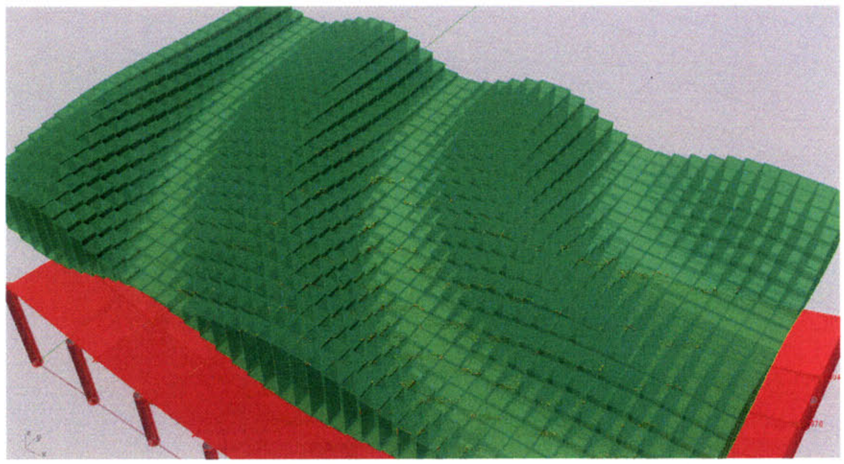
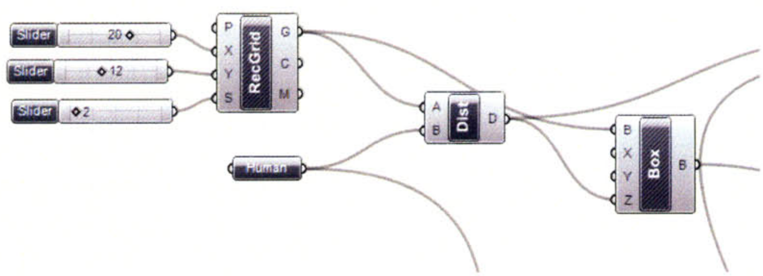


Figure 6-3
Double curve algorithm and representation



The algorithm that animate the reconfigurable cubes are calculating the distance between human position and the position of the grid points, which belong to a predefined grid system in space. The algorithm generates water ripple wave movement by controlling different height of cube components. The design representation involove the pixelization the sin wave curvature ceiling, which is dynamically responds to the movement of the human inside the space.

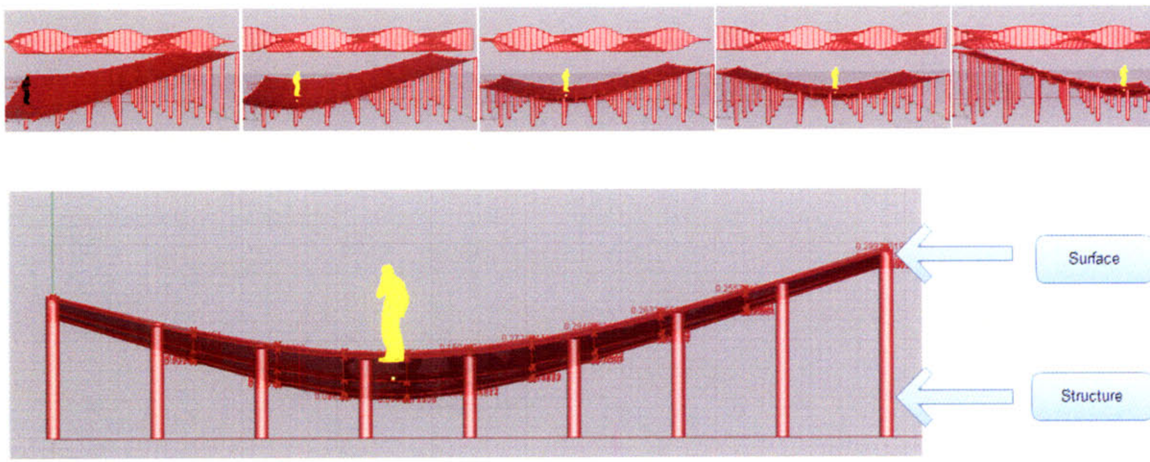


Figure 6-4
Double curve algorithm and representation

The bottom curve represents two parts, including structure and surface. The surface is formed by the different height of the structure which also conform to the moment of human, but in different algorithm logic.

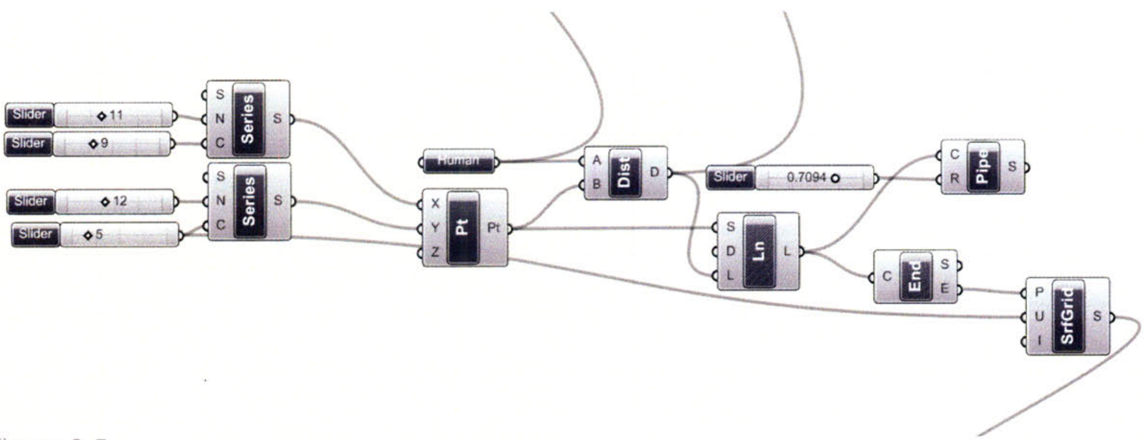


Figure 6-5
Double curve algorithm and representation

The above diagram illustrates the algorithm of making the decision of height of structure and formulates curvature surface according to the proximity of the human, it only generates a simple curvature form to load human 's weight.

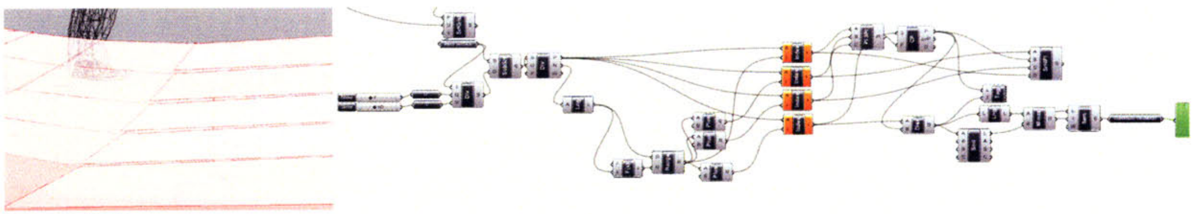


Figure 6-6
Double curve algorithm and representation

The algorithm formulates surface and flat panelizes surface in order to provide optimized tolerance to adapt to the dynamically geometrical change. It also forms gaps between surfaces, enabling each surface to be fabricated separately avoid assemble collision.

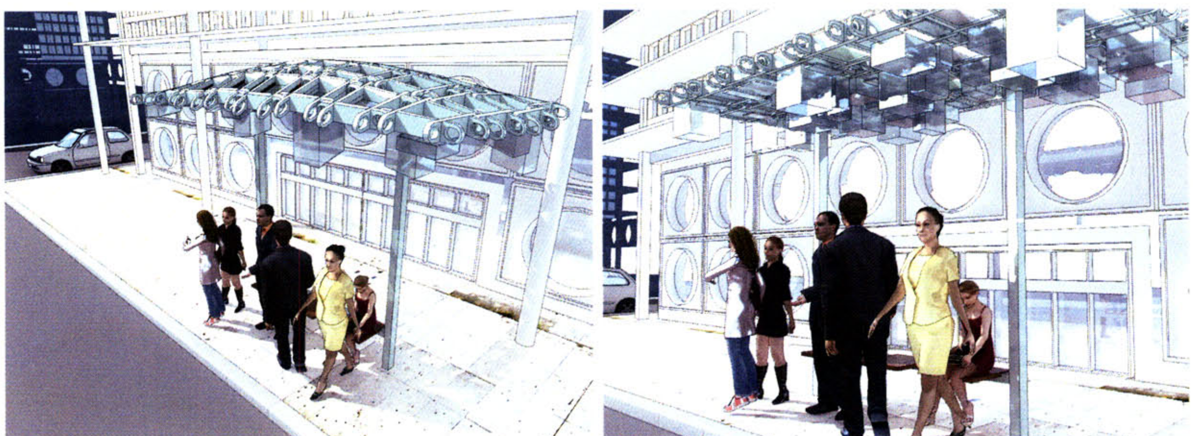


Figure 6-7
robotic bus design

6.1.2 Robotic bus stop design

This mechanism is similar to another precedent : an interactive bus stop design. The hanging glass acts as display which shows different information, such as the bus arrival time, news and advertisements. The structure could transform its shape to adapt user's behaviors.

Sensors that are embedded inside the structure detect the user's sitting behavior. Displays could move closer to the users. For example if users are standing inside the bus stop displays could raise.

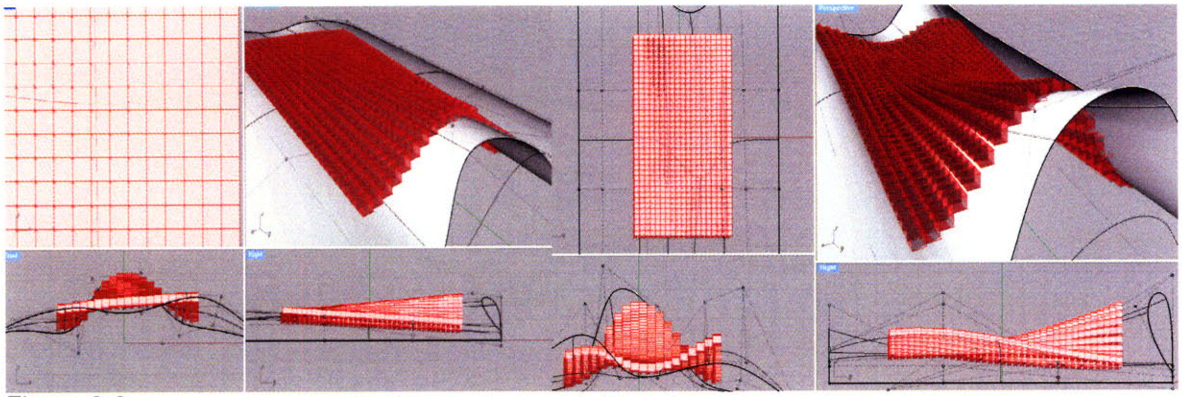


Figure 6-8
robotic bussurface relationship study

6.1.3 surface relationship study

The above illustration shows the study of movement of parametric changes. The red boxes could be displays. If the attractor (people in the physical environment) change their height, the surface is getting updated and the red boxes follow the surface changes and move vertically.

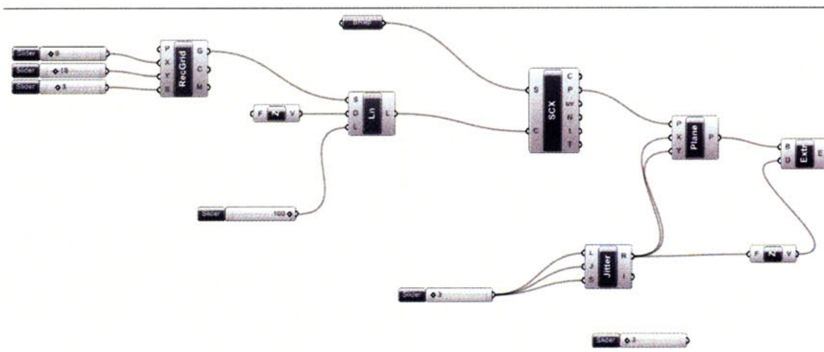


Figure 6-9
robotic bussurface relationship algorithm

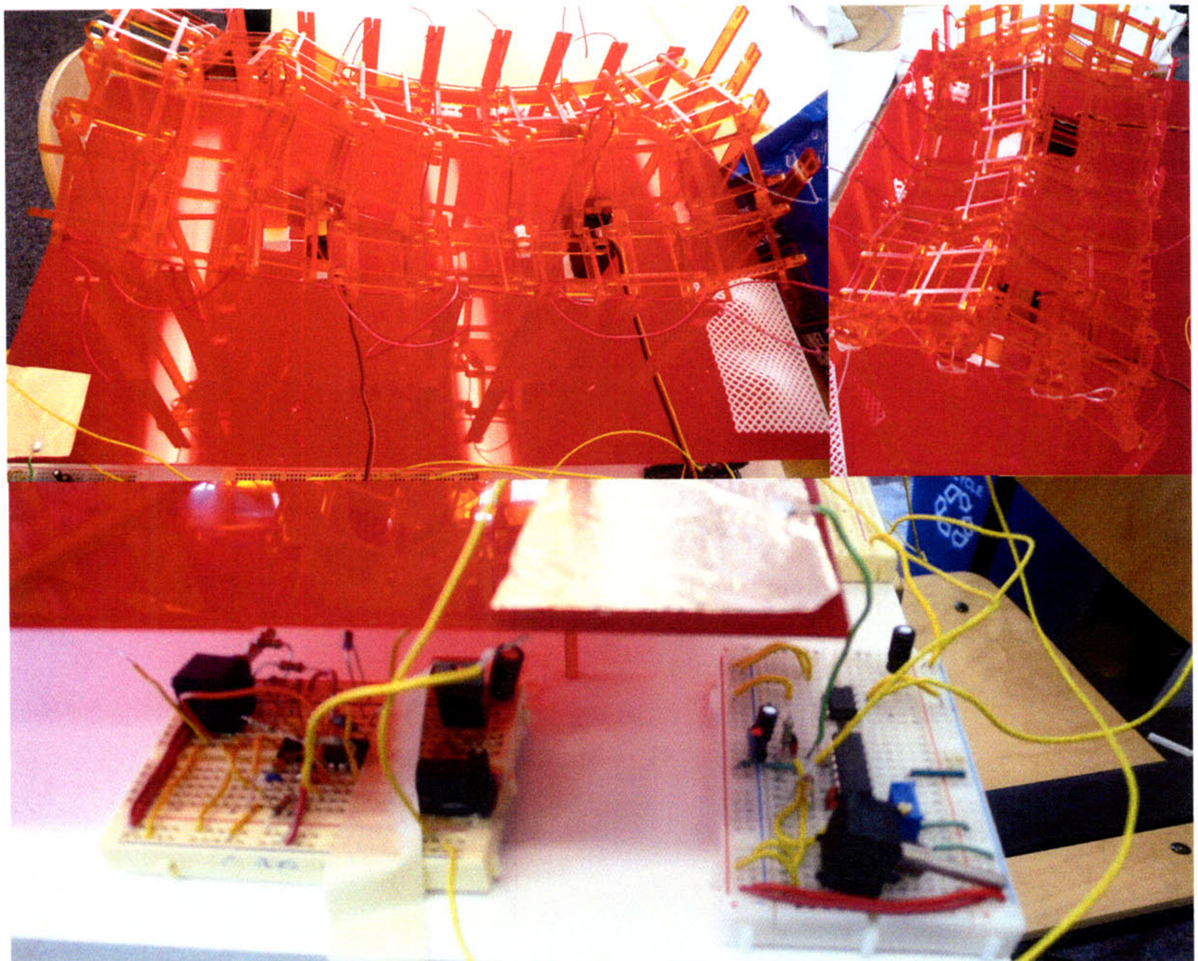


Figure 6-10
robotic bussurface embedded electronic design

6.1.4 surface relationship with embedded electronic design

The illustration above shows how the study model is controlled by microcontroller, which is embedded similar knowledge to respond human behavior. The proximity sensor sense human's distance then moterize the surface structure to raise.

6.1.5Conclusion:

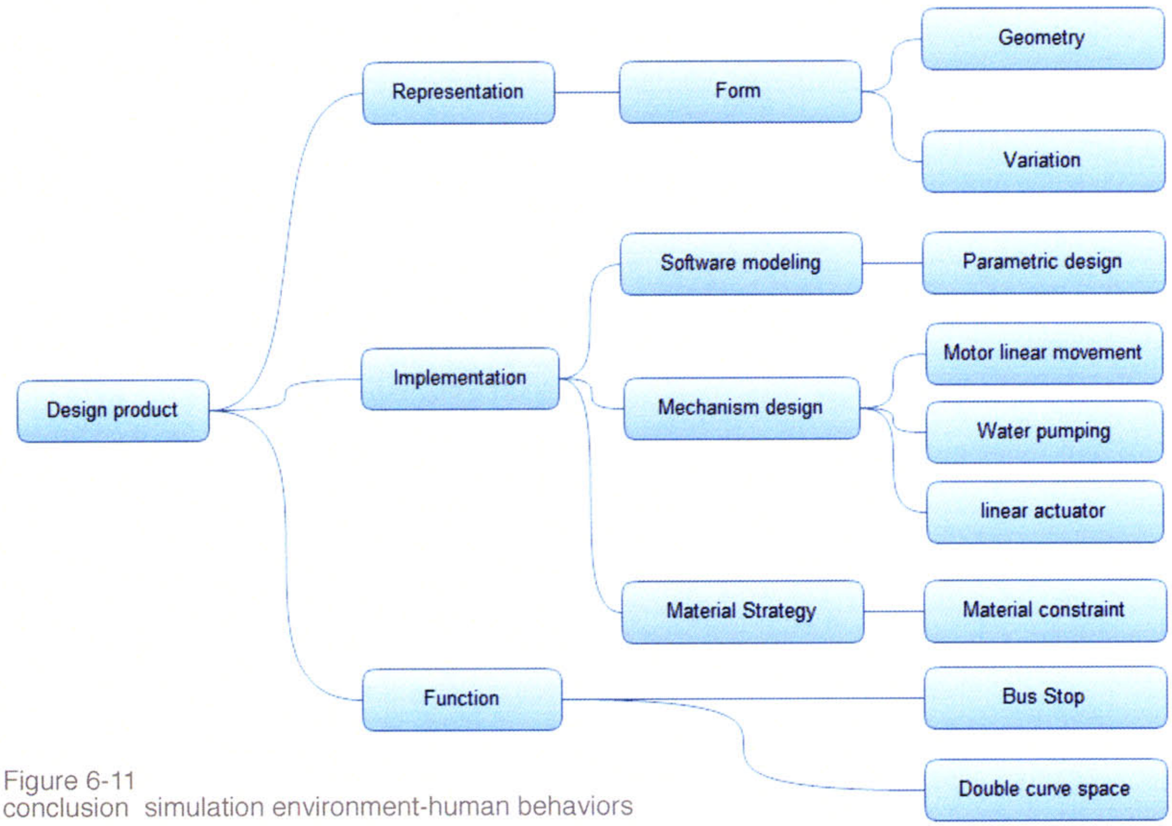


Figure 6-11
conclusion simulation environment-human behaviors

The previous two experimental design study through sequential practices to investigate responsive surface design. The design product includes three major parts, such as representation, implementation and function. The representation in this design study demonstrates the goal and initial design concept to keep the variation of dynamic architectural form. The implementation invoLoved the execution process for supporting and evaluating if the goal is actived. The process of implementation is this case is similar to traditional design process, which finds requirements problems then use design languages and experience to solve the problems. The function part in this study is given by the designer after studying the possible solution. Because of this reason, the function part in this case is less important than others.

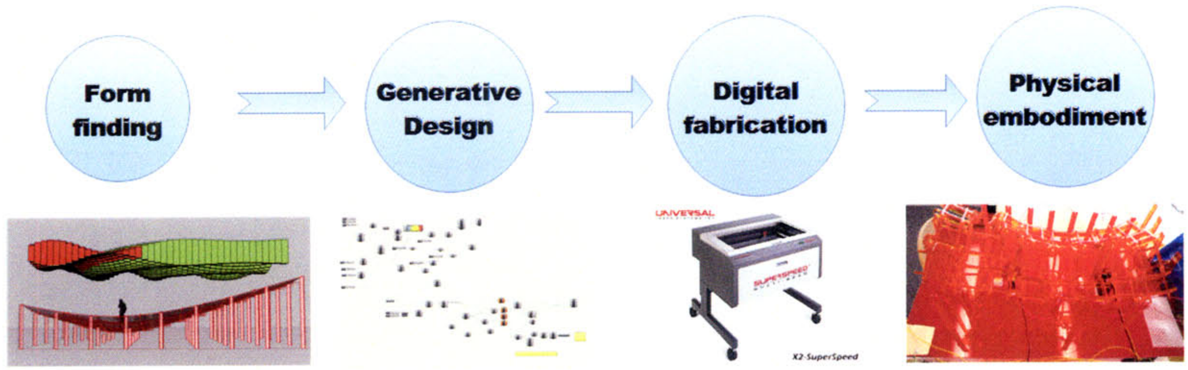


Figure 6-12
design phases for dynamic form

The diagram above illustrates these related design phases involoving different design strategies, to generate different design output. These designs at current stage are separated design processes, but provide designers the thinking of how to implement the variation of parametric design in the real world and what is the value of keep variation of parametric design in the physical world.

Traditional digital fabrication generates variation of possible forms for design research studies. Then, literately test tolerance and modify the design model, until find the optimized fitness. The iterative adjustment process consumes time and material, and also raise the cost. Parametric design tools can be successful as a test platform for fabrication and assemblage study through algorithms that formulate alternative parts and find the optimized solution to fabricate.

Therefore parametric designs can deliver the spread-sheets to control mechanism indirectly generate design output.

The disadvantages of these processes are separated and linearly working on different problem solving solutions. This process makes design become complex. But from these experimental studies provide a basis to think the value of good design tools and design working flow.

The next chapter investigates the relationship between parametric design data which is automated generated from algorithm and the design concepts.

6.2 Simulation tools-sunlight

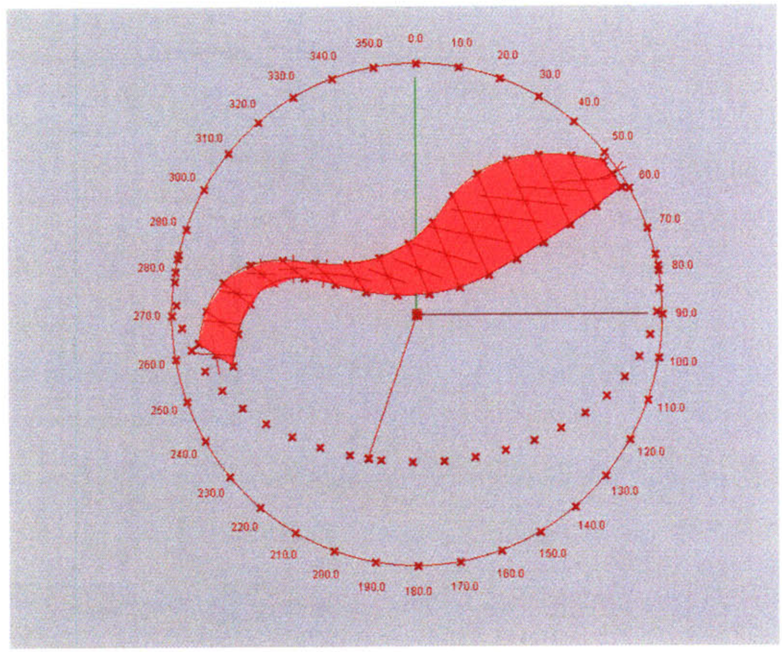


Figure 6-13
simulation tool-sunlight

6.2.1 Responsive louver system

In order to archive better performance and to optimize the design process, designers use simulation environment, such as solar, wind analysis to do preliminary study. Traditional way of simulation environment uses analysis software, such as ECOTECH to analyze and optimizes a 3d digital surface in order to satisfy prescribed daylight or wind requirements and optimization algorithm by software then export the datasheet as design reference. The disadvantage of the design process has to use multiple soft wares to explore various design, optimization and simulation in order to find the appropriate form and performance and to show how they are interrelated.

In this chapter, I will demonstrate two studies by using parametric design to interactively generate alternative forms and to optimize the design process.

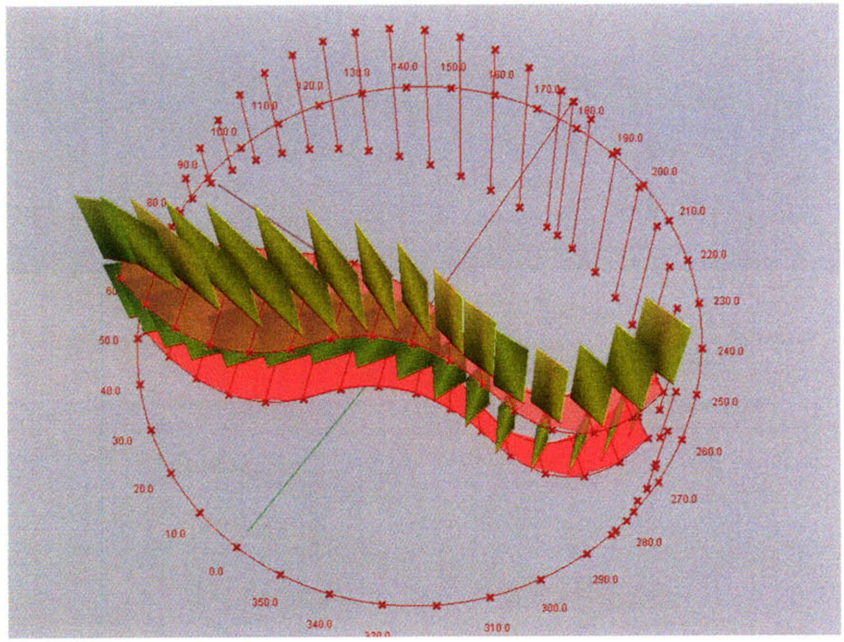


Figure 6-14 responsive louver system

The above illustration demonstrates the louver system which responds sunlight direction change. The sunlight direction was determined by algorithm, PSA (http://www.psa.es/sdg/sunpos.htm) which is written in c# language, and an algorithm is used to calculate the orientation of the sunlight. The system was originally developed by Ted Ngai (http://tedngai.net/experiments.html), for free to use. I modified the algorithm, enabling 3d model to generate different shapes to follow the orientation of sun and color change by calculating the angle between sun and each louver piece.

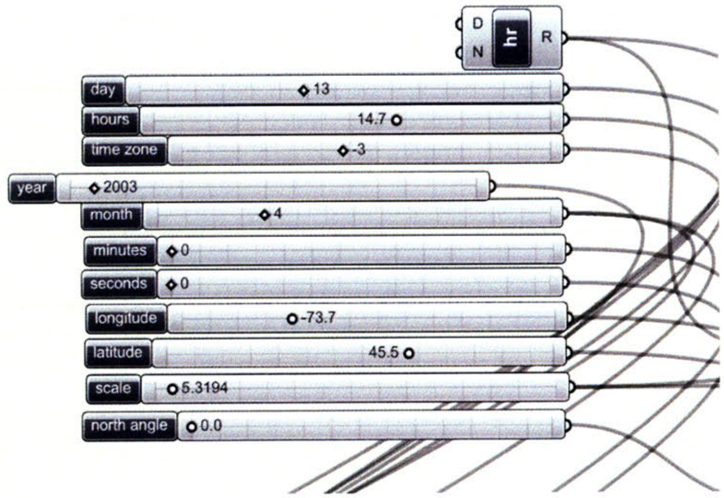


Figure 6-15 responsive louver system-data interface

The data input interface allows user to input different time (day, month, hours) , longitude and latitude. The algorithm which receives the data input from the user, enables the algorithm to calculate the orientation of sunlight. The illustration in next page demonstrates how the orientation of sunlight is generated by time, longitude and latitude. The circle represents the angle of sunlight. It allows different time input and generates different angle between center and sunlight. The vertical line which represents longitude and latitude interactively updates.

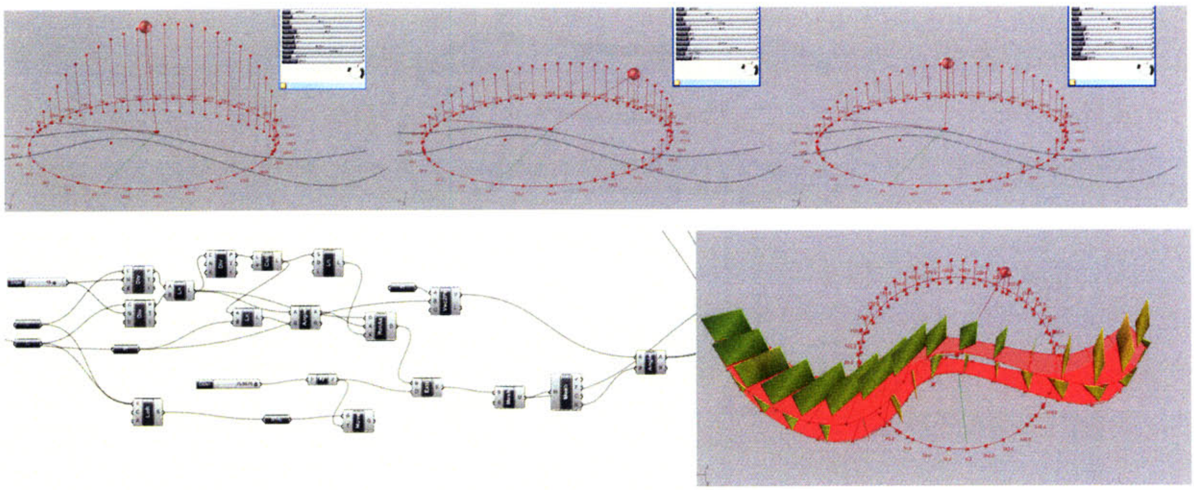
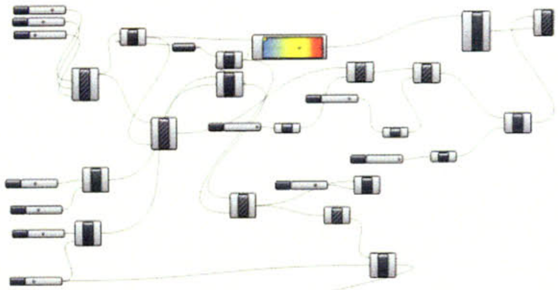


Figure 6-16 responsive louver system-structure algorithm

In general terms, the design algorithm is used for generating the louvers; therefore it calculates the angle between the sunlight and each louver which enables to generate the mechanism to response the change of sun-light orientation. The design algorithm creates the initial population for each louver to transform the direction in order to evaluate and find the optimized relationship between sunlight and each piece of louver.

Designers can use this design strategy to study mechanism in parametric design or design a dynamic system in the design process. The color gradient algorithm which uses the same strategy generates gradient color. The color range is determined by the rotational angle of each louver and the sunlight.



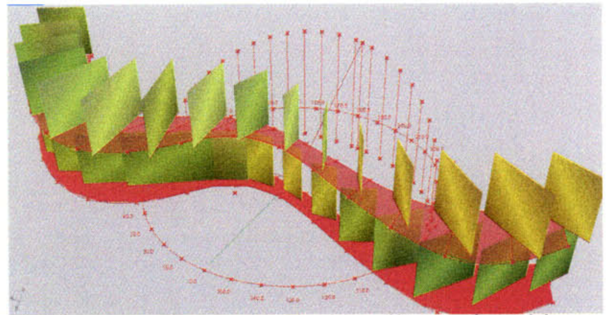


Figure 6-17 responsive louver system-color algorithm

The above diagram shows color gradient algorithm which uses the same strategy generates gradient color. The color range is determined by the rotational angle of each louver and the sunlight.

6.2.2 Responsive brick system

The diagram below illustrates the brick system which generates different size holes in the same surface. The size of the holes which is controlled by the direction of sunlight. The same concept as presented as my prescent study: LightWall project by EcologicStudio which uses parametric design to generate different types of bricks ,enabling absorb and filter light and heat. But this design provides input interface allowing the designers to manipulate the time parameter to dynamically generate many variations, rather than using other simulation environment (ECOTECT) to analysis and manipulate in complex way.

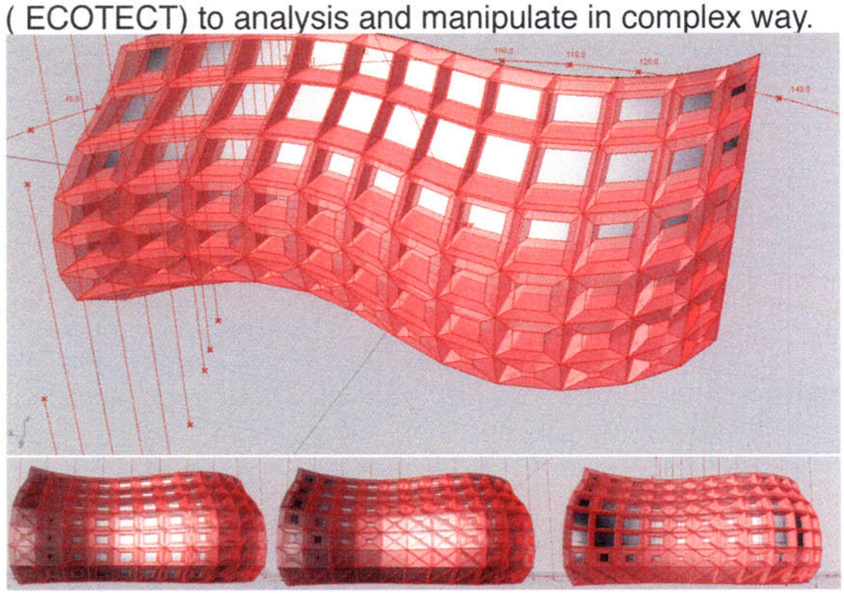


Figure 6-18 responsive brick system

6.2.3 Conclusion:

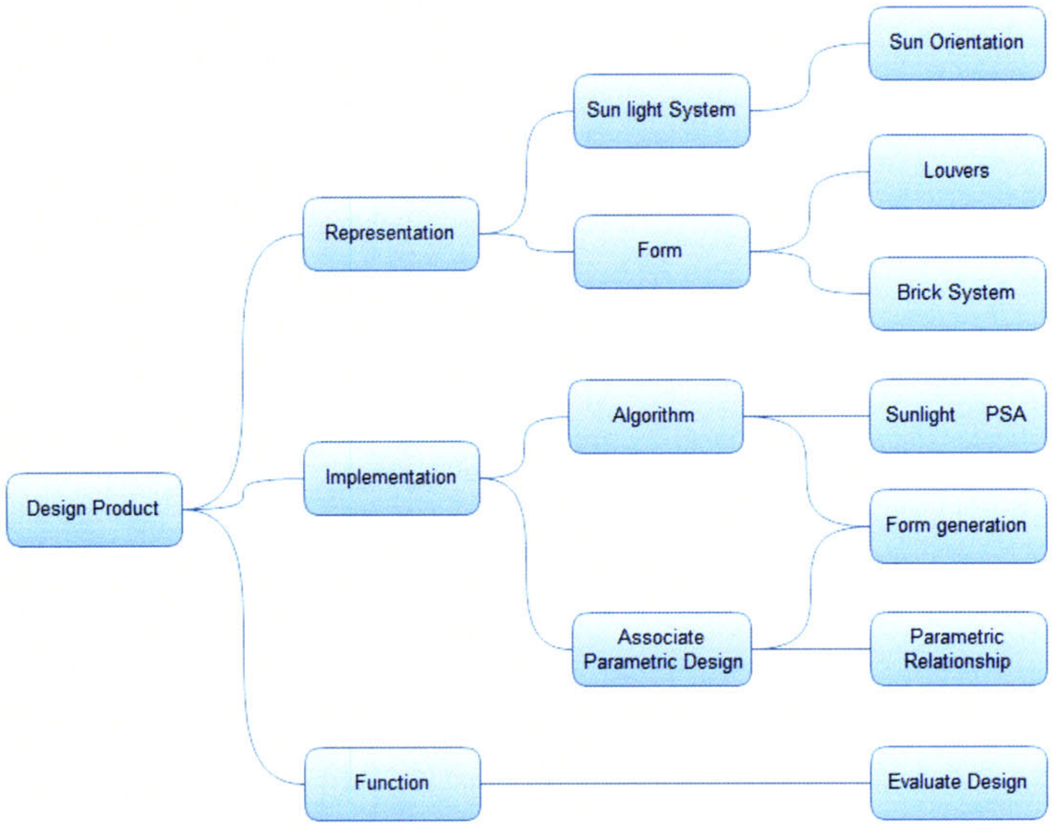


Figure 6-19 Conclusion for simulation tool- Sunlight

The notion of using simulation environment as an aid to the design process has become a prevalent driver in architectural design. The previous studies demonstrate the relationship between form and sunlight algorithm. In terms of parametric design, the use this concept becomes an aid in form findingtool in design process. The representation of sunlight system illustrates the orientation of sunlight on the basis of different input data (time, zone). This design approach attempts to help the designer to explore alternative forms and evaluate the relationship between form and sunlight by driving algorithms.

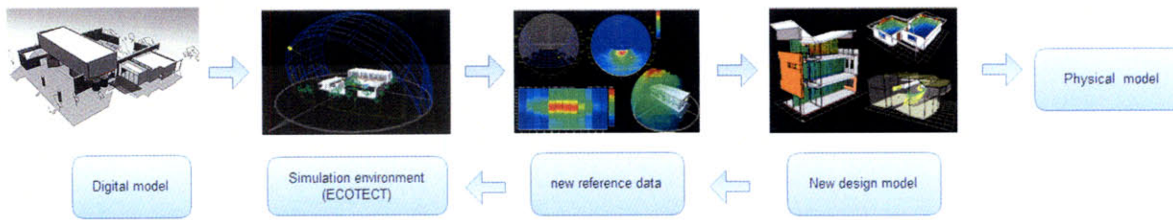


Figure 6-20 traditional simulation tool (images from http://ecotect.com/products/ecotect/gallery)

The diagram above illustrates the traditional design process by using simulation environment. In comparison, traditional simulation software offers separated software environments to study and analyze the geometry then re-import back to design software. This process makes the design become complex.

The beneficial part of using simulation environment as form finding tool is the simplicity of use and accessibility. In additional, the performance measures can be easily manipulated by the designers. While the designer manipulates simple data input interface (time, zone), the form can be generated into several variations. This strategy aims designers in the early stage of design exploration. As a form finding and design exploration tool, this kind of integrated design allows designer have more possibilities to implement to alternative design problems approaches, such as site condition, context. But the design process relies on algorithms to generate data for design input that limits its flexibility for designers.

6.3 Mechanism relationship and material properties study

Four case studies are presented in this chapter to demonstrate that the integrated parametric design usage on simulation and analysis the mechanism relationship and material properties, . In engineering, the development of simulation with perspective helps to study the mechanism relationship in order to reduce cost in fabrication. In mechanical engineering use analysis software to test friction, material properties or freedom degree. In comparison, in architectural field, architects apply this strategy in early design exploration to study component assembly process. The parametric model in these studies acts as the vehicle for the integration of the design process.

6.3.1 Tensegrity structure study

" Tensegrity is a portmanteau of tensional integrity. It refers to structures with an integrity based on a synergy between balanced tension and compression components " from http://en.wikipedia.org/wiki/Tensegrity.

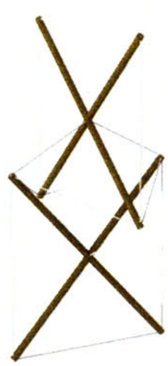


Figure 6-21 adaptive tensegrity (images from http://en.wikipedia.org/wiki/Tensegrity)

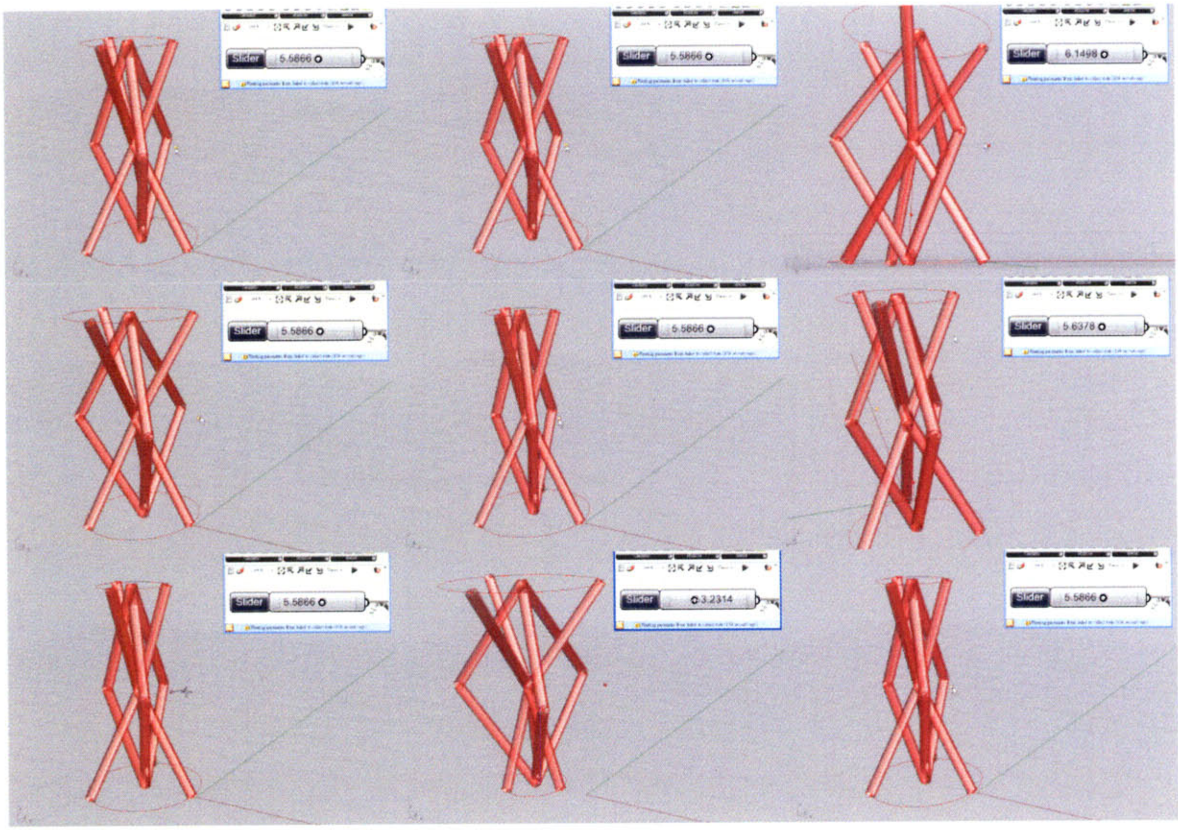


Figure 6-22 adaptive tensegrity parametric design

Above illustration demonstrates the parametric model of Tensegrity shape. The parametric model depicts how the tension and compression relationship between each component by numerically controlling the slider. While designer manipulating the slider, it influences the tension of structure, enables shape dynamic change for designer to observe and analysis variation of shapes..

6.3.2 Responsive structure

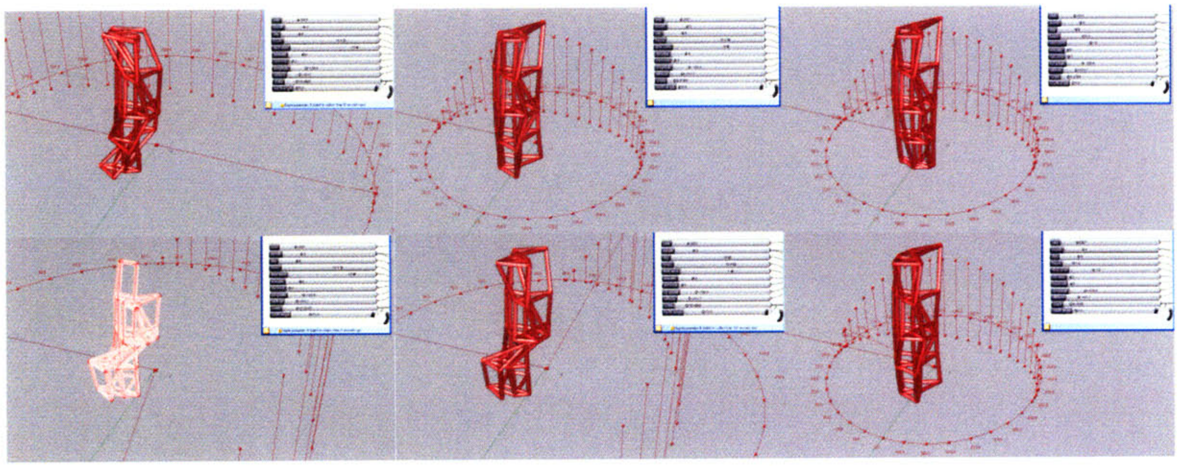


Figure 6-23 Responsive structure design

Another design study which integrates sunlight simulation and structure mechanism, illustrates the structure system automatically response the sunlight changes. The structure algorithm enables structure to connect together in horizontal level and links them to sunlight system. While sunlight position changes, the structure algorithm will dynamically update the value in order to make structure correspond the sunlight orientation change.

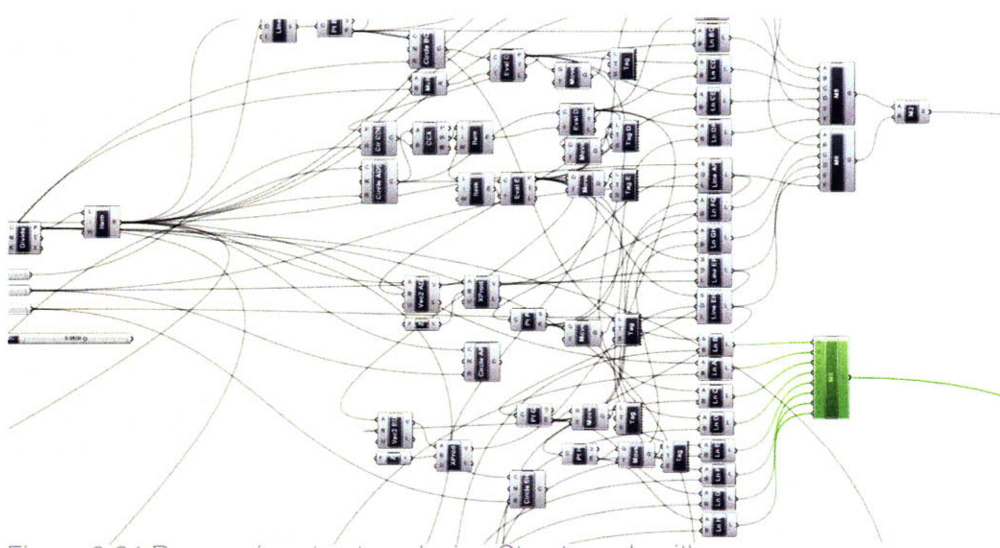


Figure 6-24 Responsive structure design-Structure algorithm

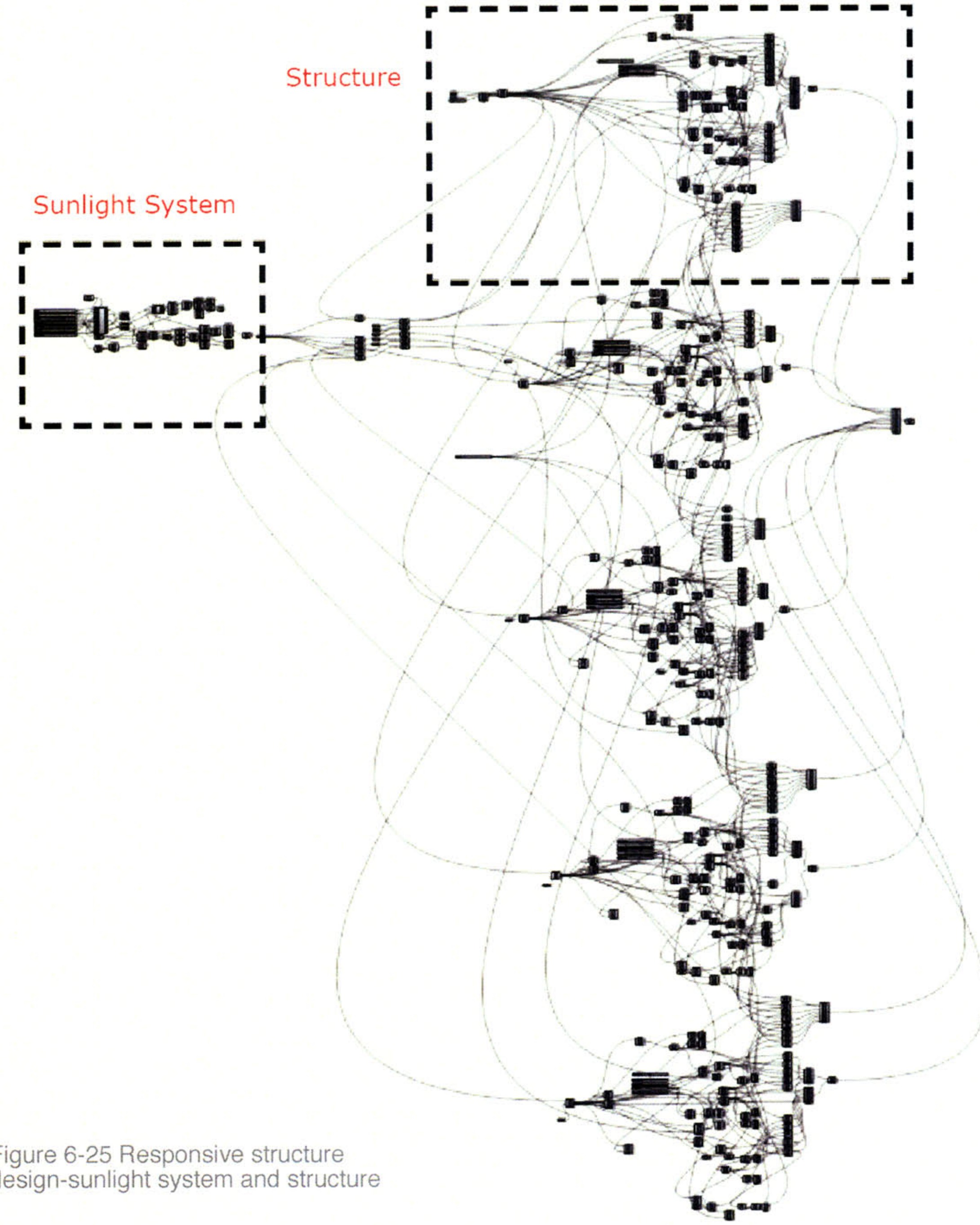


Figure 6-25 Responsive structure design-sunlight system and structure

The above diagram illustrates the parametric relationship between structure and sunlight system.

6.3.4 transform house

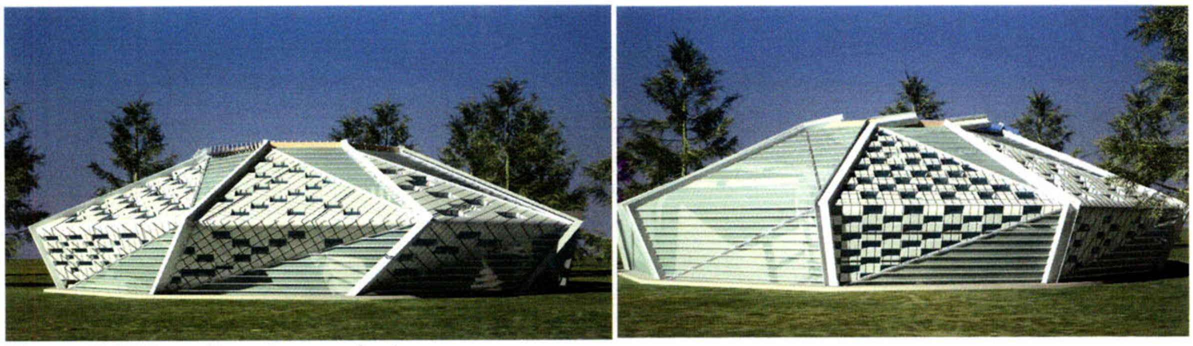


Figure 6-26 transform house design

A house could change its shape to follow the user's need. The purpose of this "transform house " design is expanding and shrinking the space but also offering different outside views for users. The kinetic structure is designed for adapting this design purpose and is able to twist. The user can enjoy different views and the house can change its shape for different conditions, such as collecting possible solar energy and follow the orientation of the sun. While there are visiting guests, the house can temporarily expand space, and after the guest left, the house can transform to its original shape. This kind of design strategy is advantageous for a small site in urban conditions, building units have to be small, so if a system could offer this kind of flexibility to users to temporarily expand space in order to satisfy the user 's different needs.

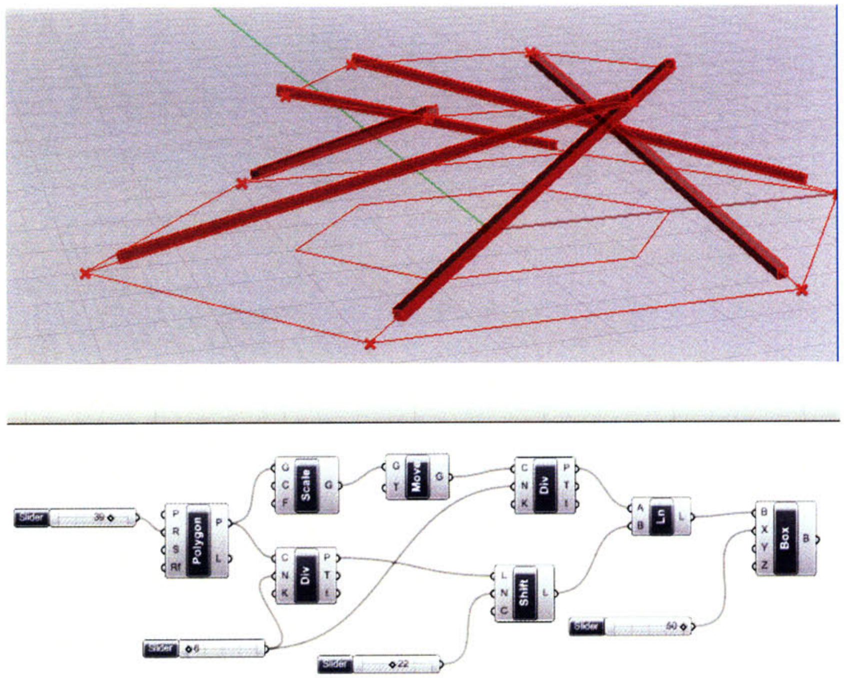


Figure 6-27 structure relationship of transform house design

The illustration above demonstrates a parametric structure study, it shows not only the relationship between shapes and structure, but also illustrates how a structure can adapt to a change of shape. While the upper shape changes , the structure can rotate to adapt to the change to maintain a stable configuration.

6.3.5 Green house and parametric brick system design.

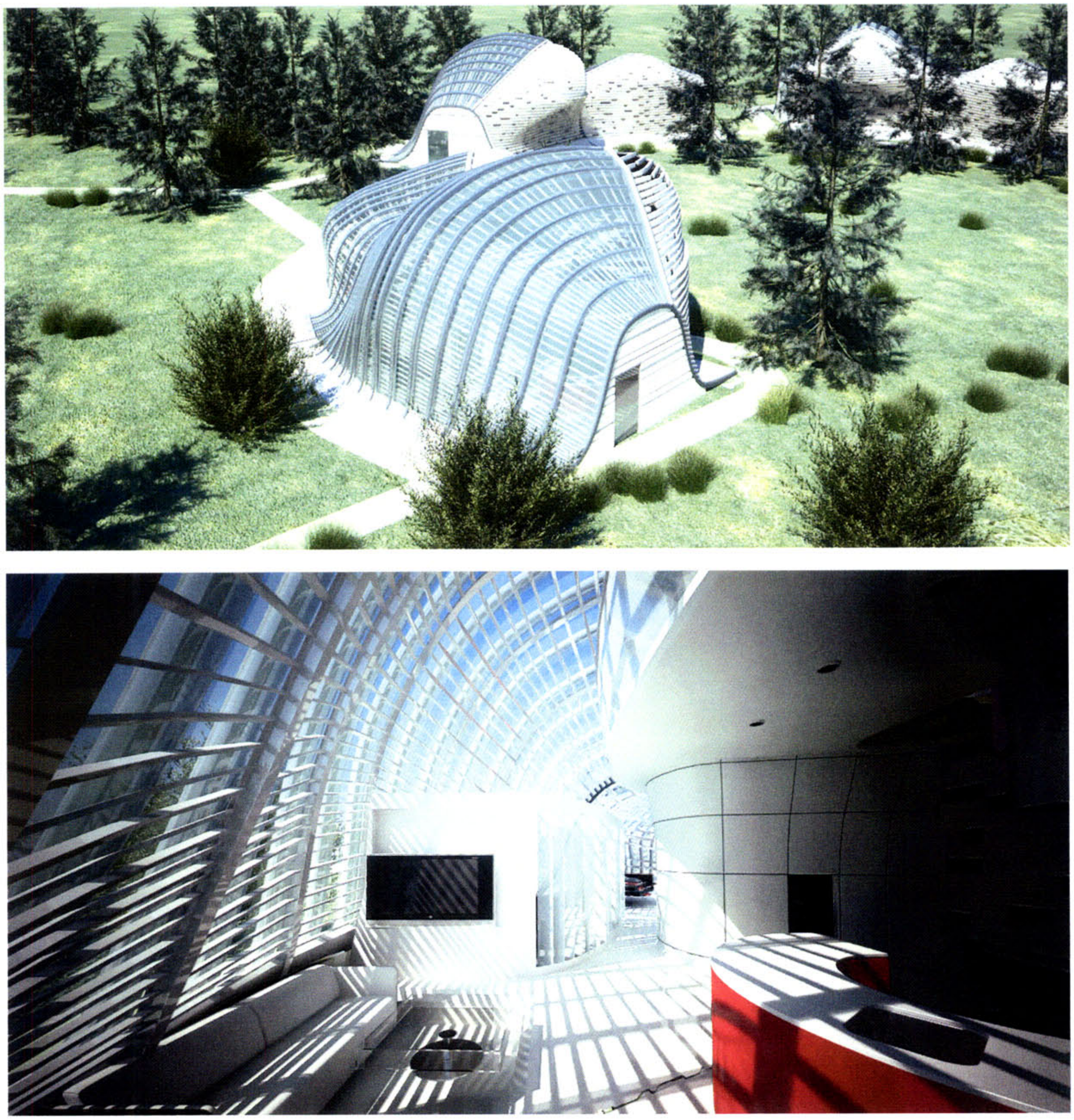


Figure 6-28 green house design (copyright owned by MIT Design Lab)

Figure 6-28 demonstrates a green house design which is designed for a family, has a living room, a kitchen, a toilet and one master bed room. The building is sufficient for young couples at design time, but in the future, when they have children , this house is not big enough for an expanded family.

Figure 6-29 below illustrates the backside design of this green house design. The back side is constructed as brick system which is designed for expansion space to fulfill the user's need, such as building a new bed room for children or expanding the living room. The illustration on the right demonstrates the parametric design for this brick system. The brick is changed and updated by the surface. Let's consider that in the future, the house is expanded, so the surface of the design will be changed, and the layout of brick system will have to follow the new change. If a new system could be pre-designed by the designer during the design development stage, it could not only benefit the user to modify the building according to their needs in the future, but also extend parametric design in a different way beyond its static form after finishing the design in software stage.

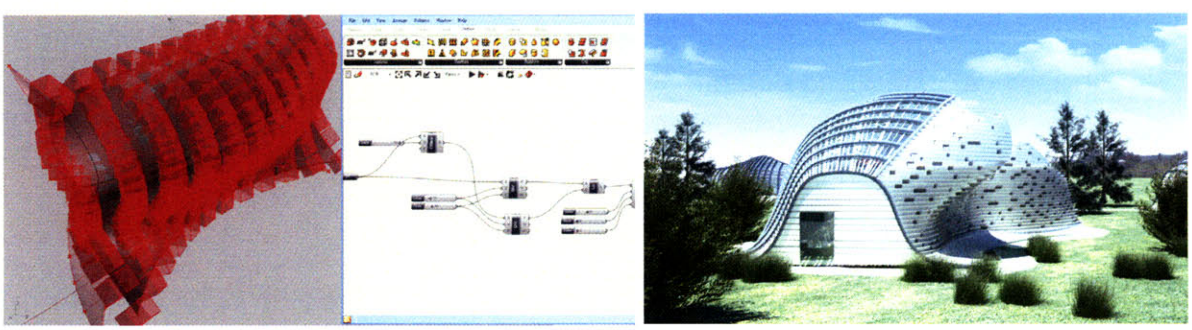


Figure 6-29 green house design (copyright owned by MIT Design Lab)

6.4 Visualization

Designing with parameters propose the possibilities of evaluating the design range of possible outcomes. The data visualization demonstrates the idea of using parametric design as a simulation platform to process sensor data and generate interactive visualization. The system is built up by two stages; one stage uses parametric design as an evaluation system; another stage generates visualization. This research is much similar as agent base or export system approach which is used in software engineering to test components and different behavior model, such as influenced by different use behavior. This research was my contribution for design without boundary class in 2009 spring term

The design process

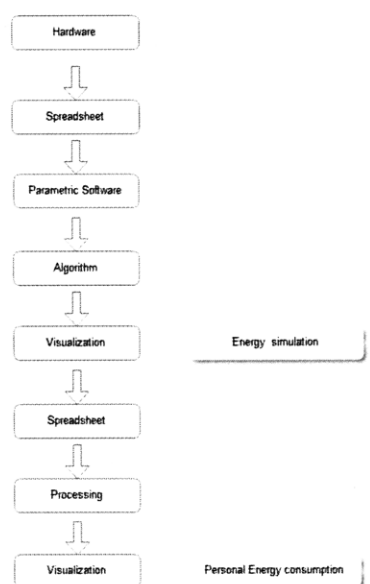


Figure 6-30 visualization design process

Hardware:

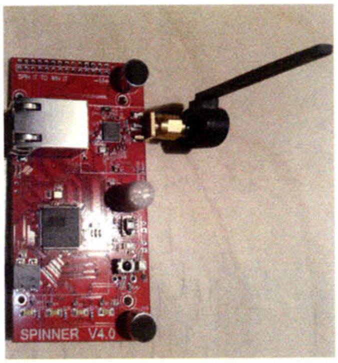


Figure 6-31 Spinner images and text from http://www.media.mit.edu/resenv/spinner/introduction.html

" Spinner is a novel sensor network system designed to detect and capture fragmented events of human behavior that can be collected and sequenced into a cohesive narrative that conveys a larger overall meaning. The network will be comprised of wearable sensors, environmental sensors, and video sensors that can identify and record events that fit specific narratives. Alternatively, the system can capture all events along with narrative meta-data for cataloging and browsing. " (images and text from http://www.media.mit.edu/resenv/spinner/introduction.html), This part is not related to my research , so I won't addressed too much

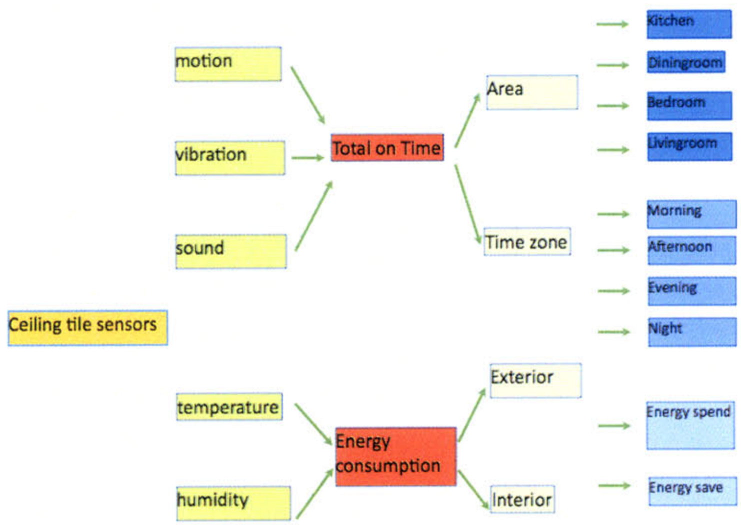


Figure 6-32 sensor data calibration

The sensor collects five different types data, and generates xml and spreadsheet files for other software to use. From five different sensor data, algorithm can calibrate to two different data for implementing into parametric software. Above diagram illustrates how the calibration works.

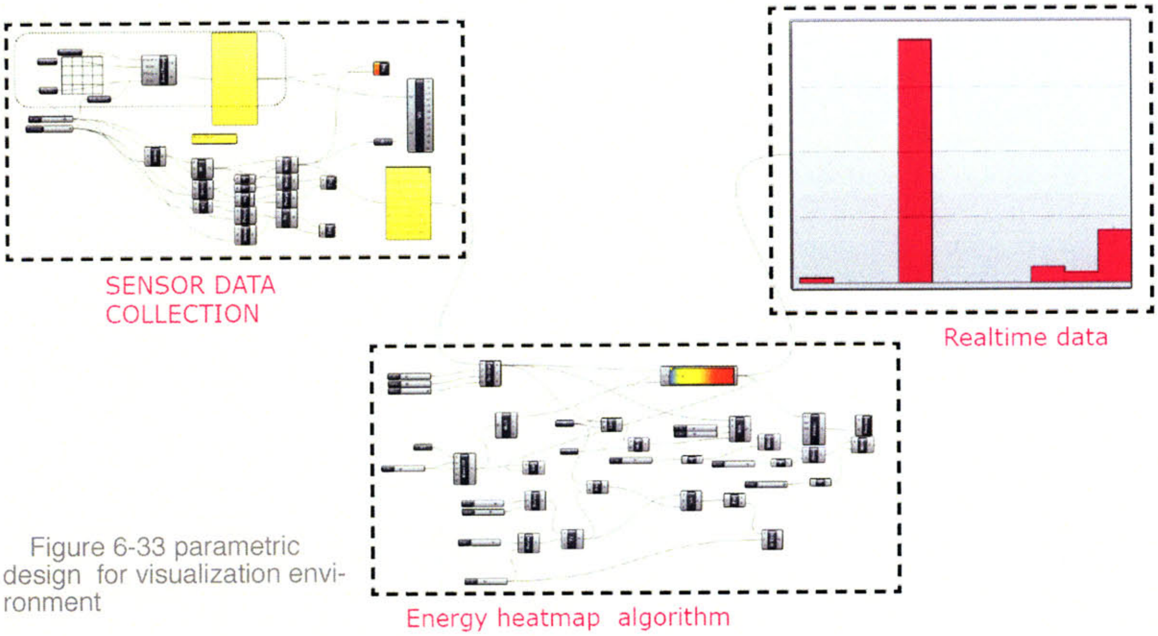


Figure 6-33 parametric design for visualization environment

The diagram illustrates parametric relationship which includes three blocks: sensor data collection, energy heat map algorithm and realtime data. The sensor data collection reads the spreadsheet data which is generated from Spinner. The energy heat map block process the sensor data numbers and use algorithm generates heatmap visual representation.

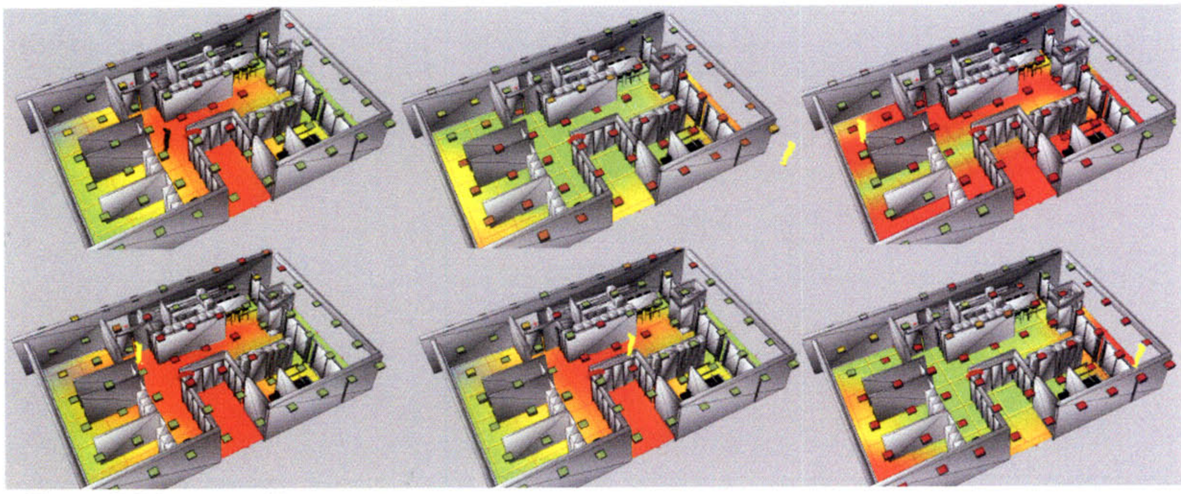


Figure 6-34 parametric design for visualization heat map

The illustration above demonstrates this heat map concept by moving human avatar to generate different realtime heatmap. The parametric algorithm is controlled by grid points which have different weights. The weight in here means different numerical accessibility which means store data and populates data from spreadsheet, and calibration. Therefore grid points aims to generate range of gradient color by calculating distance of avatar and weights of grid points.

The real time block shows the energy consumption of realtime graph. The graph not only shows the value of energy consumption in different location, but also generates data to processing software.

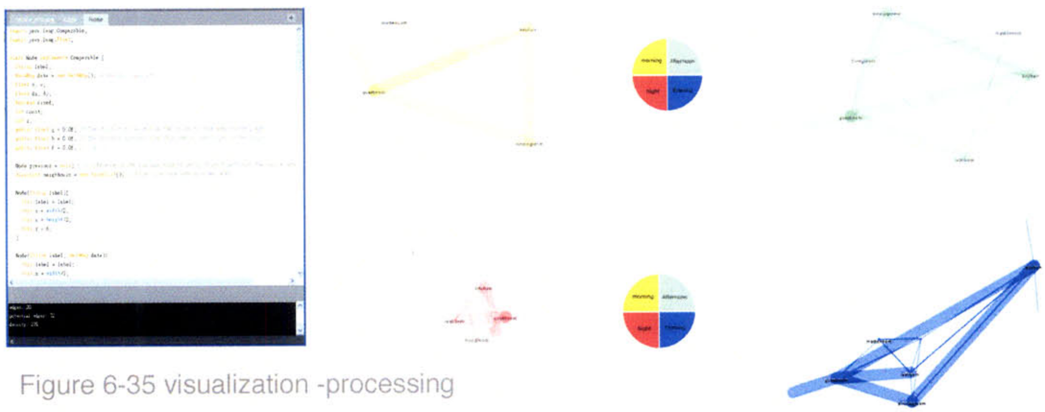


Figure 6-35 visualization -processing

The processing includes three different blocks: visualization presentation, data input (XML), data search. The visual representation shows different color, stroke, and line-width. The color means different time, such as morning-yellow; cyan-afternoon; red-evening; blue-night. The stroke demonstrates different location. The line-width shows energy consumption situation. The algorithm search the value from parametric data then populate values to the node-tree data structure(each node means different location, such as kitchen, living room, master bed room) , if node gain more value than average values, the interface represent more wide line.

This exploration of integrating multiple software aims parametric design plays an important role to analysis data and enables to expand use of parameters in different way.

The diagram demonstrates how to implement parametric variables into different application.

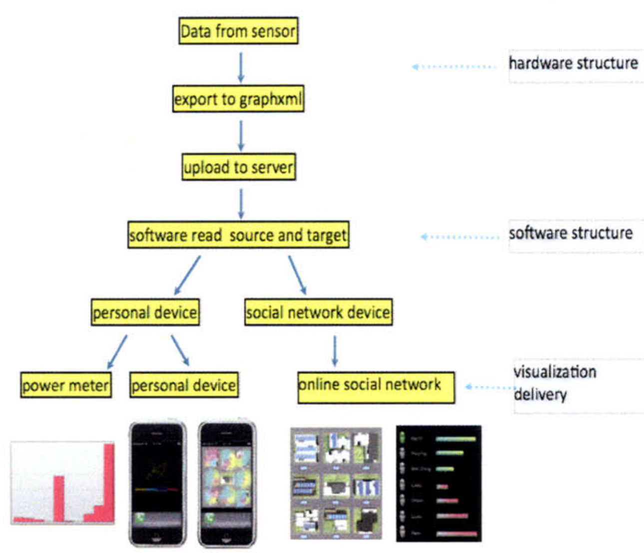


Figure 6-36 visualization -implement parametric design into different application

6.4.2 Conclusion:

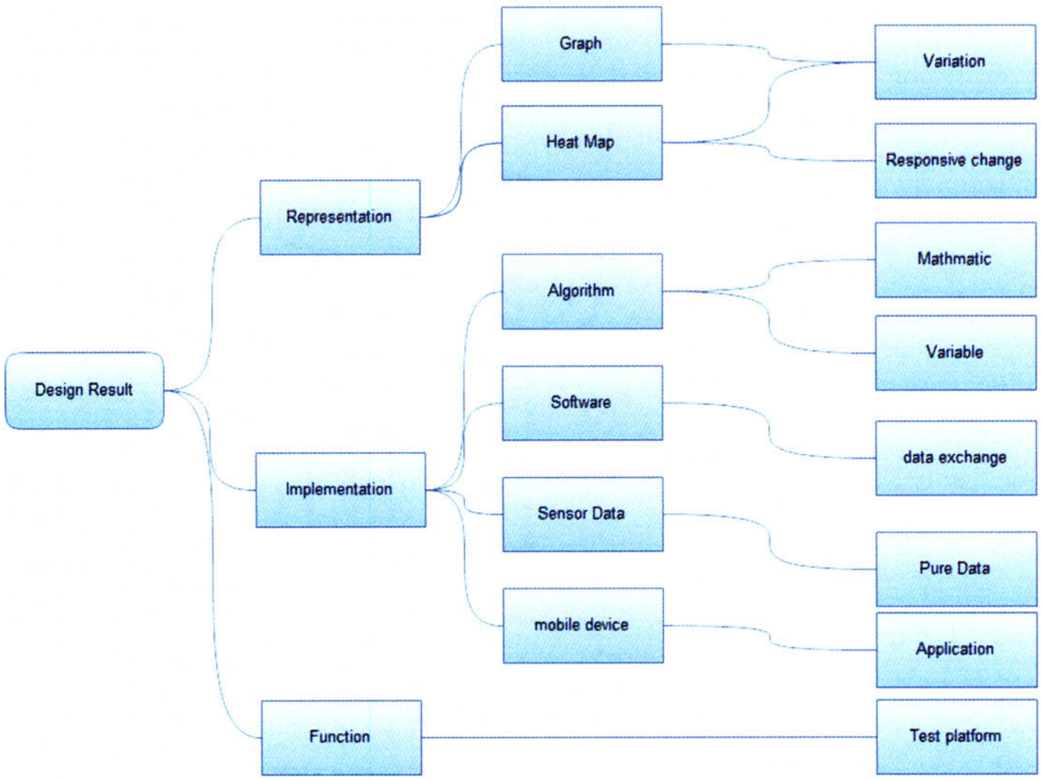
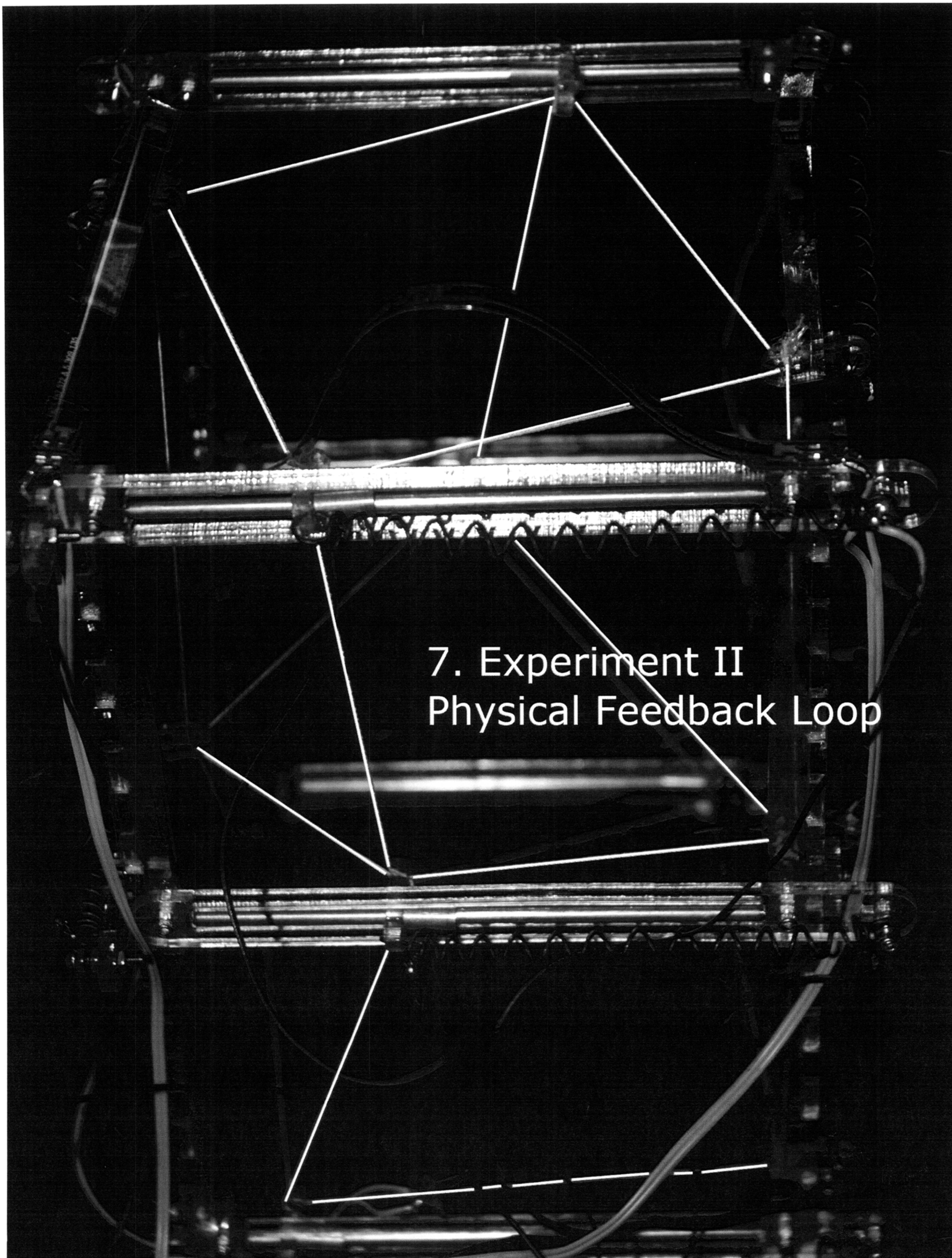


Figure 6-37 conclusion for visualization

This design strategy in this case study can be embodied in design explorers. It is important that this design strategy aims to expand the use of parametric design. It is very common in software engineering to evolve the design target to different exploration. The visual representation doesn't provide definitive answers in terms of design solutions, but provide different explorations for designers and users.



7. Experiment II
Physical Feedback Loop

7.1 Objectives

This thesis aims to introduce a design strategy which would enables parametric design not only being limited with fix constraint and variation problem but also allows designers use feedback loop system to run parametric designs as design exploration tool in earlier design process. The physical parametric design motivates the designers to start working with physical models at very early stage of design process to be able to easily testify their concept and updated their parametric result.

7.2 What is Physical Parametric Design?

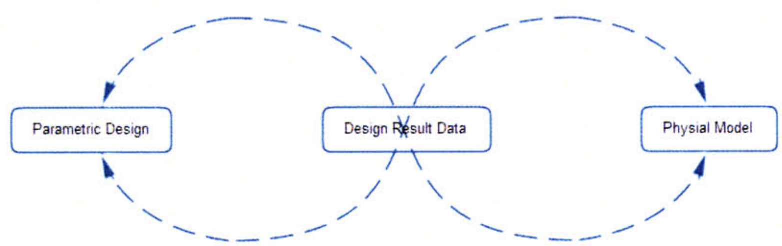
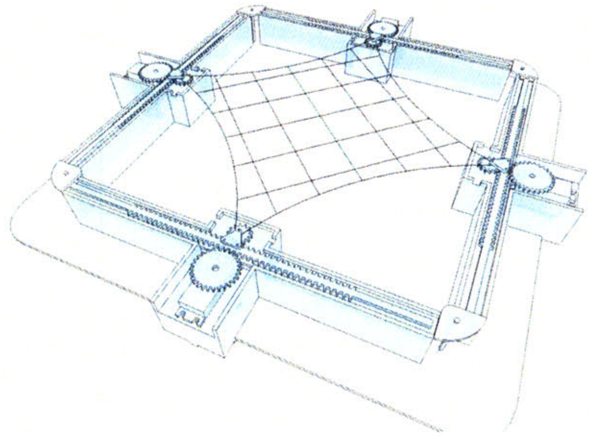


Figure 7-1 physical parametric design - relationship between physical model and parametric model

The Physical Parametric Design demonstrates the idea of a physical feedback loop design system. The Physical Parametric Design includes two stages of design process. At first stage, the physical parametric design enables designer directly manipulate parametric design and implement the design result into physical models; At second stage, the design output from physical model allows designers manually adjust the design then sensors which are embedded in the physical models will transmist positional data to update the parametric model for designers. This bi-direction design not only aims to keep variation from parametric design in physical condition, but also enables designers to observe and manipulate the design results then physically update digital parametric models. In order to implement this assumption of concept, I will use two case studies to testify this proof-concept idea.

7.3 Tension surface



This study presents a reconfigurable plan which can corresponds to parametric model. The inside surface represents a reconfigurable surface which enables to generate different configurations. The surface configuration can be dynamically changed by motors and gears driven by four different directions.

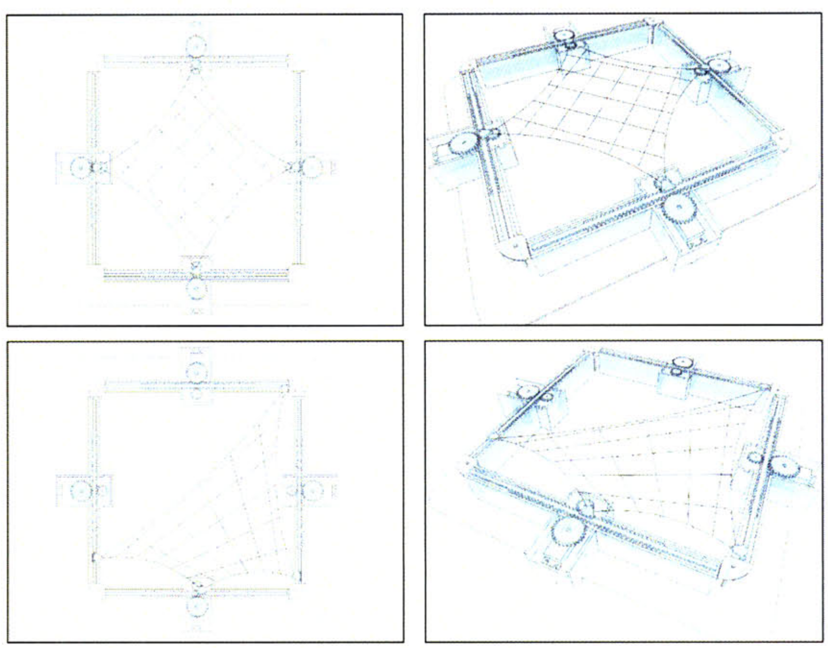


Figure 7-2 diagram of tension surface design

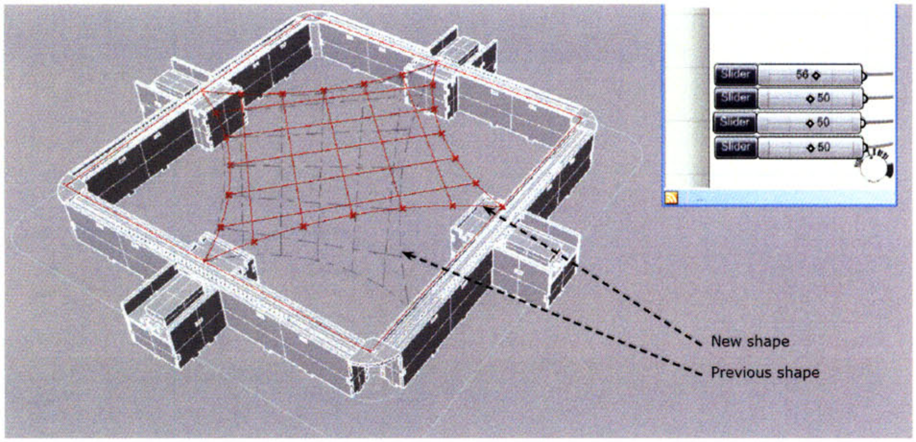


Figure 7-3 diagram of tension surface design

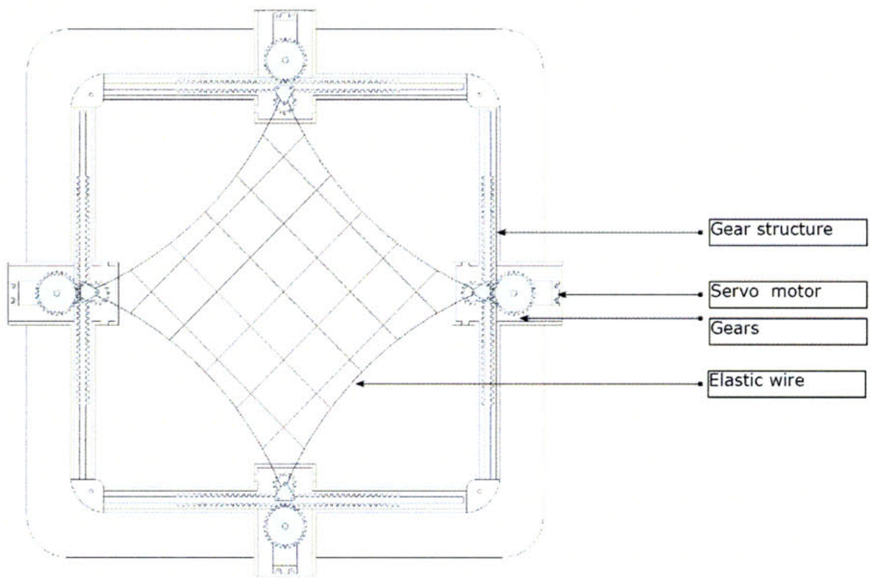


Figure 7-4 diagram of tension surface design

The system includes three different parts: parametric model, hardware body, control mechanism.The parametric model presents input interface which allows users numerically manipulate the surface configuration. The hardware body is supported by laser cut plexi glass and gears. The control mechanism is supported by four servo motors and gear structure to create two degree freedom movement.

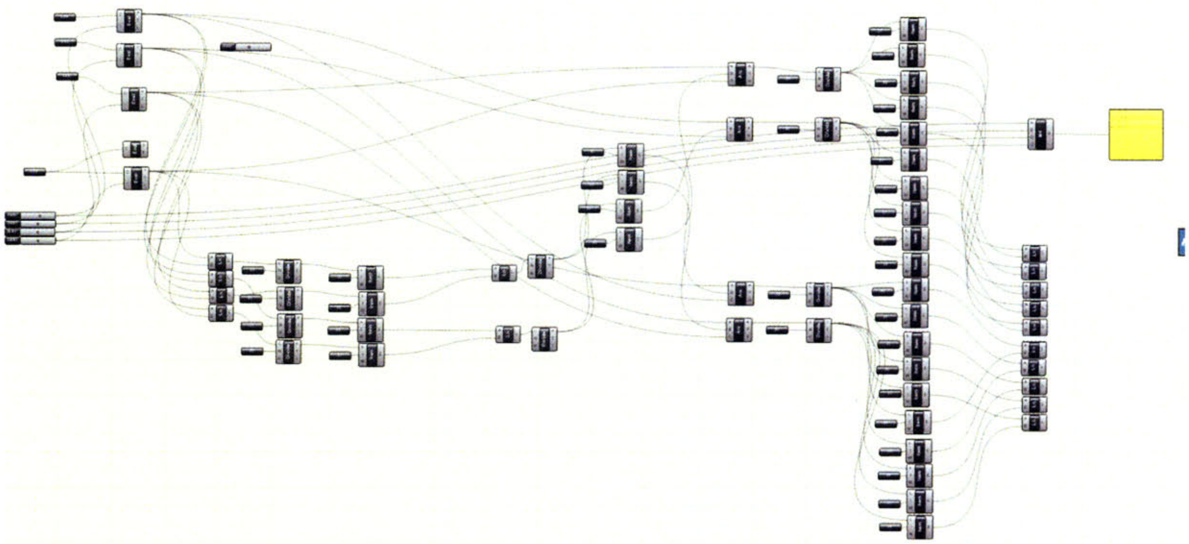


Figure 7-5 parametric design of tension surface design

The parametric model provides an input interface which allows users to numerically control different configuration. The diagram demonstrates that while designers manipulate slider bar, the parametric model will correspond the changes to update new design.

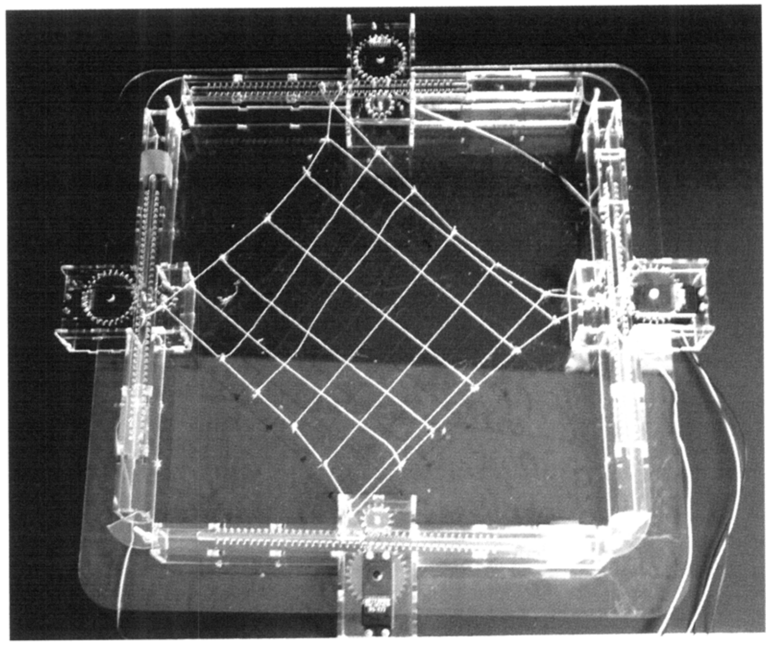


Figure 7-6 picture of tension surface design

The elastic white wire represents the reconfigurable surface which is set up the same as parametric model. The hardware body embeds servo motor and gear structure in each side which links to surface, enables the surface can be controlled through motorized gear structure to get desirable shapes. The implications for surface design and fabrication are that a possible approach to control complex geometry.

The diagram shows the surface movement driven by motors

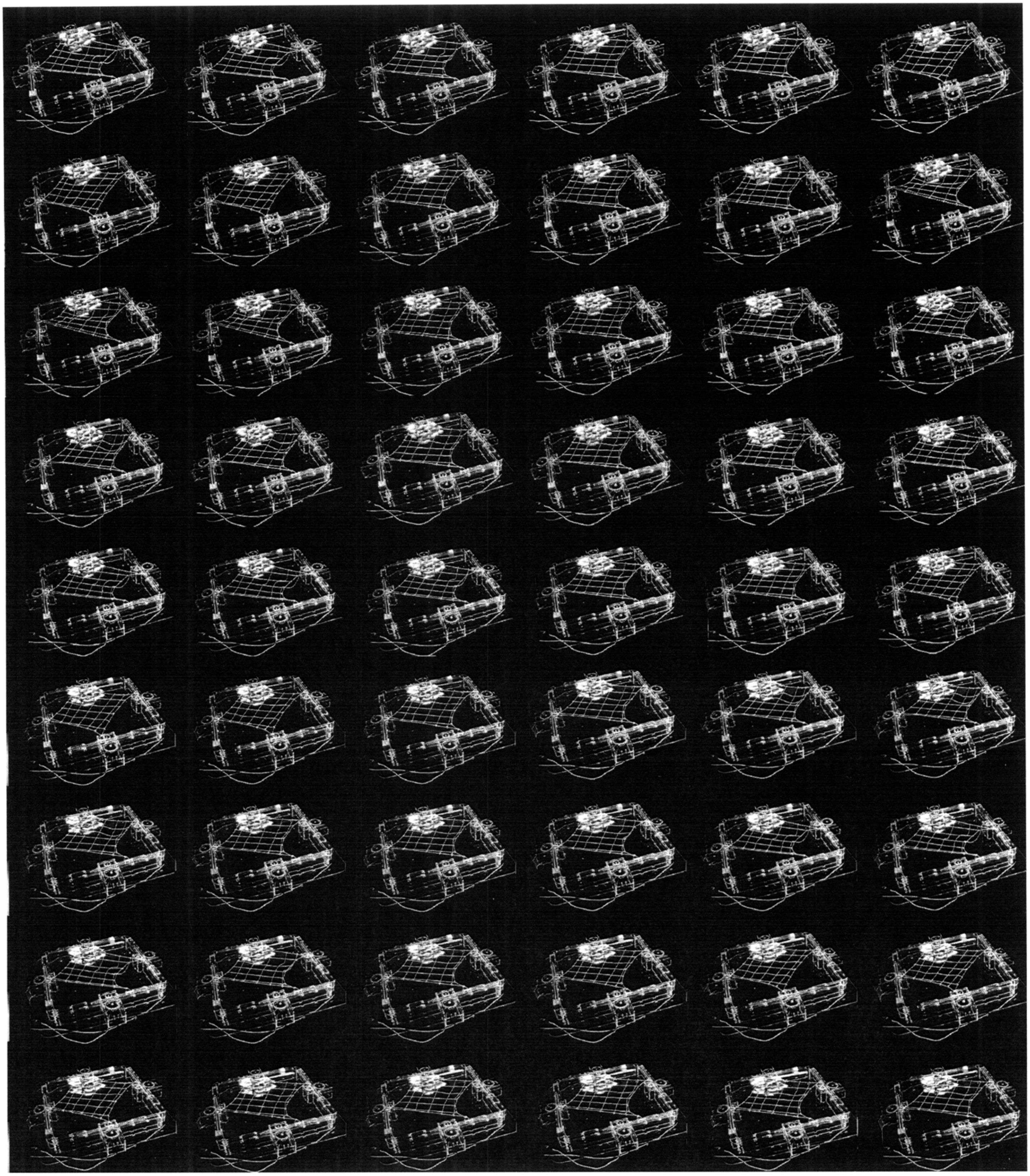


Figure 7-7 surface movement of tension surface design

7.4 TowerMaker- modeling with physical feedback loops

make sweeped geometries digitally and physically with this interactive model

7..4.1 System Design

The system is supported with parametric software, sensor, and physical mechanism control system. The system aims to enable parametric design to generate design results on physical model therefore enables sensor system to transfer back position data to update parametric model.

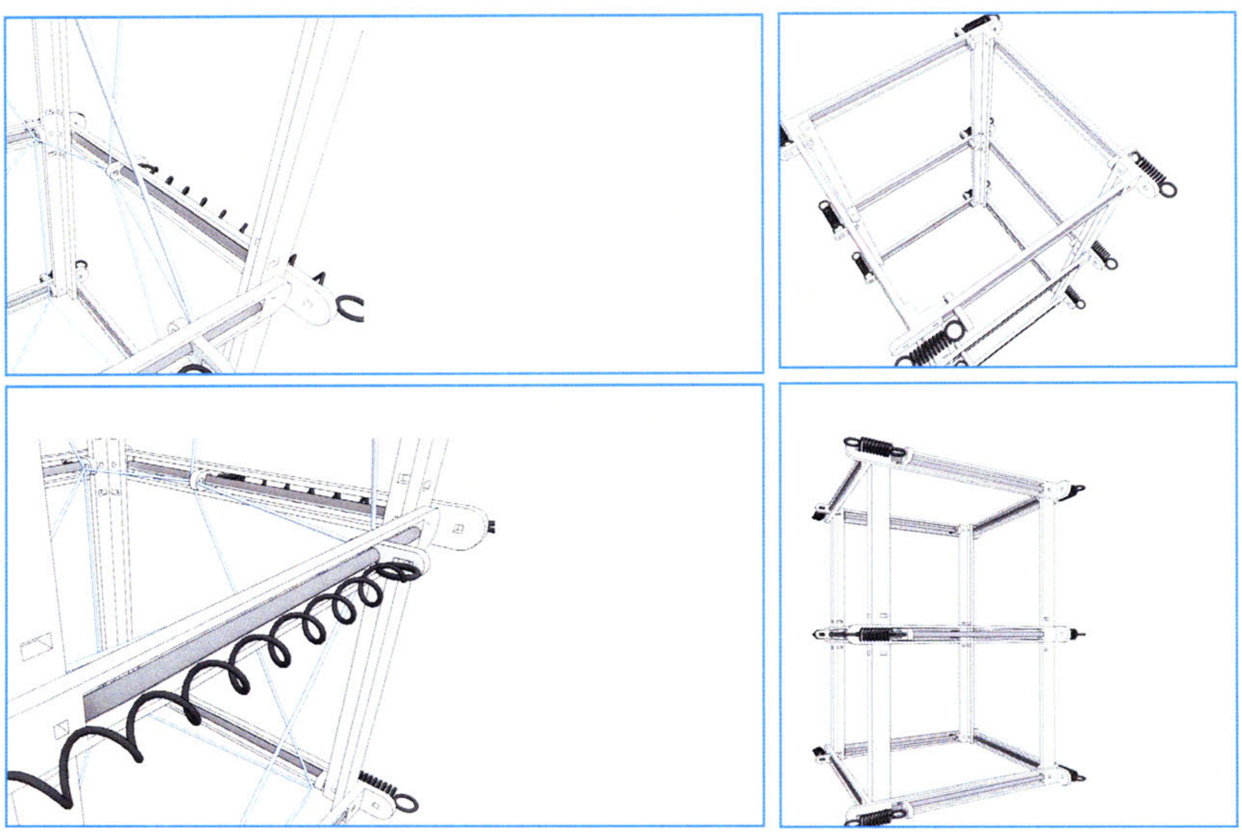


Figure 7-8 TowerMaker design

7.4.2 WorkFlow

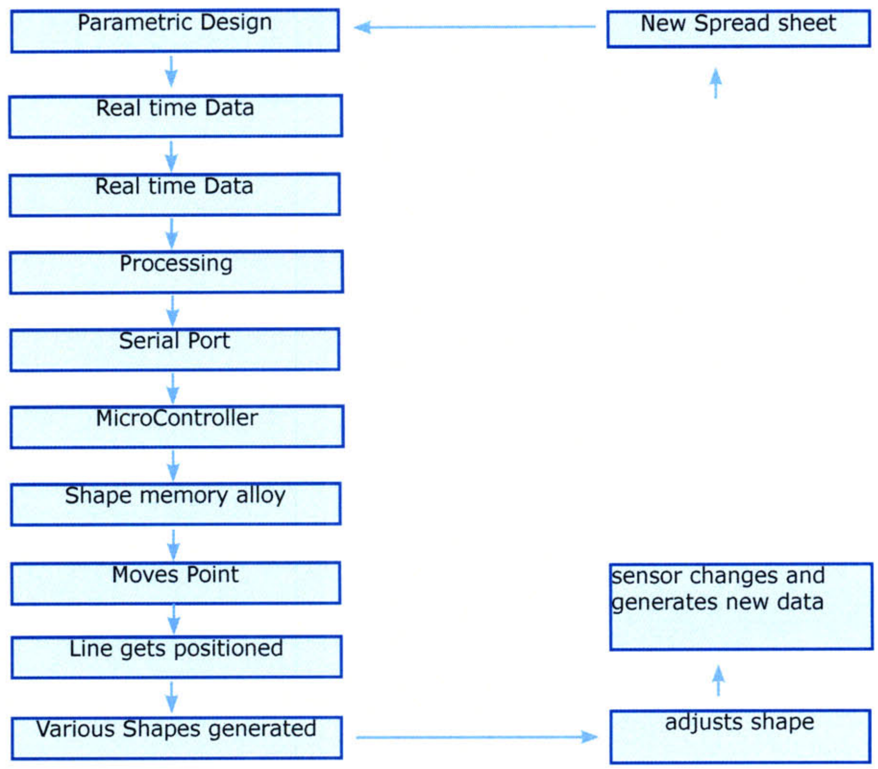
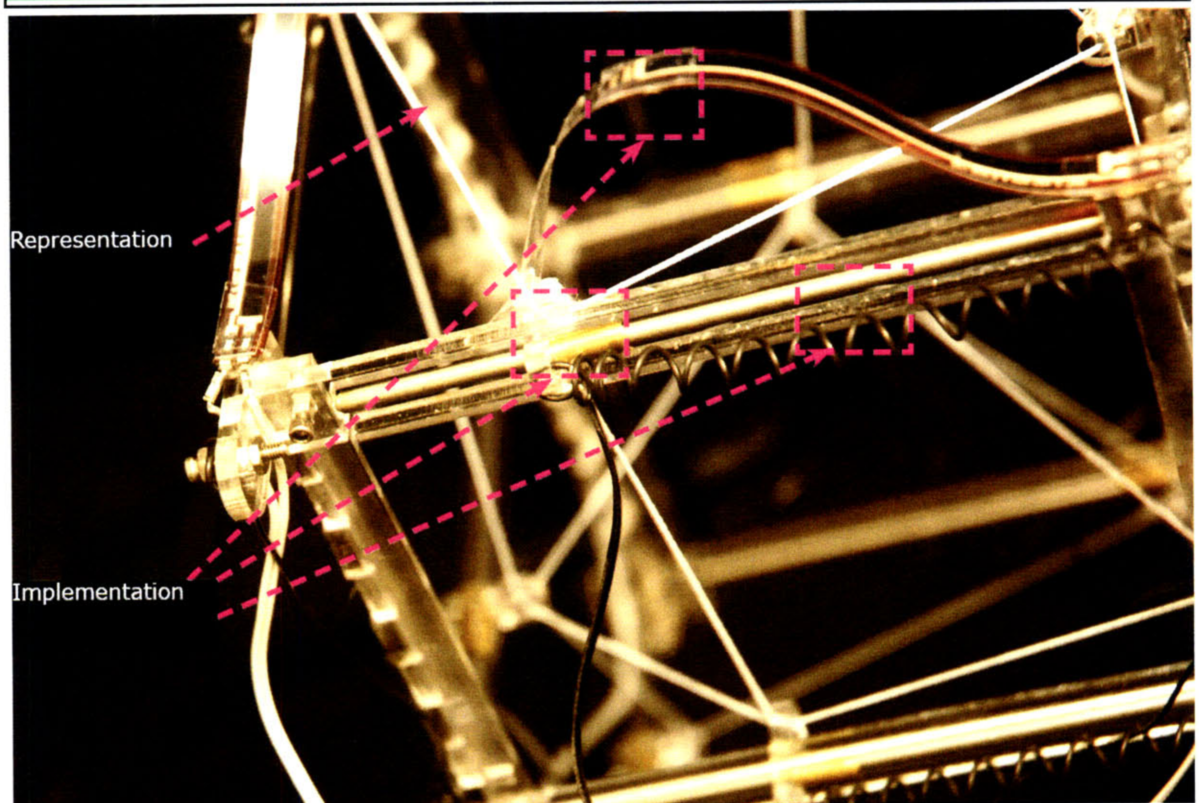


Figure 7-9 TowerMaker design workflow

The Physical Parametric design demonstrates the idea of a physical feedback loop design system, enabling designer directly manipulate parametric design and implement the design result into physical model, then the design output still allows designer manually adjust the design from physical model. In additional, the sensor in the physical model will also send data from physical model to update the parametric design model.

7.4.3 Representation and Implementation



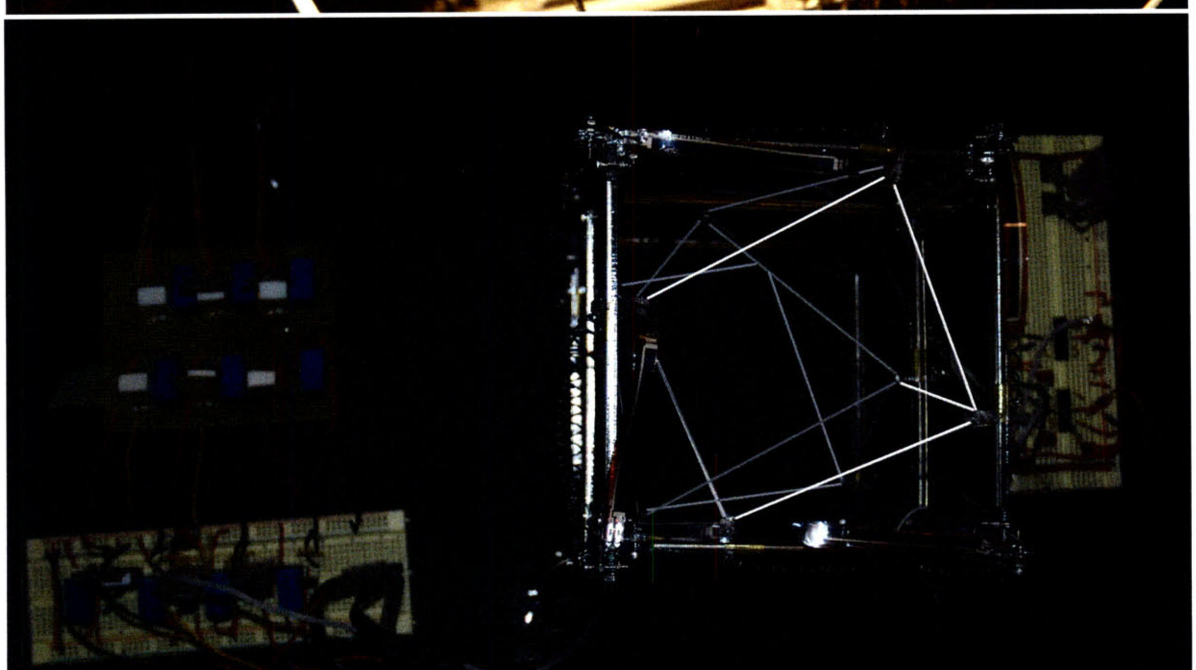


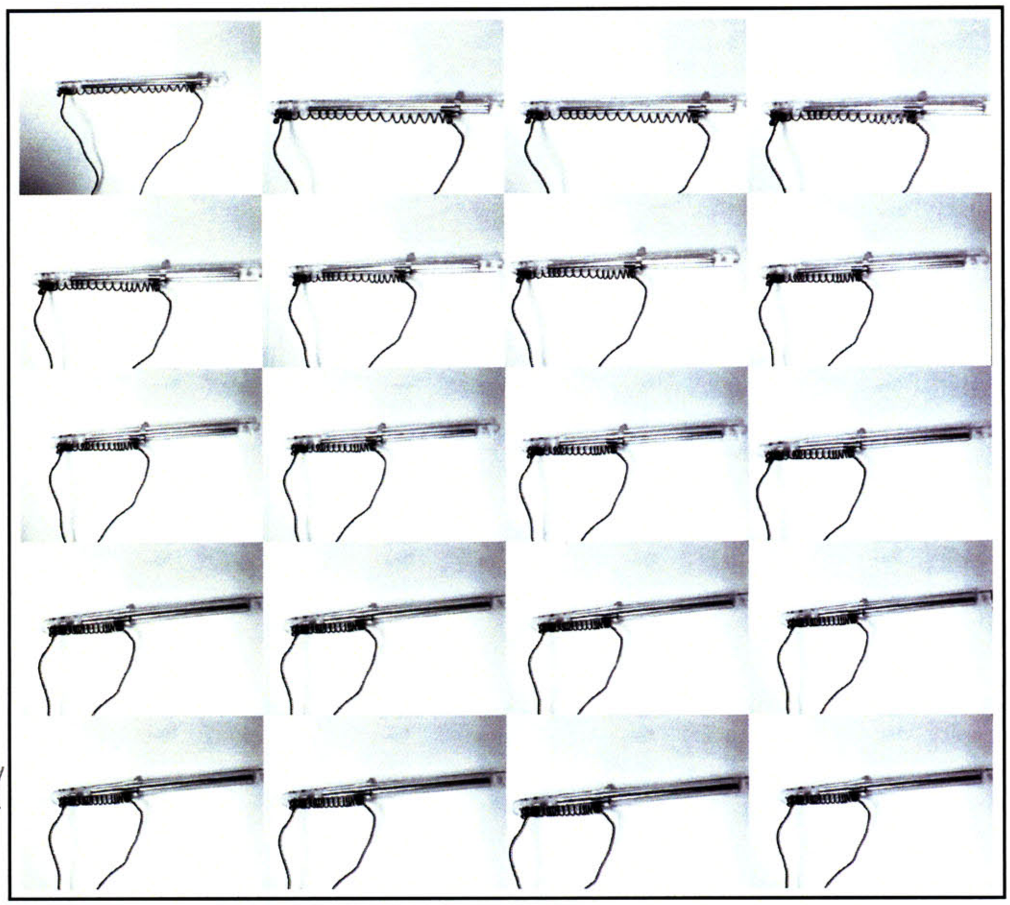
Figure 7-10 TowerMaker design representation and Implementation

7.4.4 Design implementation

(1) Shape memory alloy

In order to implement this proof-concept, the system needs good mechanism to activate. The mechanism system is carried out by springs made from shape memory alloy (SMA). While send enough current by microcontroller, the metal demonstrates muscle-like behaviors by shrinking.

Figure 7-11
The diagram shows various length movement control by microcontroller.



The diagram shows various length movement control by microcontroller.

Movement condition

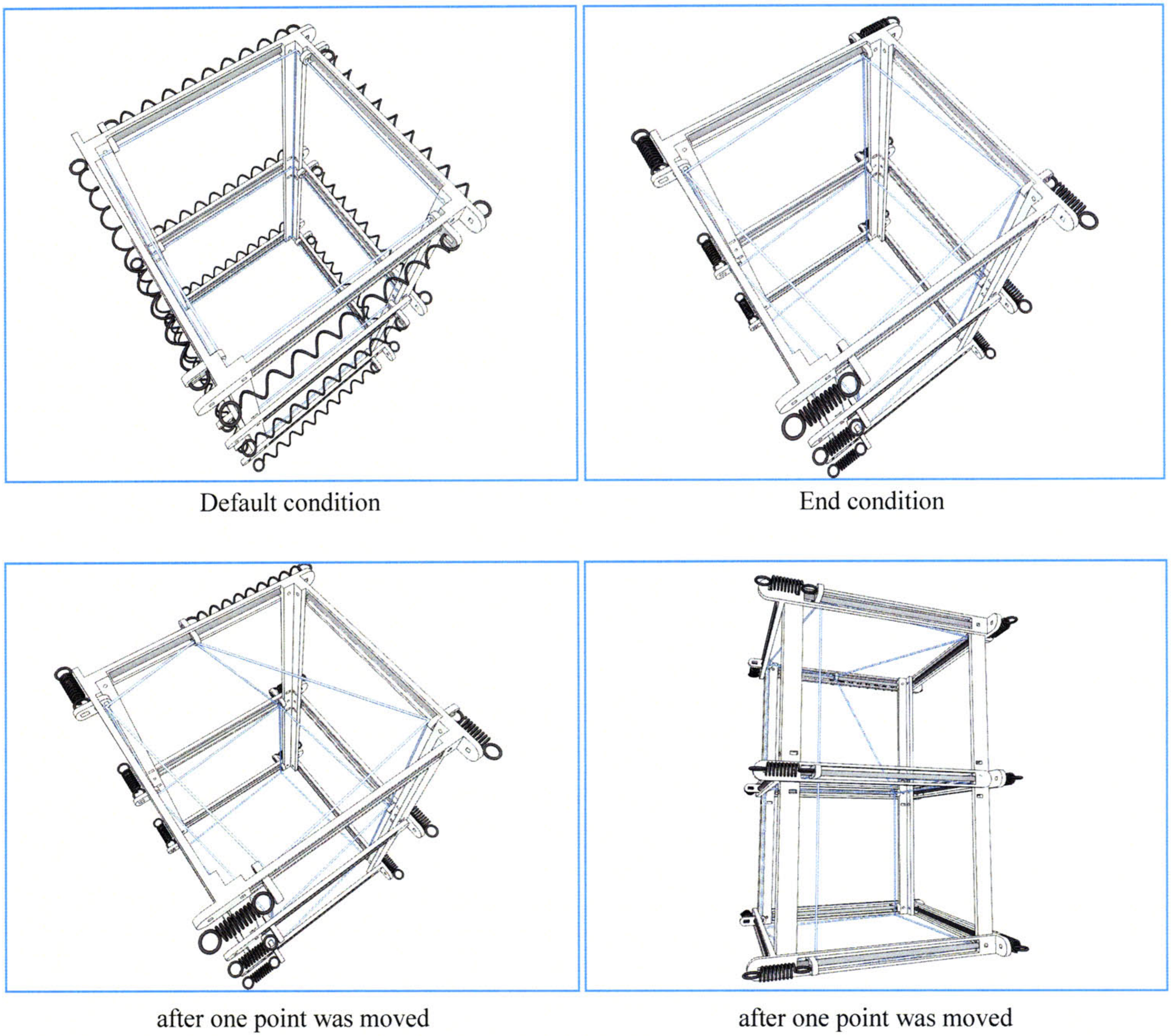


Figure 7-12 Movement condition diagram

(2) Microcontroler

The physical computing platform Arduino (http://www.arduino.cc/) plays an important role to send correct signals to activate SMA springs.

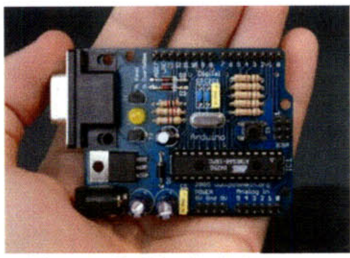


Figure 7-13 Arduino (http://www.arduino.cc/)

"Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments " images and text from http://www.arduino.cc/

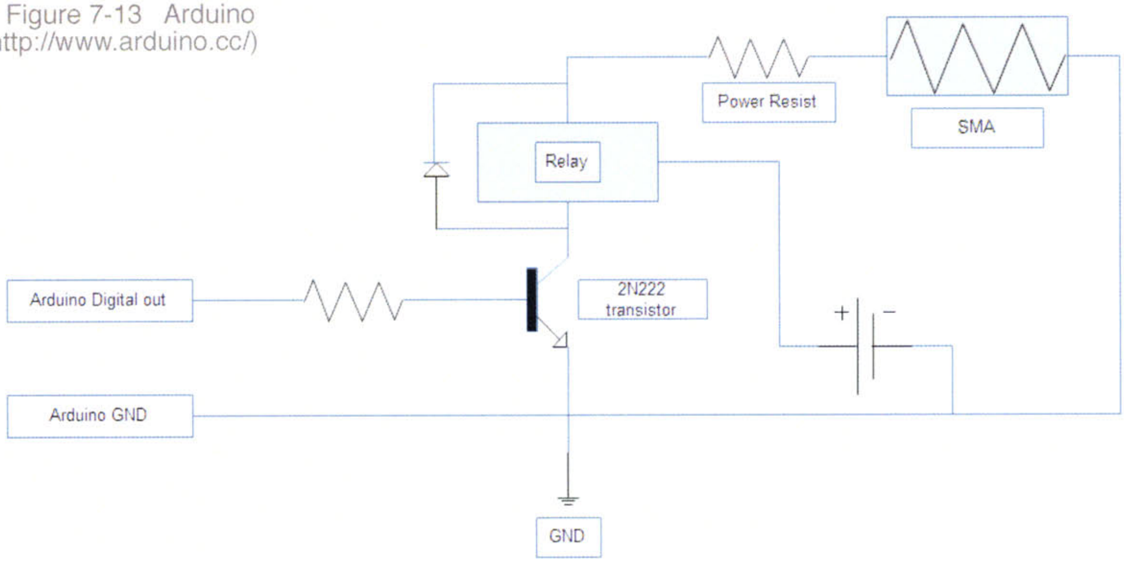


Figure 7-14 control circuim of SMA springs

Above circuit diagram shows one module of control system. AS the arduino can't support enough current, the output pins use Darlington transistors which act as switches and connect to relay to provide enough 3A current. Power resistors with a restance of 0.56 ohm are connected from relay to SMA springs to regulate the voltage drop across the SMA springs. When Arduino sends signals to activate SMA springs in certain time, spring will quickly shrink. The total time for a 120mm spring shrinks to 30mm takes 7500 micro seconds. While Arduino stops sending signals, the spring will maintain its length. By using this strategy, software can control the approximate desired length.

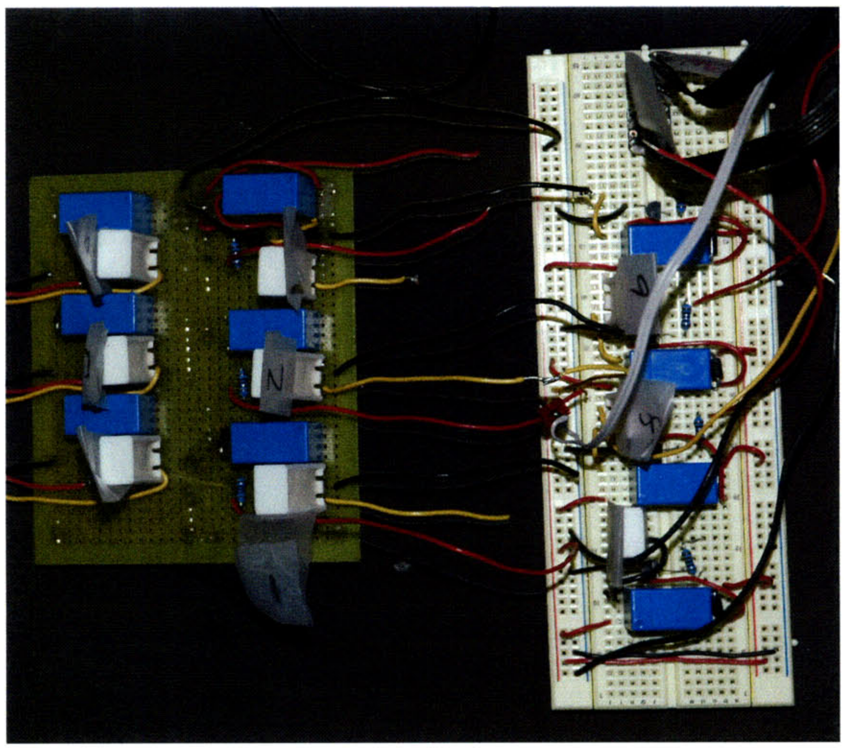
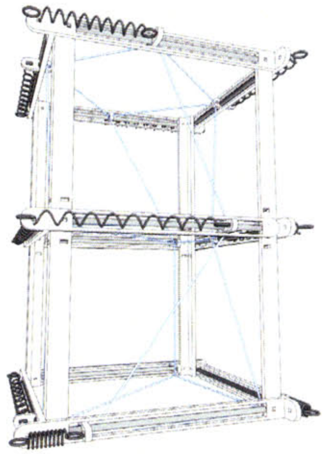


Figure 7-15 10 module of control circuim forSMA springs

(3) Mechanism structure design



In order to implement the idea of generating different polygon, the outside structure plays an important role to enable to control the inside line to generate different variations from parametric design model.

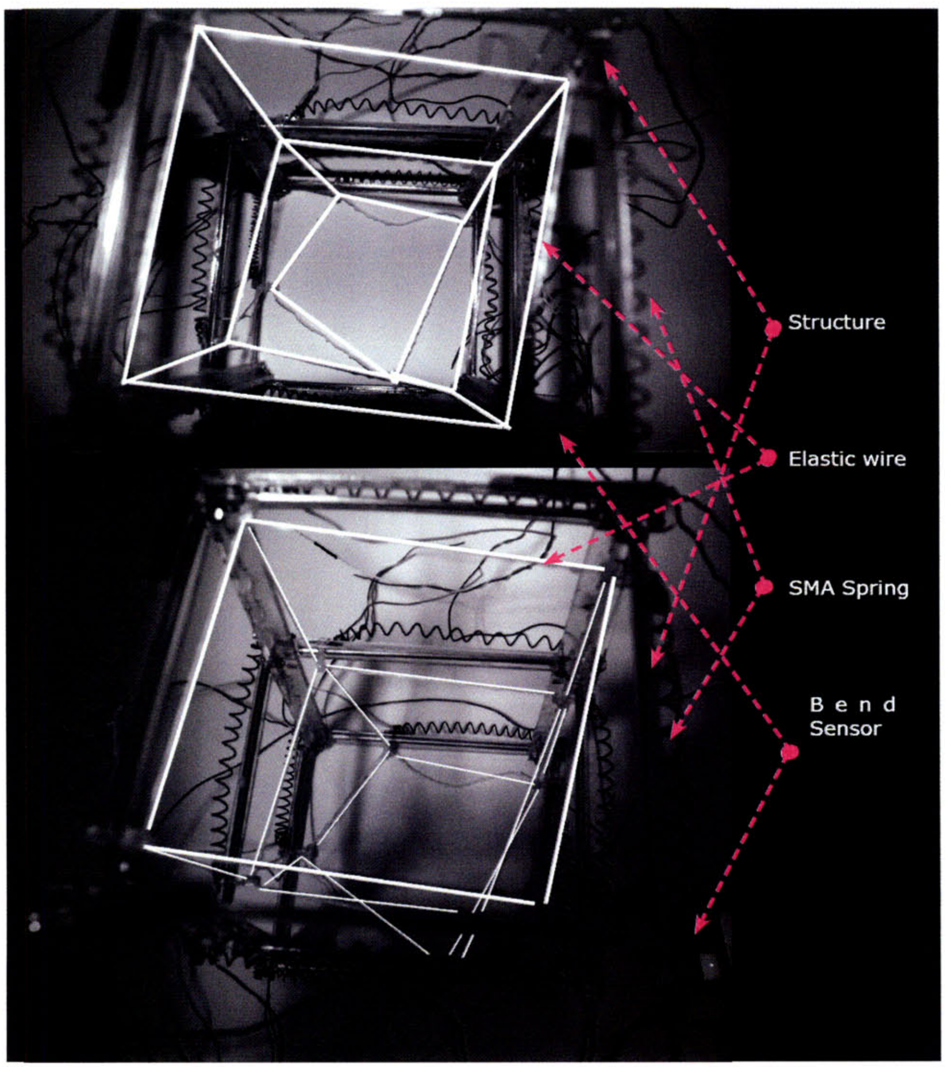
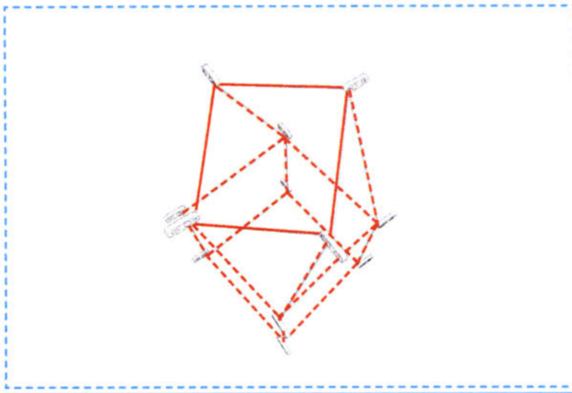
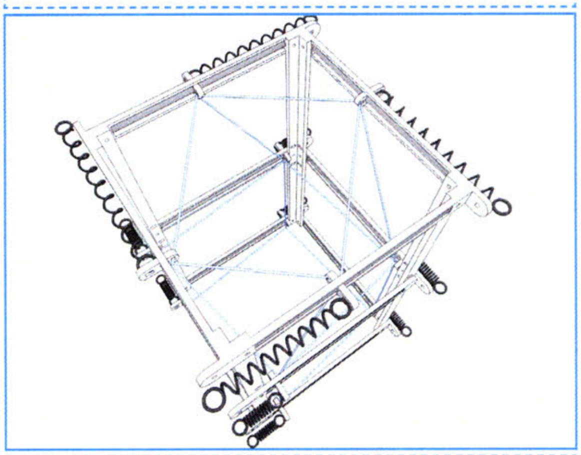
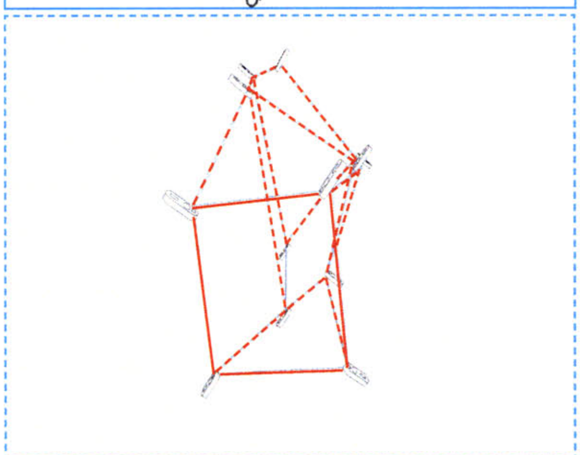
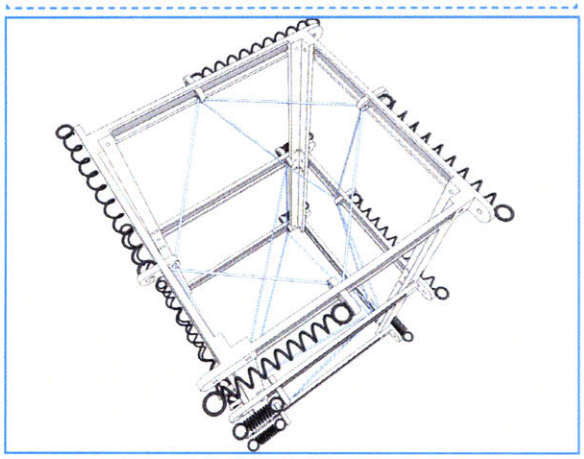


Figure 7-16
Structure mechanism









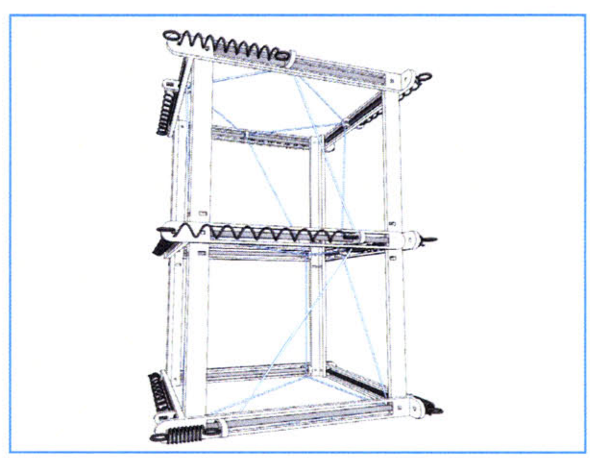


Figure 7-17 Mechanism and representation generation diagram

In order to generate complex geometry, the structure can also move vertically. This mechanism design strategy enables inside geomentry have different representation

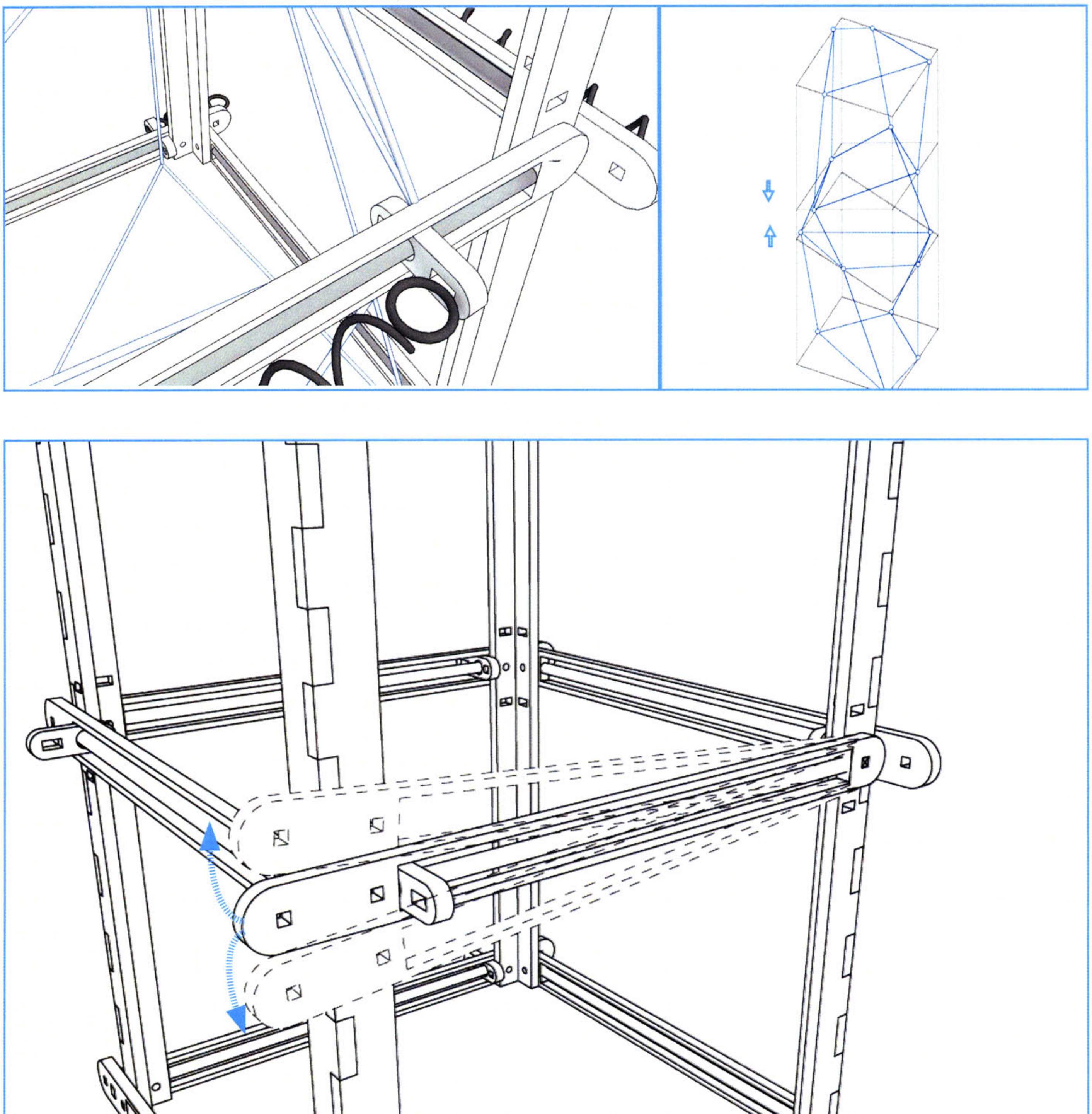


Figure 7-18 Mechanism and design diagram

(4) Position sensor

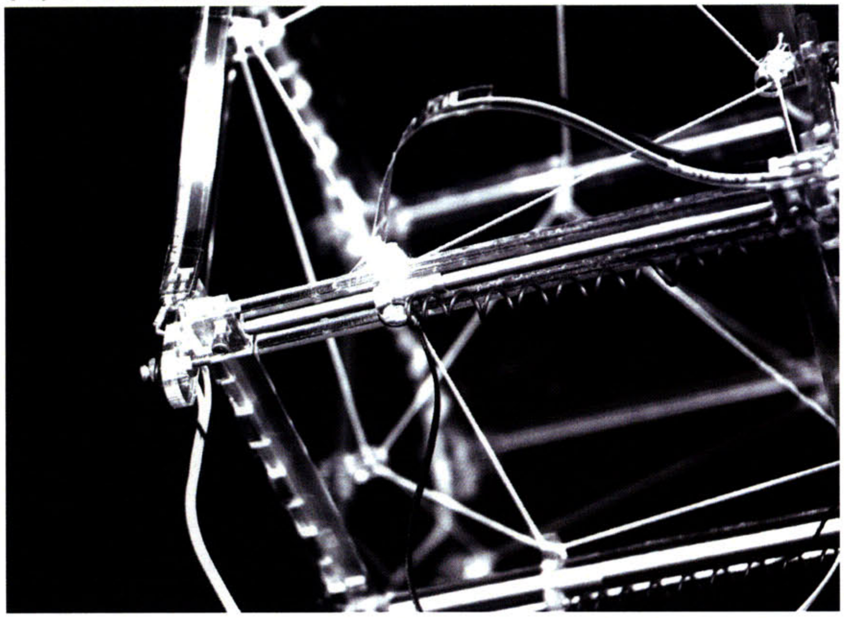


Figure 7-19 picture of bend sensor

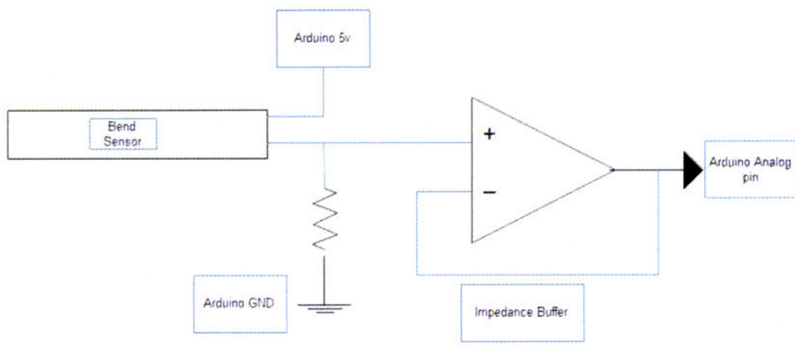


Figure 7-20 bend sensor circuit

Flex sensor is used as positional sensor which changes its resistance depending on the bending condition. The circuit aims bend sensor convert the electrical resistance for Arduino to read as voltage change. While more bending, the resistance raise. The sensor data also generates with noise signals, makes data not be clear. In order to solve the problem, I use low bias operational amplifier to filter the data. By using this properties of bend sensor, sensor data can be dynamically read into computer when designers manipulate the model, changes the length of control points.

The illustrations shows how the sensor connect to computer and transfer data to computer

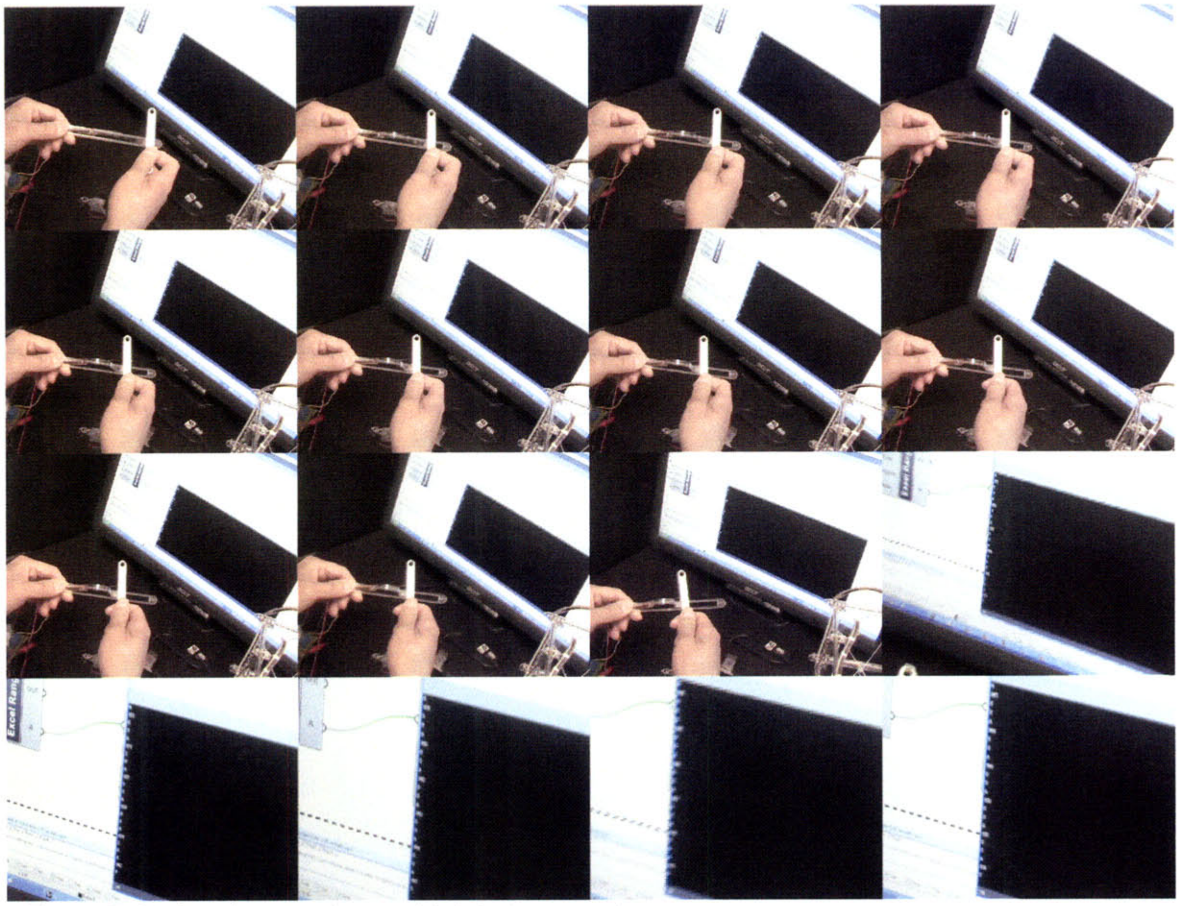


Figure 7-21 bend sensor transmist data to computer

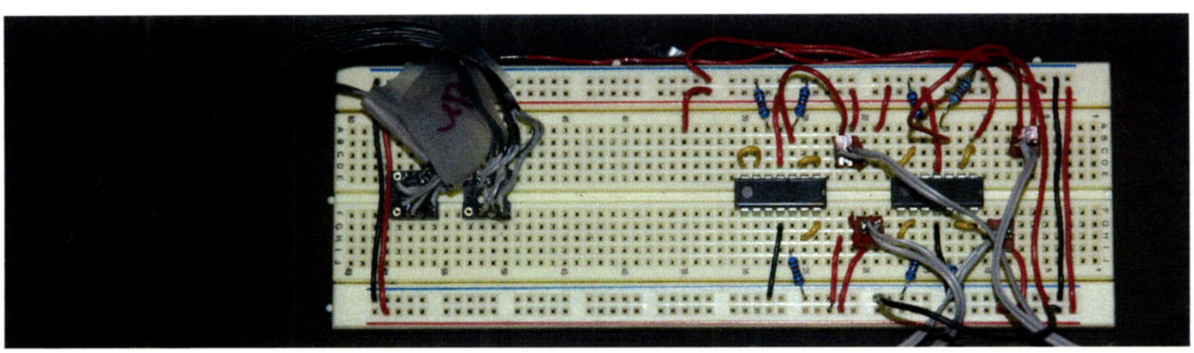


Figure 7-22 The picture shows the twelve bend sensor module

(5) Software -Parametric design

The fix constraint for parametric design is still a problematic approach. The parametric design software is powerful as a design exploration tool in earlier stage that allows designers numerically manipulate different numbers and generates different forms. But while designers try to change the design or give different numerical input, the parametric model will broke parts.

Unlike traditional parametric design only can linearly create model from beining data source. The physical parametric design embeds feedback loop aims design exploration process. In order to enable parametric model to have feedback loop and the system not being broken, the parametric design system includes three blocks: Data input, algorithm and data export. The data input block aims parametric design to read parameters from spreadsheet which is generated by sensor or the interface allows designers to numerically manipulate. The algorithm block aims parametric model to present the 3d geometry in rhino. The data output block aims to export spreadsheet after finish the design in parametric software for Arduino to read the data and present the design on physical models.

This diagram illustrates the data structure relationship of designer input , data export , and input data from sensor.

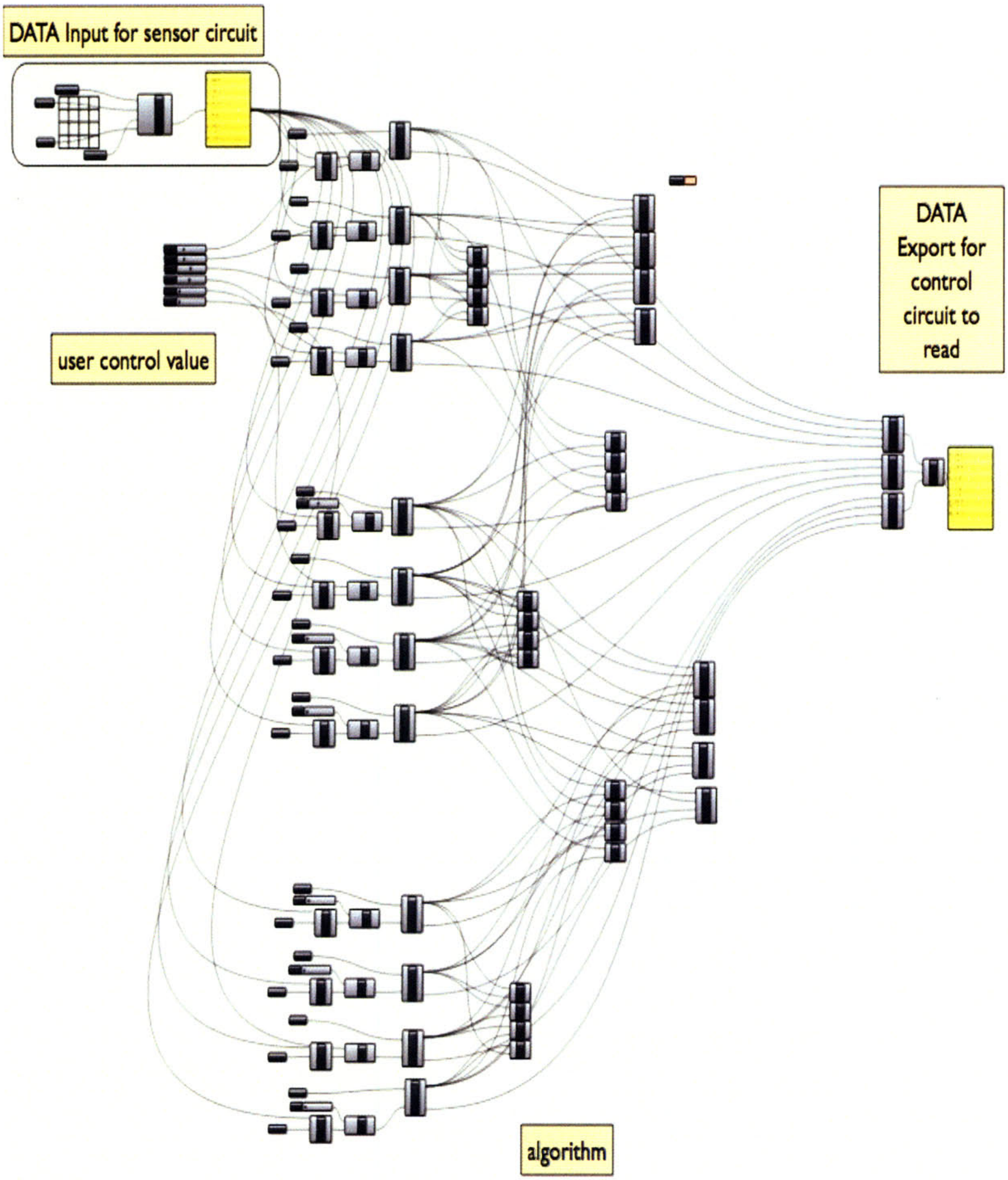


Figure 7-23 parametric relationship diagram

(6) The logic gate for filter input data

In order to void parametric design model being break apart by different data source input, each node structure embeds a logic gate. The logic gate is scripted to perform a logic operation on one or more logic inputs and produce one single logic output aims parametric design model can only be influenced by only one data input. By using this strategy, parametric model still maintains flexibility rather than limiting by fix constraint problems.

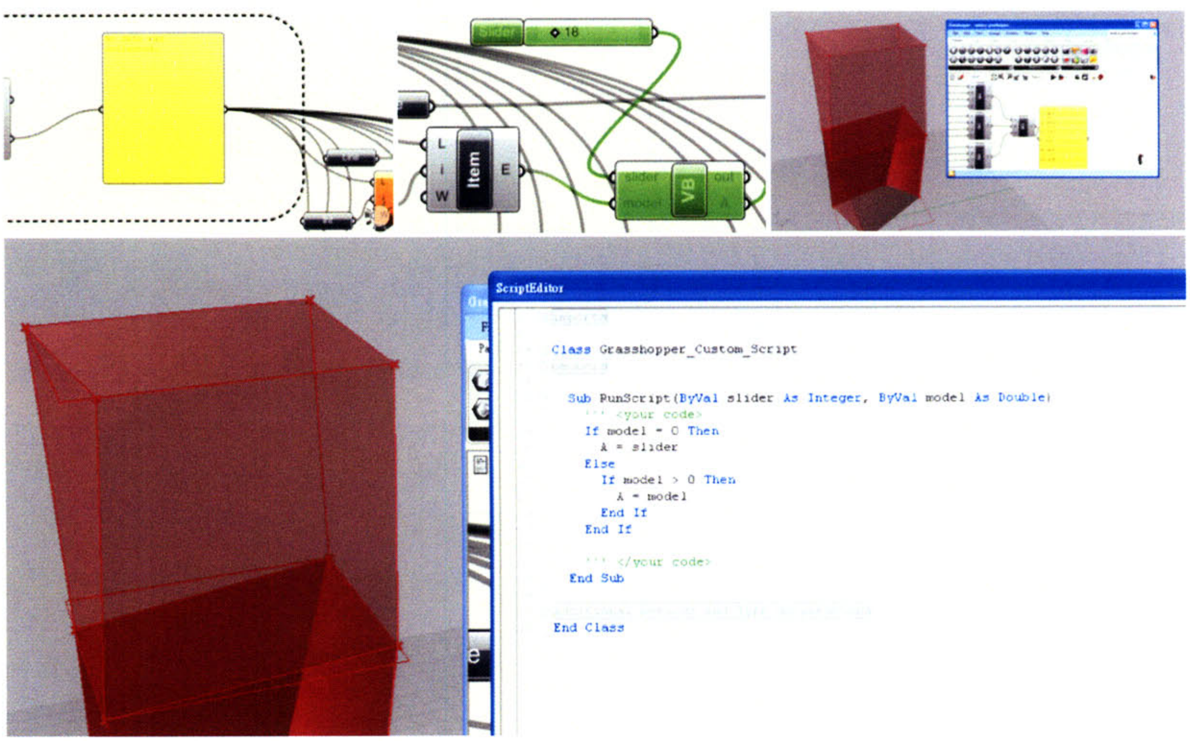


Figure 7-24 logic gate script

(7) Software -Processing and Arduino software

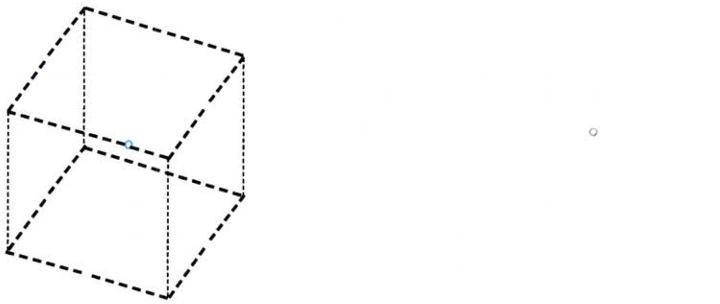
The processing software plays an important role as a mediator which reads the spreadsheet data and sends signals to activate mechanism control system. In order to update spreadsheet to control parametric model, processing reads sensor data from Arduino and updates new values to spreadsheet. This bi-directional software use enables designers not only generates design from parametric model onto physical model, but also updates new parametric model from physical model.

Figure 7-25 Arduino and processing data communication

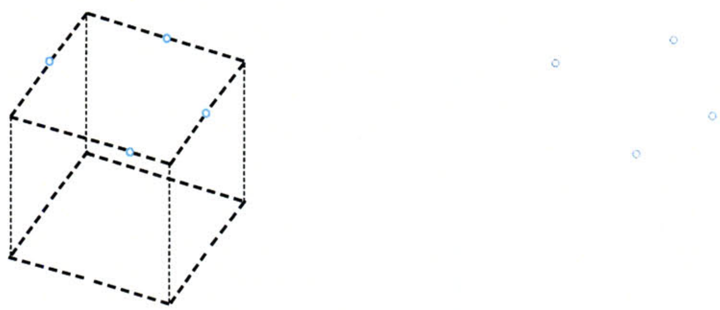
The diagram shows the parameters accessibility from processing to arduino.

(8) Design generation by physical parametric design

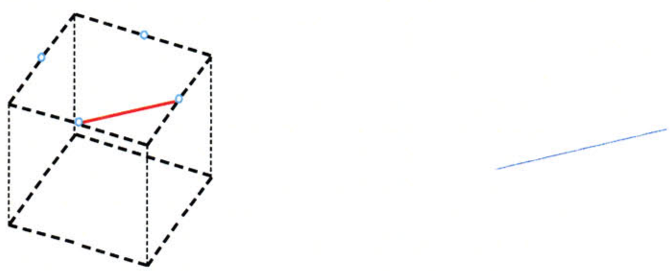
Structure	Geometric Representation with Quadrilateral shape



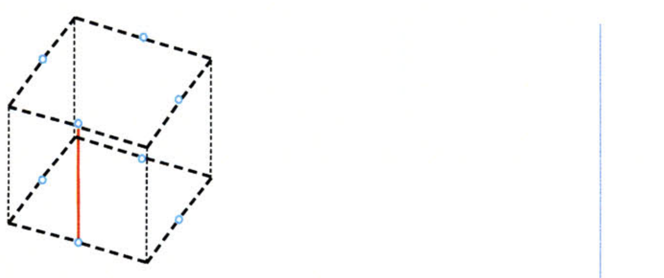
Point



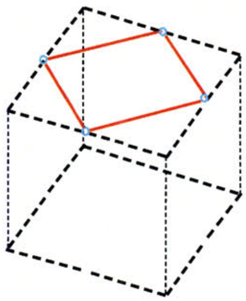
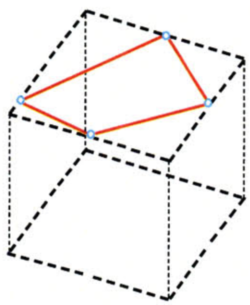
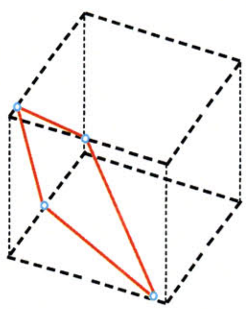
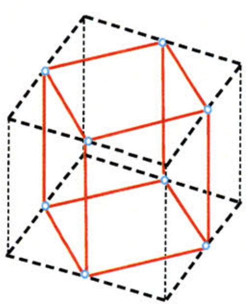
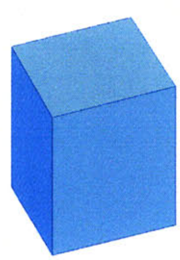
Multiple Points in registration plane

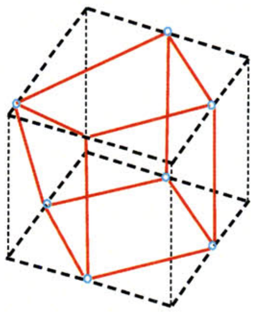
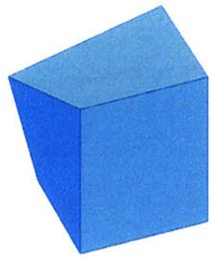
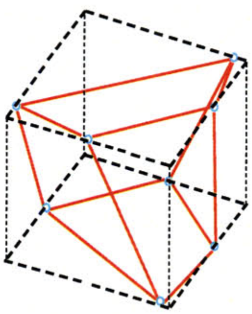
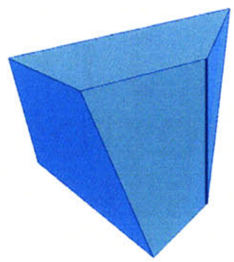
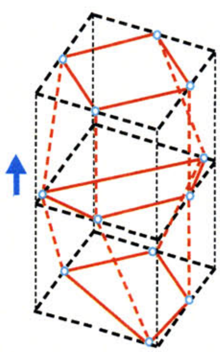
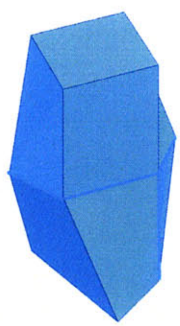
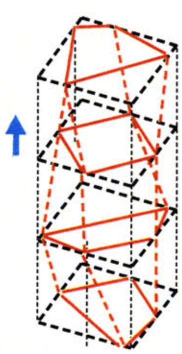


Horizontal Line in registration plane



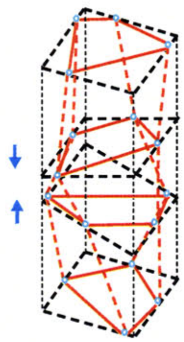
Vertical Line not in registration plane

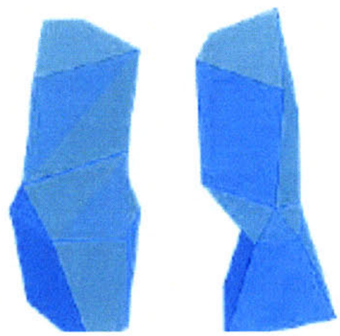
Structure	Geometric Representation with Quadrilateral shape	
		2d polygon
		2d irregular polygon
		polygon in vertical plane
		volume or 3d shape

Structure	Geometric Representation with Quadrilateral shape	
		Shape after one point was moved
		Shape after several points were moved
		Stacked shapes
		Stacked shapes

Structure

Geometric Representation with Quadrilateral shape

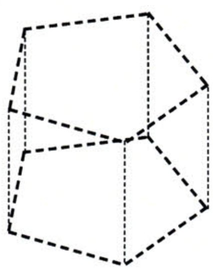


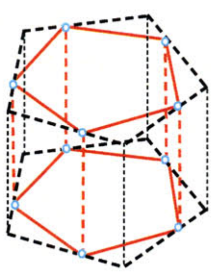


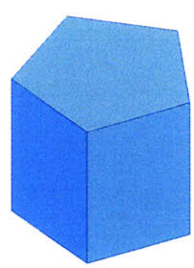
Stacked shapes after manual adjustment

Other Polygon Structure

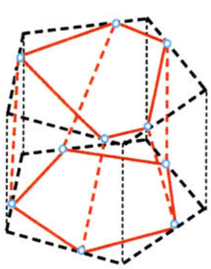
Geometric Representation with Pentagon

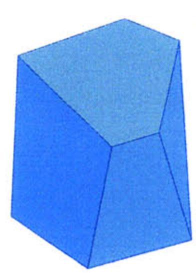






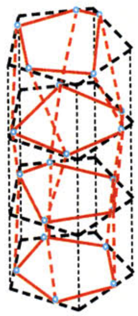
volume or 3d shape





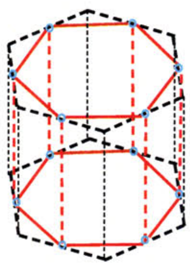
Shape after several points were moved

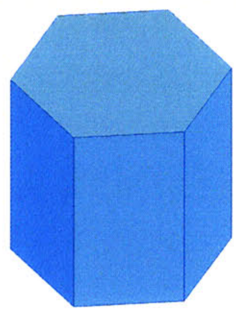
Other Polygon Structure | **Geometric Representation with Pentagon**



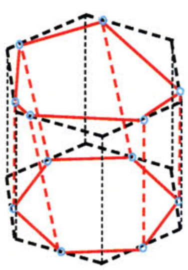
Stacked shapes

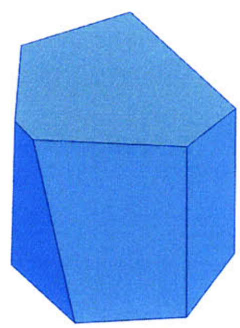
Other Polygon Structure | **Geometric Representation with hexgon**



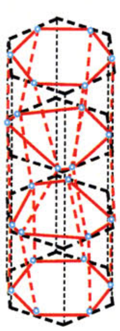


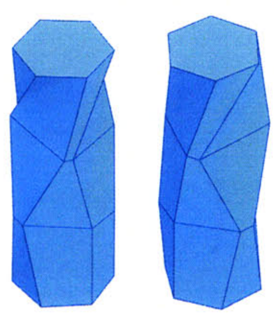
volume or 3d shape





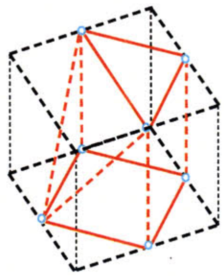
Shape after several points were moved

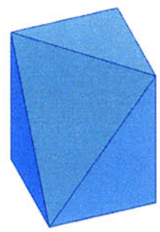




Stacked shapes

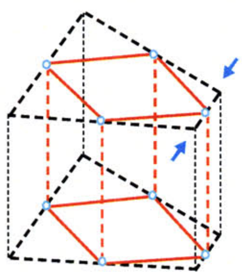
Structure | Geometric Representation Quadrilateral and triangle shape

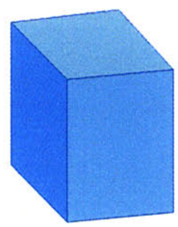




different connection relationship polygon

Structure | Geometric Representation with different registration plan





structure change polygon

Figure 7-26 possible design generation diagram

(9) From parametric design to physical Plan process

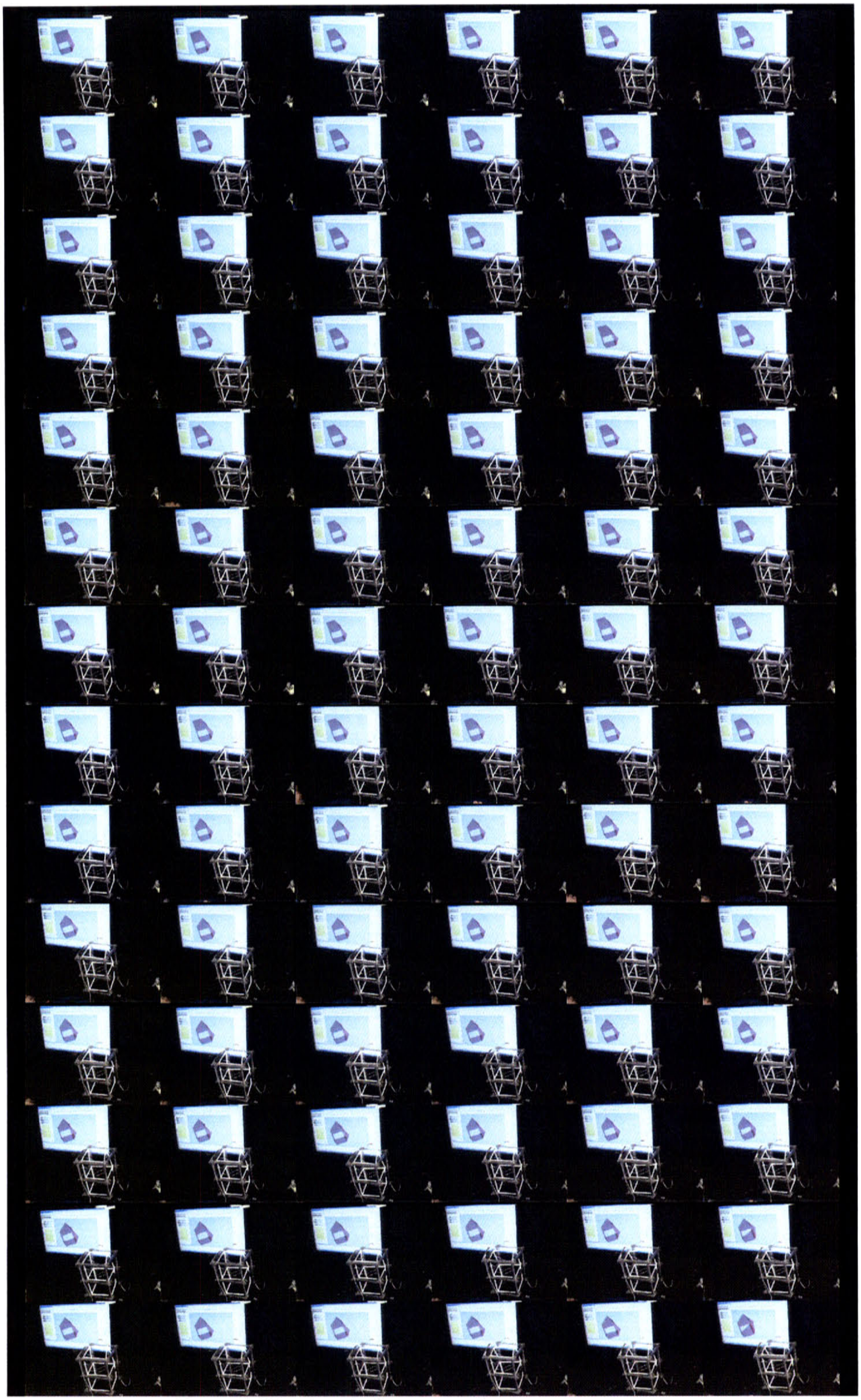


Figure 7-27 plan design generation process

(10) From parametric design to physical Elevation process

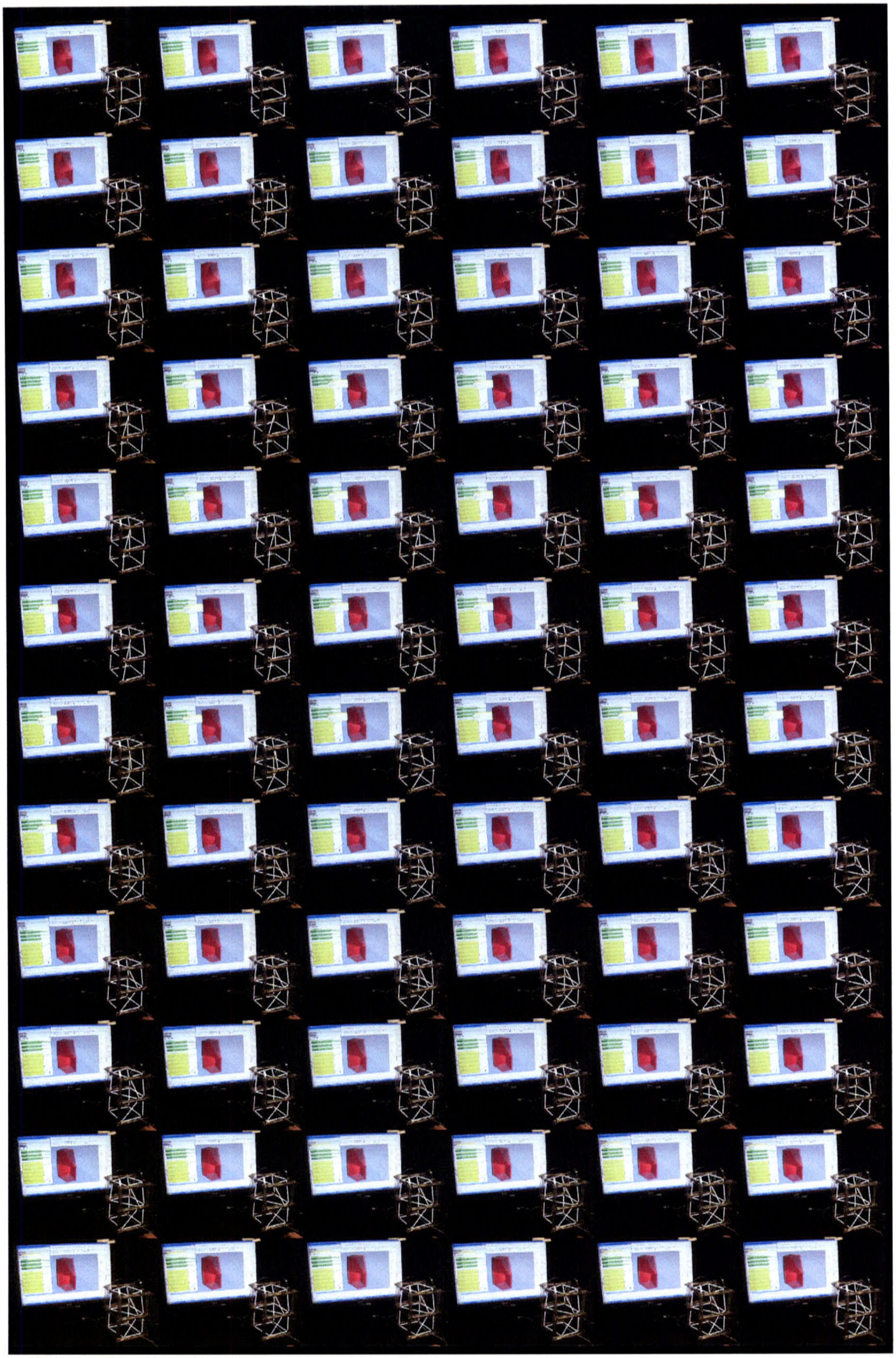


Figure 7-28 elevation design generation process

(11) From parametric design to physical Polygon process

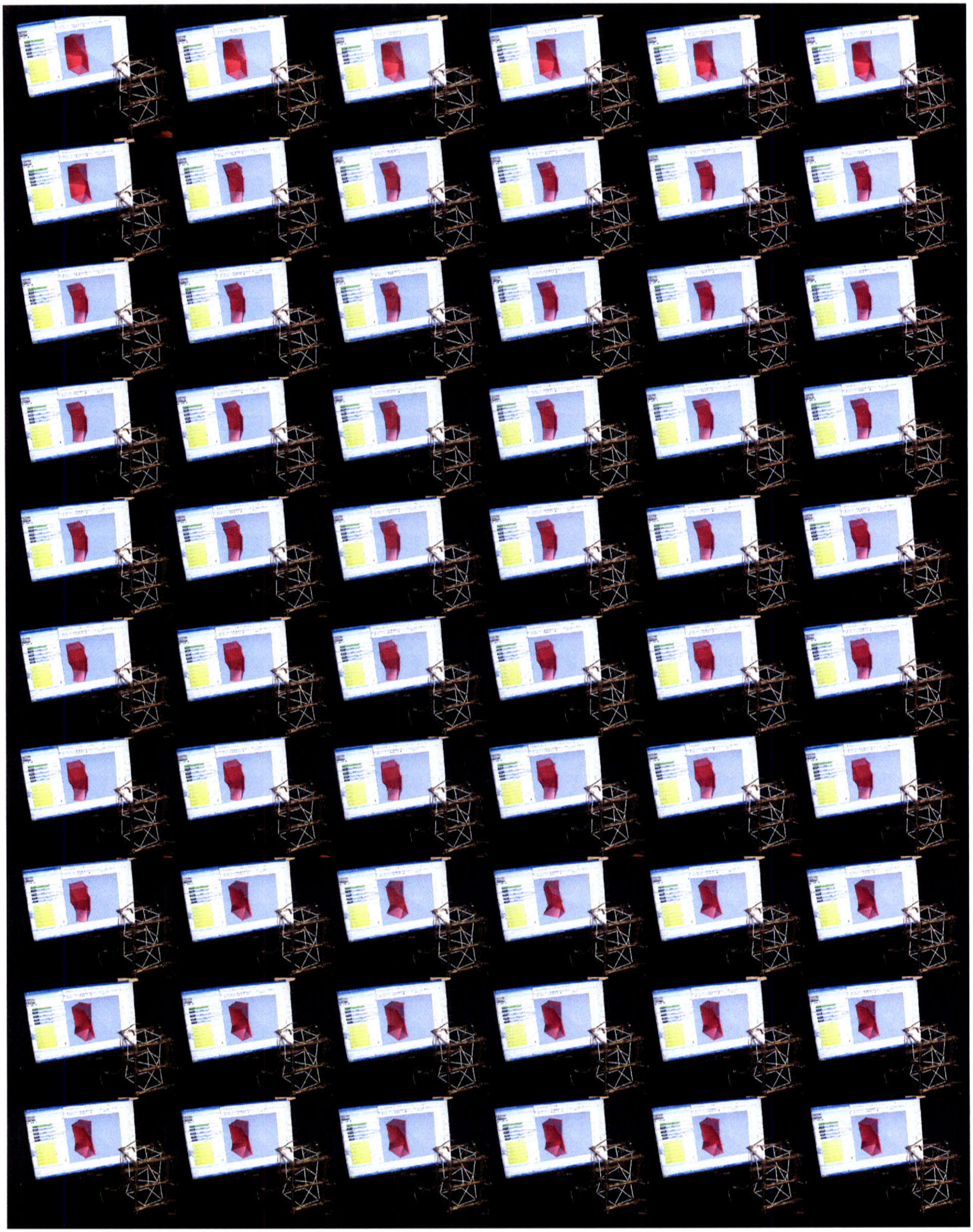


Figure 7-29 polygon design generation process

(12)From physical model to parametric design

The diagram shows
th updated result
from sensor data

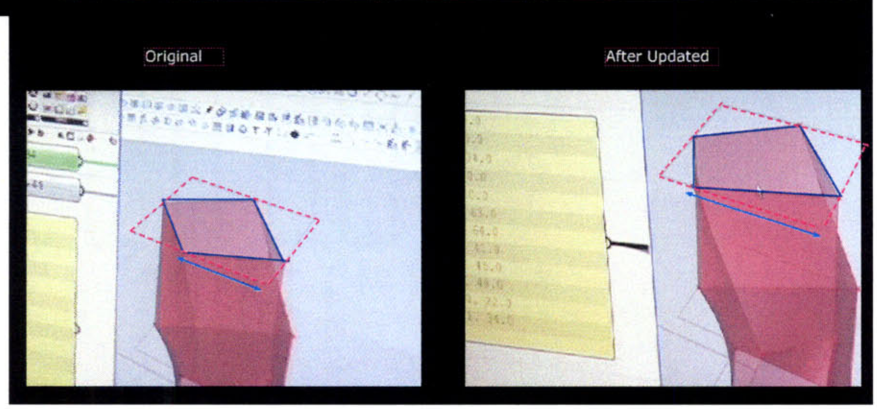


Figure 7-30 sensor data updates parametric design process

7.5 conclusion

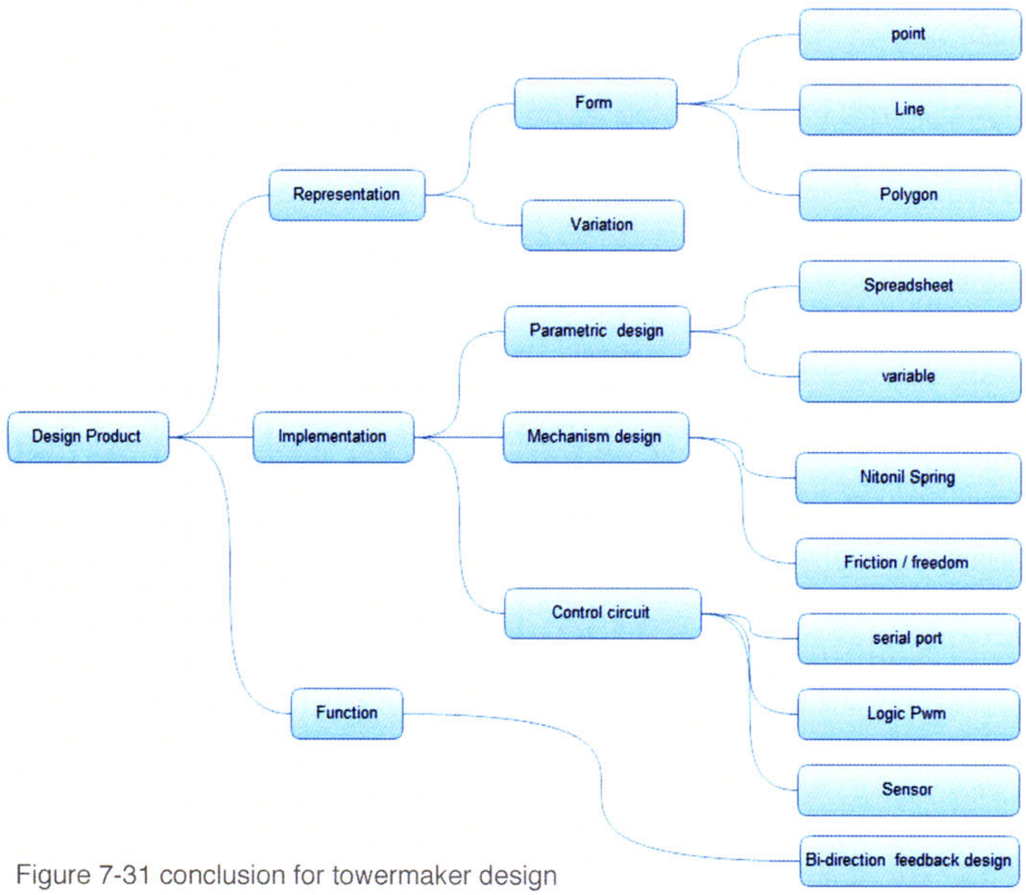


Figure 7-31 conclusion for towermaker design

In terms of representation in this study, the control mechanism plays an important role to aim parametric design implement into physical model. This design process enables parametric design keep variations in physical world and correspond the change from parametric design. The elastic wire represents alternative geometries which can be generated by Physical Parametric Design. It also implies the possible way to generate complex geometry in the future.The skill of transmistting data bi-directionally aims parametric design fix constraint problem.

8.Conclusion

8.1.Outcome:

The proposed design strategy of physical parametric design intends to demonstrate possible methods and supporting feedback loop design in order to aim fix constraint problems in parametric design. With this consideration of explore parametric design, this thesis also intends to develop some experimental works, includes simulation environment, data accessibility and feedback loop system to aim parametric design to keep different variations. These experimental researches are presented in this thesis as different studies and thinking rather than a concluded theory.

After dealing with multiple integrated problems in a wide range from software, electronic hardware or design problems, this thesis finally presents a proof-concept: Physical parametric design, in order to aim parametric design to not only keep variations onto physical world, but also enables feedback loop design to aim parametric design not being constrained by itself. This methodology aims parametric design as a more powerful design exploration tool rather than a drafting tool during design process.

Some architect firms, such as Morphosis, Frank Gehry, Eric Owen Moss use many physical models to study forms and relationships between contexts. Other architect firms, such as Zaha Hadid, SOM, KPF use many parametric design software to aim architecture design process in order to control accuracy and cost. The approach of physical parametric design integrates two design strategies to aim designers explore design and form in earlier stage, rather than separate computer design and model making design in different design processes. The physical parametric design also aims designer analysis the design behaviors and material properties in early design process.

In case of being used for design and exploration in early stages of design processes. Physical parametric design provides the potential value of undetermined design process aims designers explore design forms in earlier stage. The designer can not only easily observe their design result on physical model, but also adjust the physical model and re-input the result to parametric model to update design. This infinite design process aims designers flexible design abilities during design process.

Although physical parametric design still as an experimental study in which the effort was put to create an intellectual bridge between parametric design and model making design. Personally, I believe that this design strategy still aims designers the design forms inquiry and the representation in early design process as the motivation in this thesis.

8.2 The information process for physical parametric design

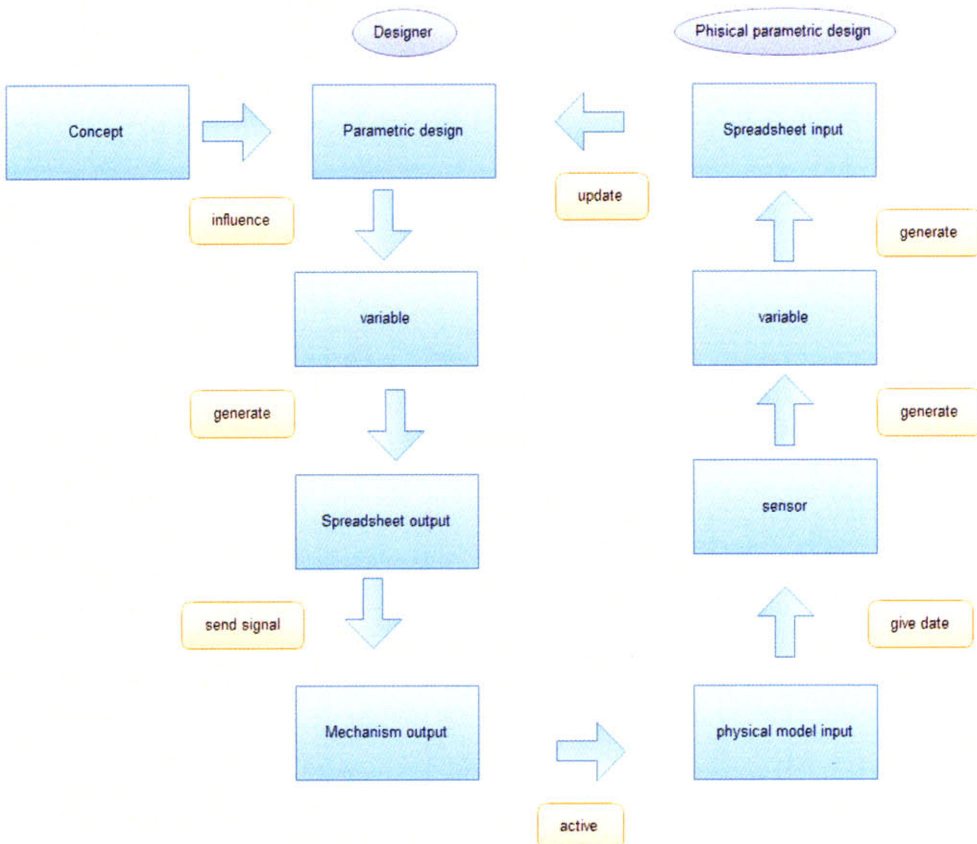


Figure 8-1 the information process for Physical parametric design

The diagram demonstrates the relationship between designer and physical parametric design tool. Unlike traditional parametric design tools only offer designer linear process until the forms are generated by tools itself. The physical parametric design offer a feedback loop design for designer to adjust the design output and re-input into computer for designer to update design process. The relationship between software parametric design and

The information process for physical parametric design

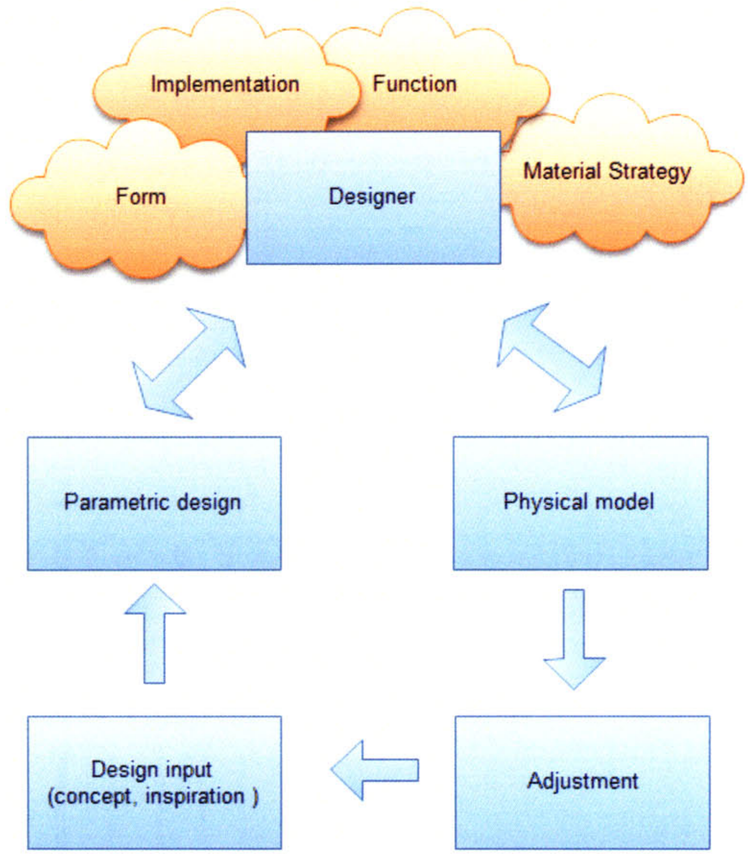


Figure 8-2 the information process for Physical parametric design

physical parametric design are functionally similar and forms a closed loop.

The above diagram illustrates the relationship among designer, parametric design and physical model. The parametric design is a tool which processes the data and information from design input and generates the design for designer. Designer plays an essential role to process the information and make decisions which is according to many undetermined decision to decide to implement design to physical model to test.

8.3 Beyound Geometry

Initially, digital fabrication and parametric design soft wares were designed for mass customization in industrial design and manufacturing industry. In order to lower the cost for consumers, mass production is an often used design and business strategy for different industry. Car, aerospace or product design industries manufacture uniform designs for consumers, so that consumers can get uniform quality and at the same price.

In terms of design and construction, buildings are more complex systems than other new technology products, such as mobile phone, laptops, therefore consumers like designed houses rather than mass produced prefab house designs. The benefit of physical parametric design is that during early design phase, the design uses a behavior knowledge-base, enabling parametric designs with its variations after physically constructing it. The contents can come from simulation tools as embedded knowledge or from users. This is the same concept of web 2.0, beyond building a website, but also allowing users share and participate information in order to generate personalization contents by users themselves.

In architectural design, customization plays an important role for design development. But after construction, the value of customization doesn't allow inhabitants/ users to have flexible usage in the future. In the design process the definitions between components are parametric design and also define their behaviors from knowledgebase tools, so that the content can be flexibly used in future. For example, everybody use Google as a platform for searching engine. IGoogle is a new web platform as users' first page to design as desktop application and integrates many applications which allows users to modify and set up their personal applications, such as calendar, stock , news, or dictionary ..etc on it. This kind of personalization service encourages users becoming unique even after they still use the same platform. In traditional design process, customization is fixed after design finished, but personalization concept may keep the design still have varieties after design finish, such as user still can modify what they need. If parametric design use this kind of concept, embedding knowledge during the design process, the design still have flexibility to update after design finish.

8.4. Limitation of Physical parametric Design

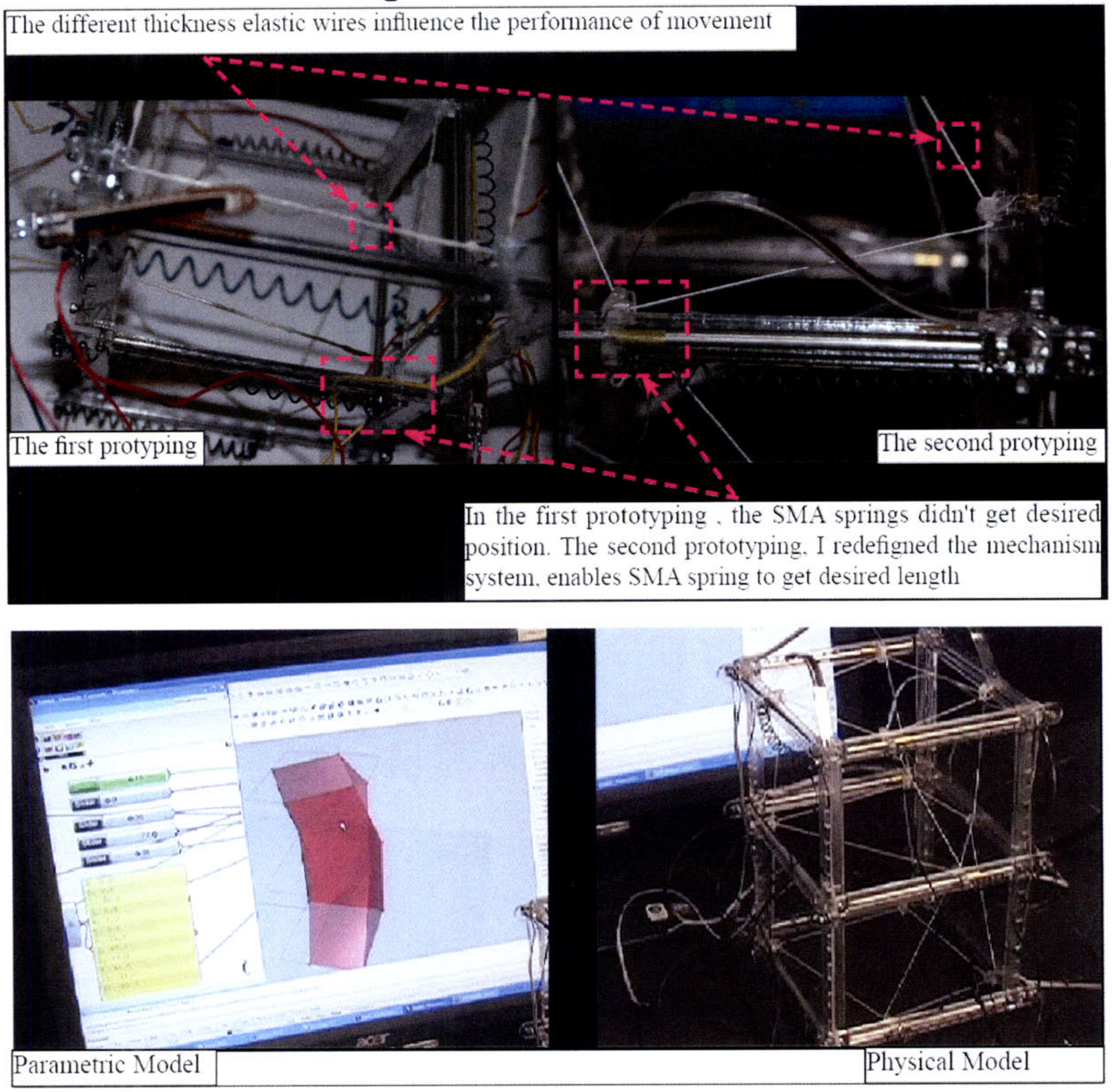


Figure 8-3 limitation of physical parametric design

(1) Physical parametric design relies on good mechanism to implement parametric design into physical world

(2) The physical model needs to build in earlier stage of design process in order to aim parametric design as design exploration tool.

(3) The parametric design system has to follow the hardware structure setup.

(4) Physical parametric design indirectly updates parameters in spreadsheet rather than directly connect variables in parametric design software.

(5) The set up of Physical parametric design is still complicated for designers

(6) In order to help design workflow, physical parametric design still need to simplify process

(7) A good mechanism system plays on important role to aim correspond physical model and parametric design.

8.5.Contribution

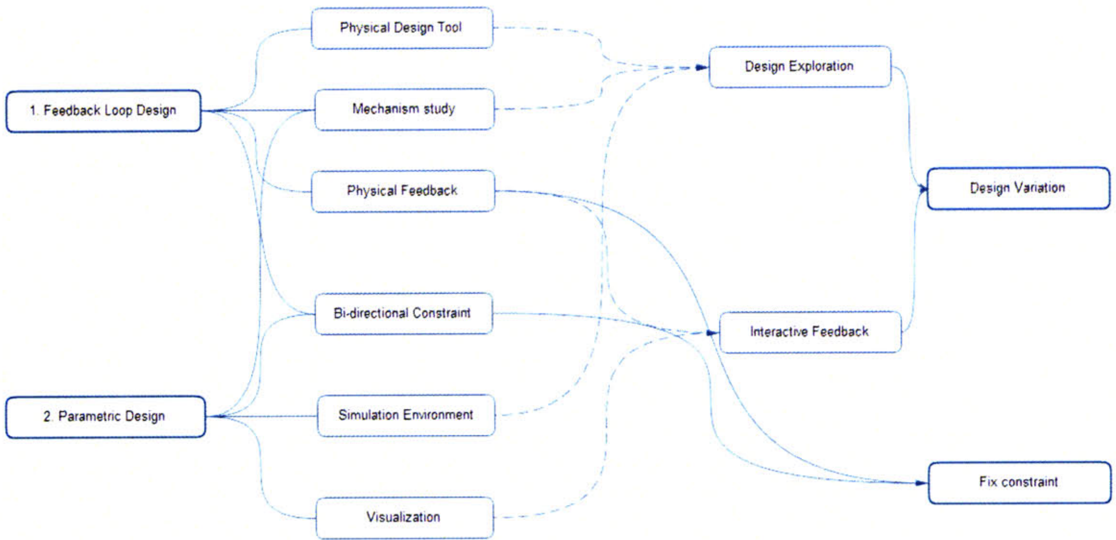


Figure 8-4 Contribuition

This thesis presents several of studies in order to explore the possibilities of keep parametric design variations in physical world and aims fix constraint problems in parametric software. In the end, this thesis comes up a design strategy, Physical parametric design, as a design exploration of form finding tools.

My contribution presented in this thesis is mainly on: feedback loop design and parametric design.

(1)Feedback loop design aims designer manipulate design result which is generated from parametric design on physical model and updates new parametric design.

(2)Parametric design studies, such as mechanism study, simulation environment, and visualization aims designers explore different design variations and enables parametric design keep variations in different design result.

(3) The physical parametric design create a interactive environment which allows designers interactive with parametric design and physical model.

(4) The proof- concept of physical parametric design manifest that bi-direction constraint problem can be solved in further way.

(5) Designers can use physical parametric design to test and experiment the studies of responsive design behaviors.

(6) The integrated design algorithm in parametric design aims design process in different stages, such as analysis, material strategy, responsive behavior, and concluded design result.

(7) The physical parametric design aims designers explore design forms in earlier design process.
In order to correspond to parametric model and physical model, this thesis introduces several possible solutions.

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Image source:

Figure 2-1 Generative Components (image source: http://www.aecmag.com/index.php?option=content&task=view&id=82)

Figure 2-2 Digital project (image source:http://www.gehrytechnologies.com/index.php?option=com_content&task=view&id=50&Itemid=102)

Figure 2-3 Grasshopper (image source:http://en.wiki.mcneel.com/content/upload/images/ExpHis_MultiVariableExpressionExampleDefinition.png)

Figure 3-1 Fix constraint problem in parametric design

Figure 3-2 Variation possibilities during modeling process

Figure 4-1 Precedent works studies

Figure 4-2 Arab Institute by Jean Nouvel
images is from http://www.greatbuildings.com/gbc/arab_institute/arab_institute.html

Figure 4-3 Aloy Community Hall
images is from http://www.greatbuildture.com/kdg/index.html

Figure 4-4 Golem (image source : Eva Schindling , Spinal Rhythms, Autonomous Embodied Evolution of a Biomimetic Robot's Rhythmic Motion Behavior)

Figure 4-5 (image source : Eva Schindling , Spinal Rhythms, Autonomous Embodied Evolution of a Biomimetic Robot's Rhythmic Motion Behavior)

Figure 4-6 Orambra
(image source http://www.orambra.com/)

Figure 4-7 MIT Kinetic architecture http://www.robotecture.com/kdg/index.html

Figure 4-8 performative design http://ecotect.com/products/ecotect/gallery

Figure 4-9 (image source : http://www.dfab.arch.ethz.ch/web/e/lehre/84.html)

Figure 4-10 Light wall (image source : http://www.ecologicstudio.com/v2/project.php?mp=0&idcat=3&idsubcat=4&idproj=10)

Figure 5-1 Experimental works and category

Figure 5-2
The information processing paradigm for cognitive psychology and human information processing
(image is from book :Designing interactive systems pp.100)

Figure 5-3
The information processing paradigm for cognitive psychology and human information processing
(image is from book :Designing interactive systems pp.101)

Figure 5-4
Concepture and Physical design
(Image is from book :Designing interactive systems pp.290)

Figure 6-1
Double curve space

Figure 6-2
urban competition /London 2008/ adaptable architecture gallery on the Thames River (http://www.arquitectum.com/index.php) by Sergio Araya, Orkan Telhan, Duks Koschitz, and Alexandros Tsamis.

Figure 6-3
Double curve algorithm and representation

Figure 6-4
Double curve algorithm and representation

Figure 6-5
Double curve algorithm and representation

Figure 6-6 Double curve algorithm and representation

Figure 6-7 robotic bus design

Figure 6-8 robotic bus surface relationship study

Figure 6-9 robotic bus surface relationship algorithm

Figure 6-10 robotic bus surface embedded electronic design

Figure 6-11 conclusion simulation environment-human behaviors

Figure 6-12 design phases for dynamic form

Figure 6-13 simulation tool-sunlight

Figure 6-14 responsive louver system

Figure 6-15 responsive louver system-data interface

Figure 6-16 responsive louver system-structure algorithm

Figure 6-17 responsive louver system-color algorithm

Figure 6-18 responsive brick system

Figure 6-19 Conclusion for simulation tool- Sunlight

Figure 6-20 traditional simulation tool (images from http://ecotect.com/products/ecotect/gallery)

Figure 6-21 adaptive tensegrity (images from http://en.wikipedia.org/wiki/Tensegrity)

Figure 6-22 adaptive tensegrity parametric design

Figure 6-23 Responsive structure design

Figure 6-24 Responsive structure design-Structure algorithm

Figure 6-25 Responsive structure design-sunlight system and structure

Figure 6-26 transform house design

Figure 6-27 structure relationship of transform house design

Figure 6-28 green house design (copyright owned by MIT Design Lab)

Figure 6-29 green house design (copyright owned by MIT Design Lab)

Figure 6-30 visualization design process

Figure 6-31 Spinner images and text from http://www.media.mit.edu/resenv/spinner/introduction.html

Figure 6-32 sensor data calibration

Figure 6-33 parametric design for visualization environment

Figure 6-34 parametric design for visualization heat map

Figure 6-35 visualization -processing

Figure 6-36 visualization -implement parametric design into different application

Figure 6-37 conclusion for visualization

Figure 7-1 physical parametric design - relationship between physical model and parametric model

Figure 7-2 diagram of tension surface design

Figure 7-3 diagram of tension surface design

Figure 7-4 diagram of tension surface design

Figure 7-5 parametric design of tension surface design

Figure 7-6 picture of tension surface design

Figure 7-7 surface movement of tension surface design

Figure 7-8 TowerMaker design

Figure 7-9 TowerMaker design workflow

Figure 7-10 TowerMaker design representation and Implementation

Figure 7-11 The diagram shows various length movement control by microcontroller.

Figure 7-12 Movement condition diagram

Figure 7-13 Arduino (http://www.arduino.cc/)

Figure 7-14 control circuim of SMA springs

Figure 7-15 10 module of control circuim forSMA springs

Figure 7-16 Structure mechanism

Figure 7-17 Mechanism and representation generation diagram

Figure 7-18 Mechanism and design diagram

Figure 7-19 picture of bend sensor

Figure 7-20 bend sensor circuit

Figure 7-21 bend sensor transmist data to computer

Figure 7-22 The picture shows the twelve bend sensor module

Figure 7-23 parametric relationship diagram

Figure 7-24 logic gate script

Figure 7-25 Arduino and processing data communication

Figure 7-26 possible design generation diagram

Figure 7-27 plan design generation process

Figure 7-28 elevation design generation process

Figure 7-29 polygon design generation process

Figure 7-30 sensor data updates parametric design process

Figure 7-31 conclusion for towermaker design

Figure 8-1 the information process for Physical parametric design

Figure 8-2 the information process for Physical parametric design

Figure 8-3 limitation of physical parametric design

Figure 8-4 Contribuition