ICHTYOMORPH - DESIGN AND DEVELOPMENT OF A FISH-SKIN DOUBLE FAÇADE SYSTEM FOR FREEFORM SUPER TALL BUILDINGS USING PARAMETRIC DESIGN TOOLS

Sergio Araya Goldberg
Massachusetts Institute of TechnologyDepartment of ArchitecturMaster of Science in Architecture Studies (candidate)
284 Vassar Street Apt. G1Cambridge MA 02139 US
sergio_a@mit.edu

Abstract

Parametric design implies a whole new paradigm of non standard design through the propagation of the difference, the repetition of variation. The ability to control variation and adaptation to local conditions allows more precise yet complex designs. This paper describes a research project designing double skin façade systems for tall buildings using a parametric approach. These designs are tested later through rapid prototyping techniques. This research aims its design towards an adjustable façade structure, articulated according to various complex geometrical conditions on the façade of a building. The skin is conceived as a light, flexible, reconfigurable composition responding to different criteria regarding the design, its environment or the program. It achieves this through different levels of control on different scales of the project, by embedding several layers of parametric features, which are nested one inside the other, in order to produce the overall rainscreen surface of the tower.

1. Introduction

In contemporary architectural discourse, within post digital culture, three concepts are used as synonyms, almost indistinctively, while they have different meaning and refer to different stages of cultural knowledge: tool, technique and technology. Digital tools and digital technologies are often used as equivalents, I will explain the differences. Tool is something that is used to perform an action, it is the *instrument*. Technique on the other hand, is a *method* or *group of methods* for accomplishing a particular task. But technology is the *body of knowledge*, available to a society, which is of use to achieve specific practical purposes. Then the computer is a tool, as it is the software running on it. They are used to execute specific actions or operations, to achieve certain objectives. The specific methods developed to use computers and software, inventing and perfecting creative processes to achieve better results, are recorded as techniques. But technology is achieved, when a new knowledge is produced from the creation and application of certain techniques, running specific tools, to achieve desired objectives. Although the research presented here is still in progress and the results presented are partial, I will use them to explain in this paper how emergent computational tools, parametric design environments and numerically controlled fabrication processes can be implemented in the development of architectural designs. I will describe a technique of nesting parametric components on different scales to build a complex yet controllable double skin facade system.

1.1. Global variables and parametric features

Here I will describe parametric techniques implemented to design complex architectural structures. I will point out two particular techniques that use parametric functions present in the last version of Bentley's Generative Components (GC) software.
Parametric design (PD) introduces the concept of solution space, where designs are not the fixed result of modeling skills from a pre-conceived idea, but the result of a set of relations and conditions built with embedded ranges of variation that allow exploring different possible designs. Two functionalities of the parametric environment implemented in Generative Components were tested for this research: using Global Variables with associative functions during the concept creation and form finding processes, and building associative dependencies and relationships within parametric features or components

which will later inform the design. These two strategies influence different scales of the final design, becoming nested conditions linked according to a pre set hierarchy.

A global variable as present in GC is a feature that can be as simple as a numerical value, or as complex as a large mathematical function. The resulting value of this variable can be linked as an input to any other feature, geometry or function, creating a dependency which is external to this second feature. A Parametric Feature is a component which has a particular creation method depending on inputs, a number of functions and internal relations that link the geometries of the feature, and a geometrical output. All this characteristics are *programmed* by the designer, extending then the basic library of features to create his own library of customized components, depending on particular projects, or on particular methods of work.

1.2. Feature population

Parametric objects have the relations between its constituent geometries and functions encoded as fucntions of its design; they adapt to variation of these values but maintain the hierarchy of relations and functions. The result is their ability to adapt while a variable's value is changed.

Building parametric features allows the designer to create *smart* elements with *embedded intelligence* which adapt to local geometrical conditions. When these objects are replicated numerously on a context field, they adapt to the specific characteristics of the geometry. This method of replication or feature population will result in a collection of different objects, and when the populated field presents heterogeneous and non constant conditions, the result will be a collection of all alike but all different components. It is possible to manage these collections of components created by populating parametric features, by changing the conditions of the context where they were inserted. It is also possible to build into the parametric feature itself, dependencies to global variables, which can be controlled externally. Such strategy allows the designer to set up behaviors and ranges of adaptation inside the features themselves and also allowing external control. In this research paper I explore these functions by embedding both kinds of dependencies on a simple feature, in order to test its adaptation capacity, responding both to internal constraints and to the adjustment of external global variables.

2. Digital fabrication processes

Digital fabrication is a general term that refers to manufacturing processes which are executed by machines controlled by computers. Every machine has its own particular fabrication method, imposing an ad hoc logic required to manufacture an object. A recurrent struggle on contemporary post-digital architecture, is realizing designs, beyond the electronic environments of digital 3D modeling tools.

When a parametric model is built, the relationships between primary geometries and functions are set; therefore it allows integrating also fabrication logics, which will later facilitate its manufacture. Learning these fabrication logics implies understanding which processes are best suited for building specific designs. For the purpose of this research paper, 3D printing methods were used. These are additive fabrication methods, they deploy or add material, using several different processes and materials, requiring specific knowledge of proprietary software, and specific operational skills to operate the machines. Two different processes that employed material deposition building methods were used on this research. A ZCorp machine was used for testing the results of geometrical dependencies and parametric variations, providing appropriate resolution for scale models and short fabrication times to fabricate several tests. A Stratasys machine, using a soluble support material, was used to build articulated parts that needed movable joints to perform basic movements. I implemented this method in order to build solid pieces with movable parts, and with sufficient material strength to resist the mechanical demands at model scale. The tolerances used, allowed movement between hinged parts but providing enough friction surface to fix the pieces in place after adjusted.

3. Double skin facade system for tall buildings

The case selected for the research project is a double skin façade system, specifically focusing on super tall buildings. The name of the research project, Ichtyomorph, responds to being inspired in a fish skin structure. Its ability to turn and dribble while swimming, depend on the skin of the fish, composed of a mesh of layered fibers, which pulsates driving superficial patterns along the skin of the fish. This reorients the hundreds of operable scales which become hundreds of small flaps providing stability and precise control, giving the fish its agility in the water. Ichtyomorph is an adjustable façade structure articulated to respond to varying geometrical conditions. A secondary objective is to design a facade for detached from the support structure, as a flexible composition that may be reconfigured.

3.1. Parametric shape and adjustable building silhouette

Five spline curves placed on a vertical axis control the curvature of a loft surface derived from them. The distance between these control sections is regulated by a function that adjusts this value proportionally according to the desired number of floors. Adjusting the factor of proportionality between the spline control sections, will change the external appearance of the tower. After the shaping process was developed, a rationalization of the building took place adjusting the geometries using the Sketcher in Catia, locating the core structures for the express elevators and deciding the transfer floors. The rationale for the core location included the orientation of the tower on the site, promoting natural sunlight and inclining the tower towards the SW to self shade the west facade reducing heat gain and preventing excessive UV loads.

3.2. Double diagrid structure

Twisted buildings provide structural advantages as they inherit through this rotation a diagonal relation in the vertical axis, providing a natural diagrid structure. Diagrids are efficient against both vertical and horizontal loads, required given the asymmetry of complex shapes. Given the central spinal core structure, a perimetrical diagrid structure completes the support frame of the building. This diagrid was developed as a nested parametric feature based on a subdivision factor on the shape surface. A *rhomboid feature* was created in GC using four points as input reference. The lofted shape of the building was used to place an array of points based on UV values, subdividing it according to a resolution factor, a global variable. This collection of points on the surface is a second order of parametric features, depending on variables that control the surface itself. Using the *shape feature* as a vehicle, the rhomboid feature is populated creating a controlled diagrid. I set up variables for controlling the magnitudes on the section of the structure independently, responding to varying structural conditions optimizing it accordingly. A second diagrid, offset from the previous one, acts as the support structure for the rainscreen surface. The same method was used, but the resolution of the subdivision function is four times bigger, as the structural diagrid nodes happen every four floors, but the rainscreen support diagrid based on the floor levels is aligned to each slab. This second diagrid is a *flexible structure* that can be re-formed (deformed) according to varying external and internal demands, changing slightly the silhouette of the building. A special *parallelogram articulation* scheme

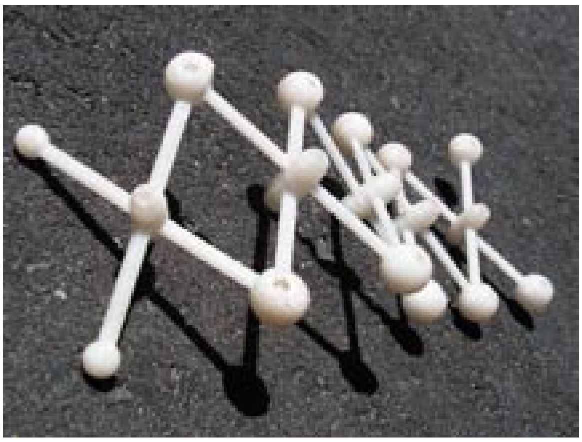

Figure 1: The spherical articulation provides double curved deformation on diagrid structure.

Figure 2: Articulated spider prong joints provide independent operability for each scale feature

was used, providing proliferation of deformation along the structure, reducing partially the need of distributed actuators, as the articulation system will "transfer" the deformation or kinetic operations throughout the whole structure.

A parallelogram articulation works only on a plane, so I implemented a spherical *knee* articulation to provide three axis of freedom. This was developed as another parametric feature, with controllable size (radii) and variable tolerance for the articulation. The tolerance was adjusted to the FDM process used. Finally a connection node was also developed for the joints where the rainscreen structure is connected to the supporting diagrid.

Different stages of results were 3D printed. The shape of the building was built as a reference. Then the supporting structural diagrid was printed to examine its varying section. The double diagrid was printed to study the overlapping diagrids.

3.3. Fishskin

The final set of features nested into the design, is the *scale feature* used for the rainscreen. Given the doubleskin strategy, the external surface does not need to be hermetic, as the internal diagrid structure supports the glazing of the building. Furthermore, it provides an air chamber, allowing natural ventilation as an air refreshening system and as a natural cooling device to reduce energy consumption inside the building. The scale was developed as a frame, supporting two triangular glass scales in a rhomboid fashion, scaled to match the rainscreen diagrid.

Figure 3: Sequence of construction, from surface to structure to double skin system.

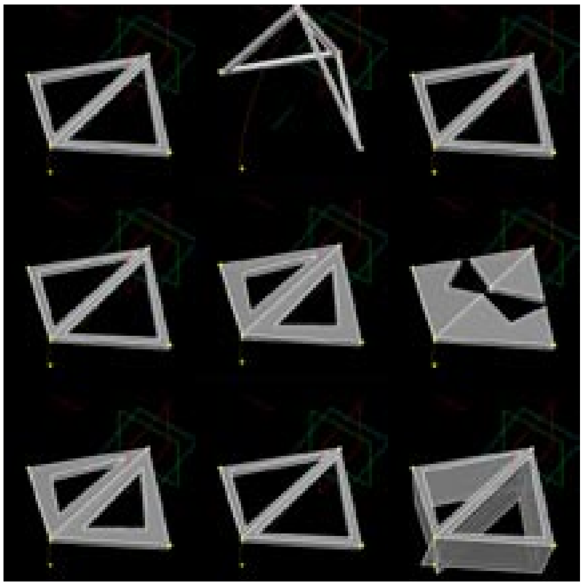

Figure 4: Kinetic behavior of the scale feature simulated by external global variables.

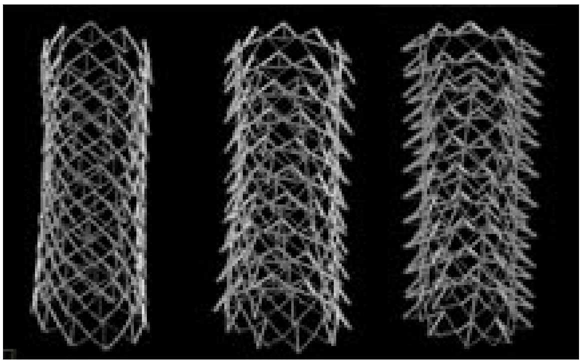

Figure 5: Populated section of the building, adapting to local conditions and accepting external control via variables.

Figure 7: Section Model of the structure studying the surface effect pattern of scale features.

The scale feature is controlled by several global variables, in order to reproduce its kinetic behavior. The frame is controlled in size and section, and also in shape, allowing different support/transparency ratios according to the orientation of the scales on the façade.

The crucial function is the variation of the angle of the scale, which is related to the reaction of it due to weather conditions or programmatic requirements. For this purpose I scripted a function where the angle was controlled by two law curves, in order to produce a non linear series of values, achieving a *surface effect* control over the scale-surface.

One law curve controls the vertical orientation of the scales, and the other law curve controls the orientation in horizontal, meaning all the scales of the same floor. Several tests were printed to examine the results of these embedded parametrics and possible variations. The tests were printed solid, discarding the transparency of the glass scales, favoring the visualization of the surface patterns obtained and the strength of the scale model, and also allowing light/shadows studies.

For the purpose of this paper, basic solenoid actuators were created, using stepper motors and translating rotational movement into linear motion. The stepper motors are controlled by a microcontroller programmed to run the motor a precise number of turns in one direction or in the other. A node composed of four actuators would provide complex three-dimensional actuation over an articulated surface. For the scale feature developed in this research, only one actuator is required, providing the necessary linear movement. Basic capacitance sensors were developed to test the possibility of turning on and off a device based on proximity of a subject. The sensor now turns on an LED, in the same that it would turn on the microcontroller triggering the actuator.

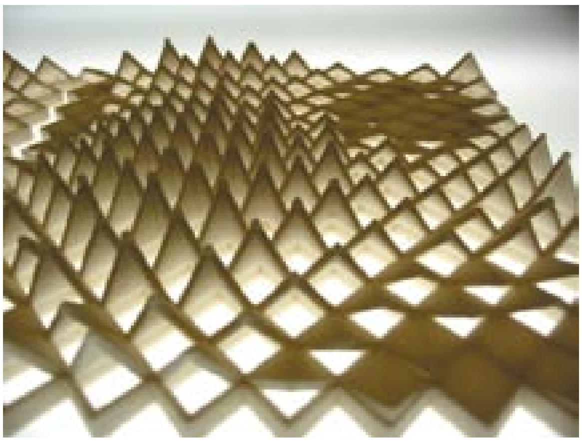

Figure 6: Surface effect pattern printed on ZCorp to test light/shadow performance.

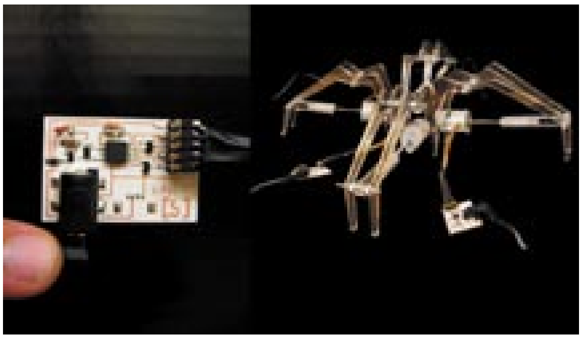

Figure 8: Microcontroller and actuator node using four solenoids created from stepper motors.

4. Conclusions

The example used for this research paper shows how different parametric techniques can be used to respond to large complex design projects. It also explains how these parametric strategies can respond to different scales of an architectural problem, during the design process, from form finding stages to layout and programmatic decisions to detailed resolution of a compound assembly.

This paper illustrates how these tools allow constructing a solution space, beyond providing a dimension of freedom for design exploration and fabrication, which can be used to enhance solutions responding to increasingly complex problems with creative and flexible solutions.

This research paper shows the scalability of parametric techniques using a nesting strategy, creating dependencies between geometrical elements as well as between mathematical functions and relationships. Furthermore, this scalability is also desired for fabrication purposes, providing the ability to be tested using rapid prototyping techniques but being later implemented through industrial CNC production.

Further development of parametric design techniques and implementation of new techniques using rapid prototyping methods, will progressively change the conceptual approach to the application of computation in design processes. The required comprehension of the relations between precise mathematical constructions and forms, and the application of fabrication logics at initial design stages, will lead to a much richer platform for architectural design. The ability of embedding kinetical behaviors and mechanical properties in designs to match actual fabrication CNC methods, allow us to imagine responsiveness and kinetics as integral dimensions of smarter architectural designs.

5. Further research

The research presented here is still in progress and the results presented are partial.

Although very basic, the explorations done so far regarding actuation and sensing systems is promising. Different actuation methods should be developed for different demands, providing robust solutions. Sensing system require more in depth exploration. Distributed actuation has only been tested in this research as hard coded patterns, testing the coordination and communication between distributed actuators is yet to be explored.

Acknowledgements

All my gratitude goes to my partner in research Onur Gun for his collaboration on the first stages of this research.

Very special thanks to Robert Aish, for his continuous support stimulating this research and other projects, and for inviting me to get involved with GC.

Sincere thanks to Lawrence Sass, Mitchell Joaquim and Carlos Barrios for their support and insight during the development of the research.

Thanks to the RPL and Media Lab at MIT for making this research possible.

Sergio Araya Goldberg

Architect Pontificia Universidad Catolica de Chile, Magister in Architecture Pontificia Universidad Catolica de Chile, Master of Science in Architecture Studies (candidate) Massachusetts Institute of Technology.

Areas of interest: Kinetic Architecture, Responsive Systems, Parametric Design, Digital Fabrication, Design Computing.