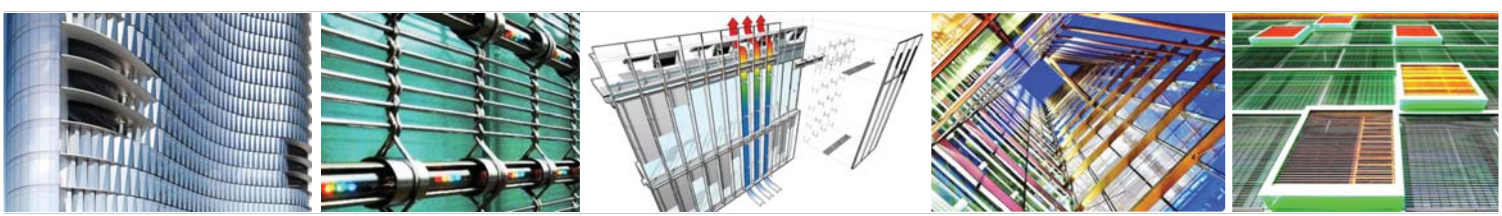
ENERGY FORUM

28 - 29 October 2014, Bressanone, Italy

Advanced Building Skins



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Adaptive Skin: Data driven design and fabrication

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Abstract

This paper discusses the implementing design logic and none-linear processes to design the building skin by injecting the concepts of parametric thinking. The point of departure was to study the performance of the skin system and realize the interplay between action and reaction in a data driven process. This paper presents a method of integrating ruled-based form seeking with the aid of parametric techniques. Computational methods are extended by exploring, collecting, analyzing, and inputting abstract data and optimizing geometric forms through ruled-based design programs. This paper further describes the experiential learning outcomes gained through the application of adaptation as a method for solving specific design challenges. The authors focus on how an adaptive solution can evolve during the design stage. The research project starts with anticipating the changing variables in the design process and embeds these variables in a parametric model. The ruled-based modeling programs are used to represent the structural, environmental and esthetic complexity within the parametric equation. Various algorithms and computational tools and techniques are used, based on rules and constraints that allow for parametric control of the geometry. This adaptive process explores parametric techniques that allow for and encourage non-linear workflows. The tools themselves open up both adaptive solutions and adaptive means. Several projects in XXX, and design courses taught at XXX were also instructed to investigate the design and fabrication processes in order to formulate a generative skin system. The paper uses these projects to showcase the design methods through studying the parametric correlation in the form and its performance. The paper describes how the emerging parametric thinking is making Architecture does not simply form, but rather perform various functions beyond those conventionally associated with building skins. With advanced parametric modeling and digital fabrication techniques, the computation was simply used as a means to express the transparent relationship of environmental, culture and social data to the driven geometric form.

Keywords: adaptive, parametric, rule-based form seeking

1. Introduction: Adaptation of form

Ruled-based optimization has intrigued architects through a controlled process where prior experience is augmented by the addition of data to drive design decision-making. This design process integrates interdisciplinary analysis and evaluative processes in automated systems which assist in designing better performing building skins. In the practice of architecture, this process is defined as performative design and is based on various generative and parametric design methods. Some of the emerging aspects in the practice of architecture involve utilizing genetic algorithms in the design process, as well as simulations and performance-driven design to generate complex building skins that respond to environmental data such as solar radiation, wind load or acoustic effect.

The use of parametrics and computation within the design process sponsors an adaptive method for making design decisions. By not being limited by a strict linear path, or workflow, where altering previous decisions are time consuming and require a regression of the design stage, designers are now able to utilize non-linear workflows where multiple aspects of a typical design can be modified at once. Design decisions can therefore be made at the latest possible time allowing for more information to be gathered and tested before any solution is offered. Parametrics and computations allow for this adaptive method through the ability to create a constant stream of observable solutions, giving the designer a greater field of options to pursue.

Making an "adaptive skin" as a biological form, started with designing a generic skin component, a "shared body plan[1]" (Manuel De Landa. 2001) which can morph into various configurations based on the evolutionary rules. As described by Manuel De Landa, "a kind of 'abstract vertebrate' which, if folded and curled in particular sequences during embryogenesis, yields an elephant, twisted and stretched in another sequence yields a giraffe, and in yet other sequences of intensive operations yields snakes, eagles, sharks and humans." Manuel later adds that "…if evolved architectural structures are to enjoy the same degree of combinatorial productivity as biological ones they must also begin with an adequate diagram, an abstract building corresponding to the abstract vertebrate". Today, emerging computational tools offer modeling power to simulate the adaptation of architectural forms, geometries, and elements. Similarly "evolutionary" approaches can be used to optimize performance. The design process is no longer depending on architects' intuition and personal experience to make design decisions, but rather using data and relationships to define the design logic." (Tang, Ajla 2012) (Figure 1)

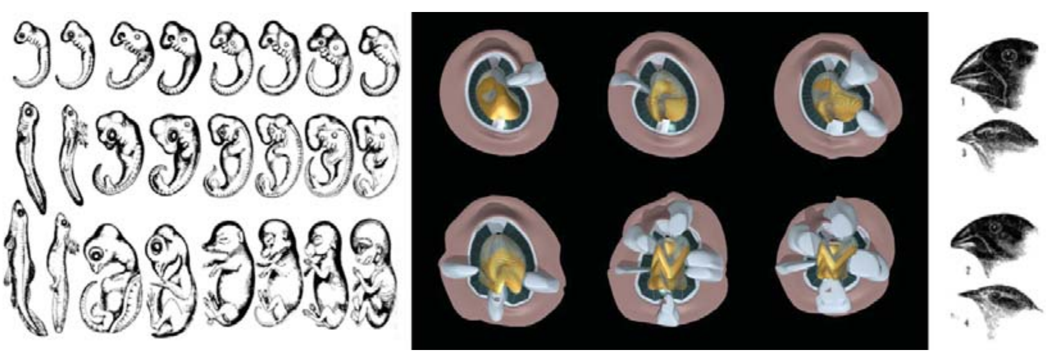

Figure 1: Left, vertebrate archetype. Middle: Greg Lynn's embryological house. Right: Finch population in Galapagos Island.

2. Research and teaching methodology

In 2014, the authors launched several research projects and parametric design focused studios. The primary investigation focused on the adaptive and transmutable nature of architectural skin which can be defined by rule based processes and further supported by transmutation theory. Investigations began by critically analyzing the historical significance and theoretical impact of the evolutionary design processes of John Frazer's Evolutionary Architecture and Manuel De Landa's "abstract vertebrate" and "material expressivity". Students explored several computational methods for generating designs through parametric modeling and analysis, computer driven decision-making, and design optimization. Students applied a parametric design sequence associated with procedural modeling for "shared body plan", performance-based transmutation, and digital fabrication. Through analog and digital methods, students measured the performance outcome against the predefined constraints. These approaches rely on performance data to influence and impact the design process from beginning to end. Students studied the genetic evolution theory in Darwin's finch study in the Galapagos Island, Greg Lynn's embryological house, and various computational methods such as genetic algorithm, and cellular automation to investigate the transformative nature of geometry and potential alternatives. The courses promoted the ruled based generative process for integrating simulation as a design instrument for creating hybrid conceptualizations of logical forms through digital computation. Students did series of analog and digital design experiments to explore how to anticipate the morphological change and embed the potential changing variables into the "shared body plan". Students learned how to set up the rules and make the form adapt to the performance data from solar, wind, and acoustic simulations. (Figure 2)

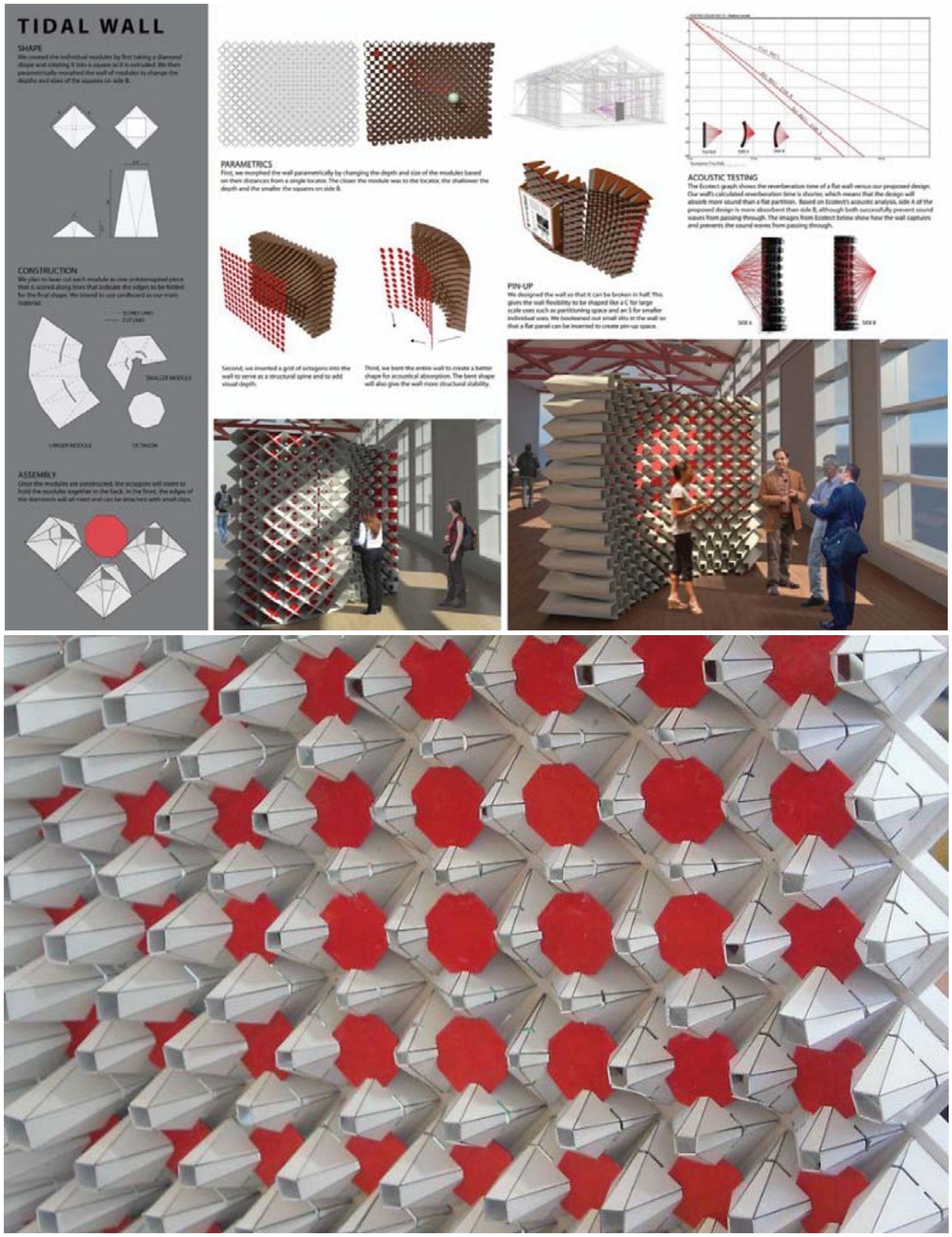

Figure 2. Students learned how to project the quantitative acoustic data into a 3D surface and use it to drive the morphing of each panel. The shape of each panel is optimized by the computer simulation based on the acoustic performance. The accoutic wall is later fabricated with laser cutting and CNC mill.

3. Material Process

Students first studied the building material to investigate the structural and formal characteristics of building skin with the intent of adapting its form to various constraints and different forces. The structural performance and material properties of both soft material (fabric) and rigid material (wood blocks) are studied.

3.1 Rigid material, adaptation happens in the object level.

The rigid material study is creating an adaptive skin over a large network of wood blocks to a create meaningful pattern. After a case study on the ventilating wall of Daniel Gantenbein Winery in Switzerland, students developed a computation method to determine how to optimize each block's orientation to achieve certain ventilation and lighting result. Each rigid block remains identical without any "deformation" or "morph". Only its orientation is changed. Here, the adaptation is operated in the object level. The essential objective is to decode the data driven process and reflection the relationship in the physical model. The variables such as air dynamics, material properties, and forces are integrated through the parametric model to generate both three dimensional form and time-based media to visualize the optimization process. (Figure 3) Using parametric modeling program to generate the rotation value of each block, the wall can automatically adapt to data input and are parametrically controlled by the designer.

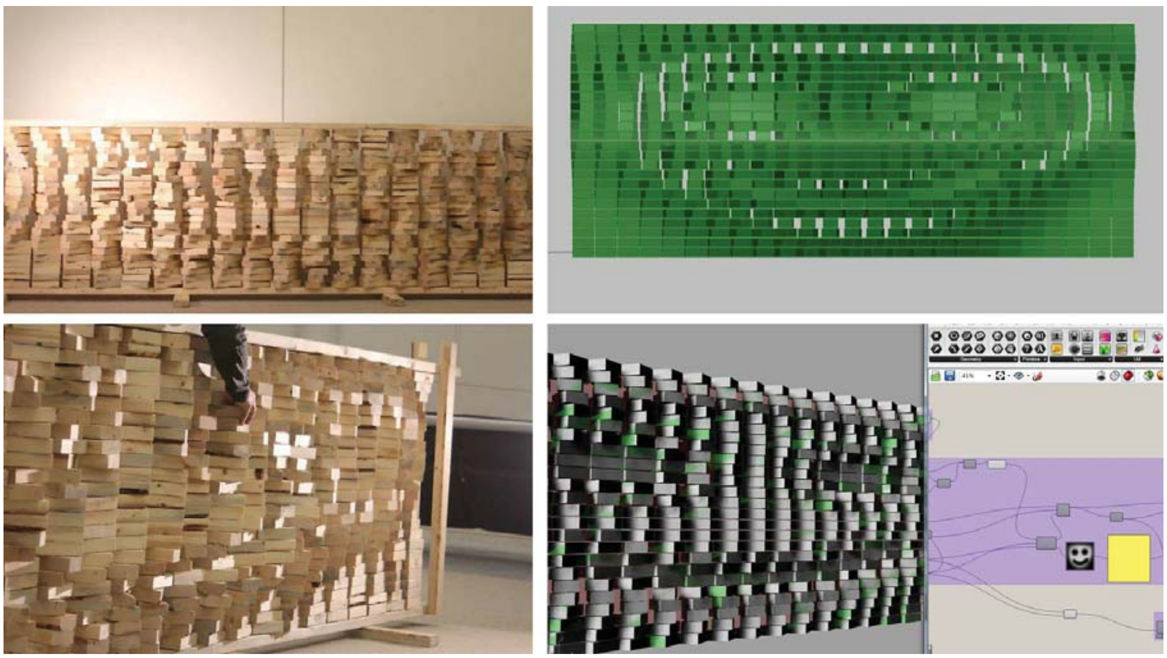

Figure 3. Rigid material for an adaptive wall.

3.2 Soft material, adaptation happens in the vertex level

Students also set up several different methods to investigate how the soft material can adapt to or negotiate with external changing conditions. For instance, student K.B use an analog method to study the adaptive nature of crocheted yarn by dipping it in plaster to infuse some structural capabilities into the material and giving it the adaptability of becoming more than just a canopy tethered to supports[2]. The study emphasized the transformation of fabric and alters the transformation into a different form. (Figure 4) In the computer simulation, the "soft" panels are animated and freeze into series of static panels and later used to populate a skin. Here, the morphing is operated in the vertex level.

Figure 4: Soft material, Gaudi Catenary study. The “soft” panels are freeze into series of static panels and later used as skin component.

4. Data processing

The research looks to build upon the strengths of rule based method and capture the benefits of parametric modeling by integrating abstract data into the modeling and fabrication process. The imported data were used to select specific type of panel from a large gene pool, as well as modify its morphologies to fit the skin surface. The author developed a parametric process, which evaluates the data represented as color values in an image. The image is then mapped on the surface. The parametric model defines how each panel component should adapt to the corresponding color. Similar as the bird morphed to different shape due to various geological locations and environmental conditions in the Galapagos Island. Skin component can also evolve and adapt to different surface conditions such as self-shading, surface curvature and stress analysis. (Figure 5)

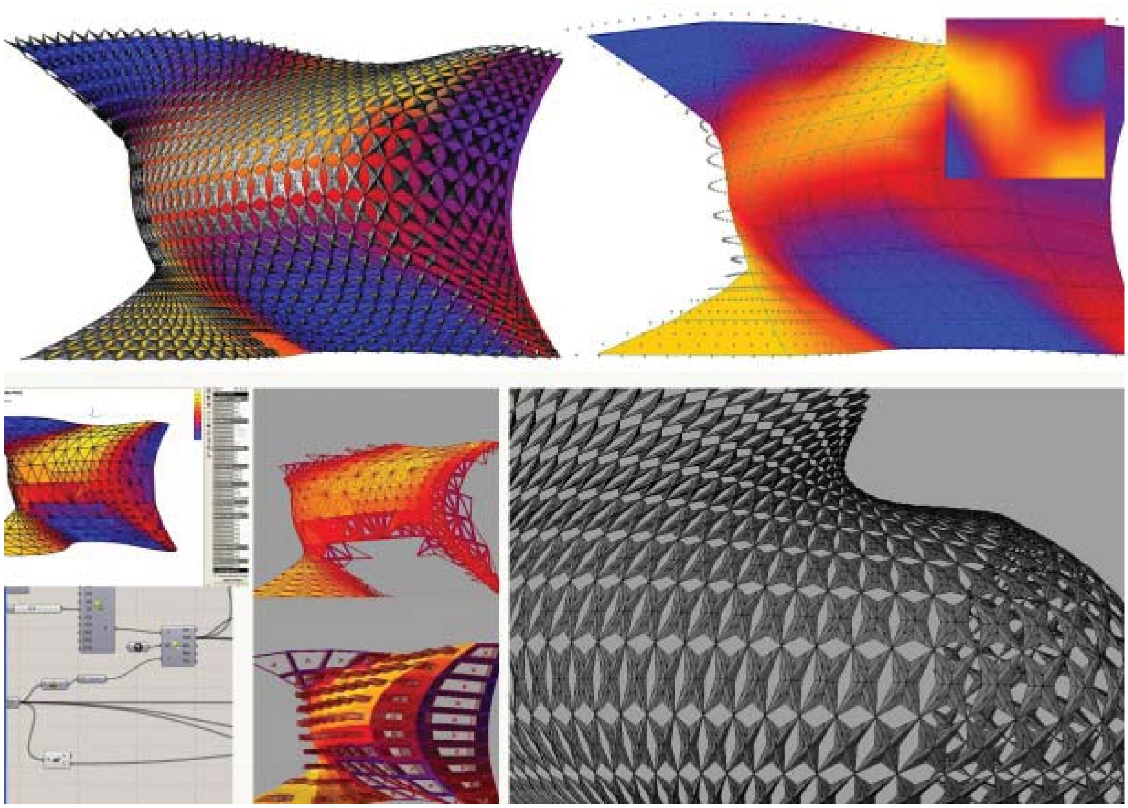

Figure 5. "Soft" panels morph across the building surface,
controlled by the solar radiation data.

After several successful exercises, student T.S comment on this process as, "Using newer simulation techniques, the responses of morphing building forms can be more accurately modeled, allowing for a greater complexity of form and change. In this case, Parametric design, allows a set of rules to morph existing systemic geometry to new constraints, and simulation allows for further testing and morphing to add to a structures ability to respond. Ultimately, the goal of creating adaptive structures that responds actively to wider conditions require a system that can both define existing and new rules, and adapt them to new constraints."

5. Projects

5.1 Skin driven by the exterior data

The idea of adaptive components has also found applications in architecture such as adaptive façade systems, lighting systems, mechanical systems. Designers today no longer need to view the building skin as static objects but as adaptive machines that are driven by various local conditions. These sophisticated skin systems have capabilities to monitor the exterior weather and modify interior environmental conditions. This project explored how the rule-based computation can change a 200-panle wall from a homogenies skin into an adaptive machine that are able to respond to different exterior conditions; light, temperature. Here, skin is no longer about Cartesian coordination; rather it is about a multitude of relations and movement. In the project, the authors developed a procedural to use image information to drive the digital fabrication process such as panelization and perforation. Each of the 200 adaptive panels responds the environment input independently. (Figure 6).

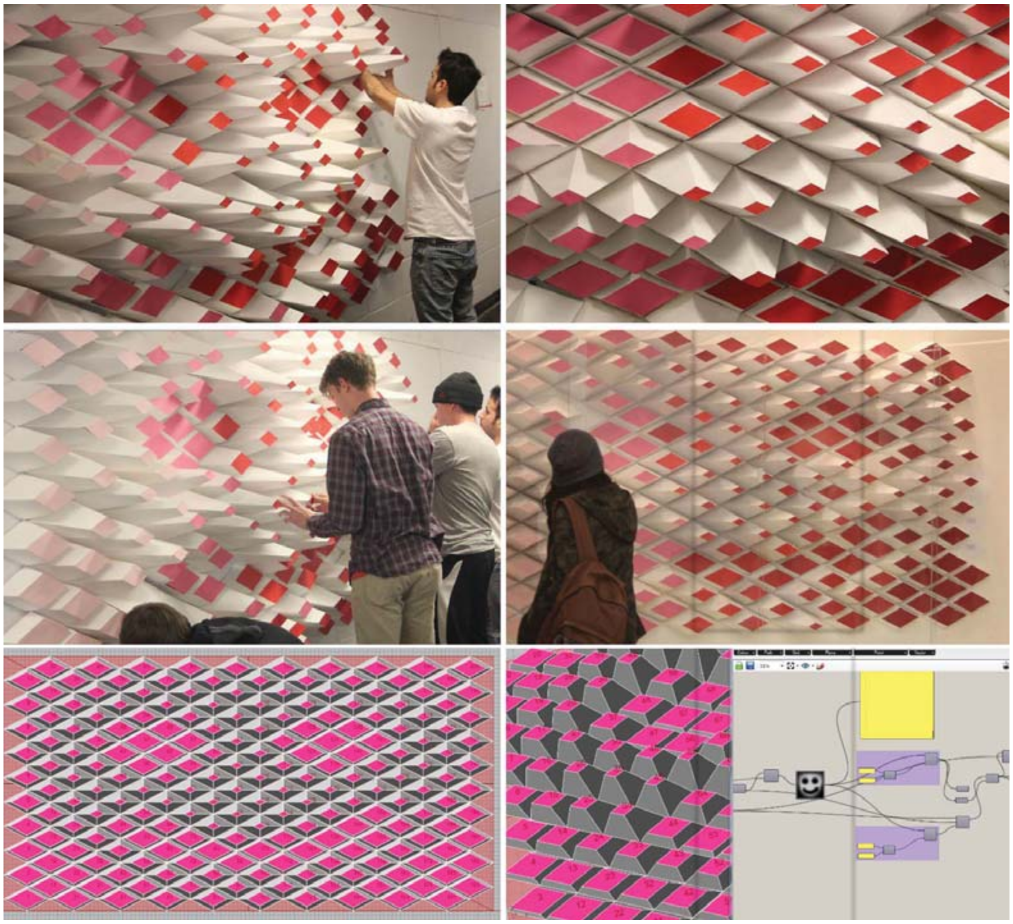

Figure 6. Heterogenic building skin using image analysis as driver to morph the skin.

Students were required to use the concept of thematic map to develop a sequence of raster images that are projected to a smooth surface. Then morphing weight, saved as a bitmap were inputted to yield a matrix of adaptive panels that acted independently. As a result, students created a high degree of complexity and explored the dynamic possibilities of building skin with relatively simple input information. For each morphing panels, students first defined parameters to capture color values embed in a 2D bitmap. By linking the 2D bitmap to each panel's morphing weight; the skin performance data such as lighting, acoustic, thermal or esthetic can be integrated into the topology. Here, the encoding of parameters as a bitmap let the students easily visualize the inter-connection between the data input and the corresponding variations across the skin.

5.2 Skin driven by the interior data

After exploring the heterogenic skin driven by the exterior data, the method of parametric relationship was reinforced to study the interior linkage between building skin and building program. The objective was to assist students to understand how the building skin is driven by the interior data, such as building program, circulation, public and privet space, and etc. The studio viewed a skin as an interface containing a large quantity of adaptive components, driven by the interior quantitative data. A modeling process has been developed by the author where the results were a complex skin system that was customized based on the proximity of the skinto the building programs it contains. This method demonstrated itself with a great power and an unlimited potential of form exploration of skin model. (Figure 8) Formal and spatial explorations using concepts of cellular automation, through the use of the Rabbit plugin to Grasshopper, allows for a mathematical pattern to be used directly in design process. The Conway's Game of Life is the cellular automation used in the project to create a spatial layout. The rules of the game create an animated pattern[3]. These rules were used as program organization tool, as well as creating a system of skin panels that is inter-related to the void public space defined by the cellular automation. Environmentally, this adaptive skin allows each public space to have access to light and ventilation. Programmatically, it allows for public space to combine in various patterns and arrangements for a wide range of functional needs. Experientially, the skin panels create dynamic and unpredictable interior and exterior relationships, spaces, and masses.

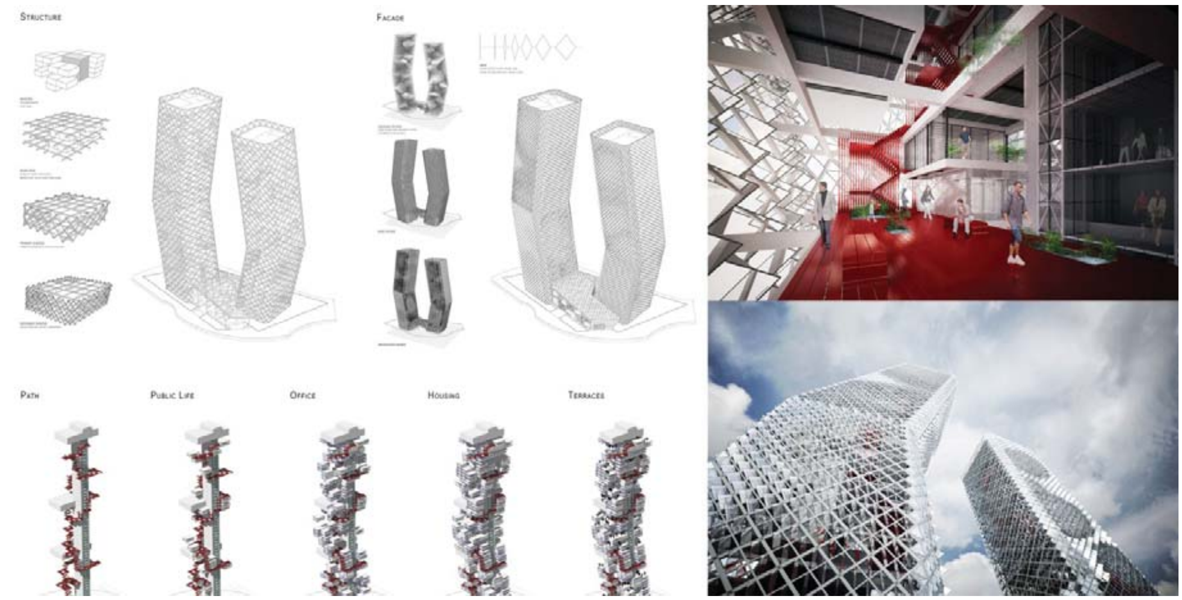

Figure 8. Cellular automation driven skyscraper skin study. In the project, the cellular system is used as a spatial layout tool to create the proposed concepts of vertical urbanism – the interpretation and application of program conditions to the vertical built form. The cellular structure enables the three main focal points of the project – a vertical path between cells, and diverse massing and voids cells, and adaptive skin wrap around the cells.

6. Conclusion

These several research projects examined approaches where rules were set and integrated into the parametric modeling pipeline in order to explore the potential to parametrically controlled adaptive skin. The projects extended to the spatial interaction within the rules and adaptive objects. The form seeking was accomplished through the exploration of several information processing techniques based on exterior data (environmental, esthetic) and interior data (functions, programs). The authors believe that the results expanded the boundary of conventional building skin design.

However, to facilitate this new design process, the marriage between the human design decision and computer controlled modeling needs to have a seamless transition that allows designers utilize the tools to evaluate design iterations. Students have argued about the computer driven optimization process and human involvement in the system[4]. They examined how "human elements" are actually controlling the data processing and final result[5]. Student A.C emphasized the human elements to "control, vary and prioritize computational results" and stays skeptical about "the heavy-handed parametric approach"[6]. The authors believe the students' reflections and healthy debates are embarking on a practical way to overcome the gap between human and digital process.

We can conclude that the humanistic evaluation of architecture tools such as parametric design programs have created a concept of instability and de-centralization of static form. The paradigm in architecture has also been conceived as an ideal form captured as single entity. It wasn't until architecture theorists such as Reyner and Banham noted the possibilities of mutable relationships between skin systems that we were critical of the architecture process and outcome. Today, we can see a much more interactive process influencing the evolution of form. The shift to morphogenetic concepts is a result of the evolution of design tools commonly used in industrial design and aeronautics. Within the process of creation, skin is now understood as a process of individualization of its paneling components, or modulation that behaves singularly to its specific condition.

Adjacent to the topic of adaptive morphogenetic, the topic of adaptive topological creation has also influenced designers to think of form as a part within a system where identity and position of each element is a multiplied across a field of constraints. Here, the formal order of components is decentralized from the predetermined form and exclusively ordered through its relation with all other elements within the system. So instead of thinking about the form as the center, parametric design has taught us to specify the process of creation first, before defining the multiplicity of elements and local sources that will determine the formal elements adaptation.

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Endnotes

1 "Comparatively speaking, genetic evolution and transmutation are successful in biology, but the use of these processes in the architecture field is limited by a major constraint. The design processes are often missing a "shared body plan", which can be defined by common ancestors found in natural life forms passing their shared body to its offspring. In other words, by changing the proportions of the components in the shared body plan, various types of creatures begin to be generated.

2 The crochet would take on a gradient, where the holes in the pattern would grow smaller or larger depending on program and the fabric would go from soft to hard and back again depending on where it was in relation to the façade. At its most rigid moments, the fabric would become a part of the building skin, fully integrated and almost unrecognizable as fabric. As the program changes from private to public and inside to outside the fabric would gradient from hard to soft, beginning to pull from building, unwrapping into the landscape and adapting to its surroundings as a soft, fluid, and

dynamic fabric piece. It is through this change in material that the building and its skin can adapt and move.

3 http://en.wikipedia.org/wiki/Conway%27s_Game_of_Life.
Any live cell with fewer than two live neighbors dies, as if caused by under-population.
Any live cell with two or three live neighbors lives on to the next generation.
Any live cell with more than three live neighbors dies, as if by overcrowding.
Any dead cell with exactly three live neighbors becomes a live cell, as if by reproduction.

4 Student A.C argued "How important is human creativity in design? And at what point should we get involved? To simplify this idea we can think of getting involved in a parametric design at two separate points, at the start or at the end. We can either start by designing a humanized form to then be enveloped by a parametric skin, or the form can be parametrically derived first and then humanized later. Not many large projects today do a great job combining these principals in a way that is seamless, as if both humanism and parametric evolution were simultaneously considered."

5 Student T.M argued, "The final results of the simulations can only be reviewed in regard to how successful the designer was in determining the malleable factors generating the form…. The relationship between computational adaption in the architectural and urban landscape can therefore be scrutinized based on the effectiveness of the 'human element' as the designer must determine the parameters, evaluate the results, and integrate the solutions with complimentary simulations and contextual factors."

6 Student A.C argued. "Where we differ is in your assertion that the human element should be used to control, vary and prioritize computational results. This is a heavy-handed parametric approach, where as I would argue a much lighter derivation. Personally I could never completely trust computational results and would instead use them as a stepping block or starting point for my own design, rather than choosing just the variables of focus I would argue the importance in prioritizing these variables and constraining them personally, or using them as design inspiration.