Oz

Volume 33 Article 9

1-1-2011

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Recommended Citation
Howe, Nathan (2011) "Augmenting Architecture through Algorithmic Modeling," *Oz*: Vol. 33.
https://doi.org/10.4148/2378-5853.1491

Augmenting Architecture through Algorithmic Modeling

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Introduction

Algorithmic modeling has infiltrated schools of architecture over the last few years. It promises to not only revolutionize the possibilities of form making but also to establish immediate work flows of fabrication that explore performative based outcomes. These outcomes give the architect more control over the built environment and provide a methodology from which this design tool can help implement more intelligent design, while not losing constructability.

This being said, one of the main issues with algorithmic modeling is that it is an explicitly goal-driven tool. If one wants to get from point a to point b, a straight line or curve is drawn. This type of goal-oriented process works great when the goal is clear. However, architecture considers complex formal, contextual, programmatic, societal, and historical issues; there is no one goal being achieved. Burry and Maher (2003) would argue that all various sourced data must be gathered before beginning the parametric process. However, given architecture's iterative process of design, this appears a rather unattainable ideal. This ideal is better suited to an engineering framework than architecture. This paper proposes a looser version of problem solving, more in line with Newell Shaw and Simon (1957)—one of reductive problem solving. If the designer can drill into each major element individually, while still considering the whole, the project will achieve a level of success.

To create a situation of reductive problem solving, the designer must know what the overall objective is. This is never an easy task because of all the forces applied to the act of designing a building. However, architecture is based around problem solving, so it is important that the designer make clear the concept for the building. Designers who jump straight into the script must temper their enthusiasm.

To achieve success within a script, one must consider a systematic approach, much like a mason. A mason must have a level and strong foundation and each stone must be considered for its job of carrying the structural forces. Once the stone has been cut and approved, it is laid. It is constantly checked against the whole for plumb and level.

Script is built similarly, with a series of components. Each component is placed to achieve a task and then checked for accuracy and for success against the whole. It is important to note that although algorithmic modeling asks the developer to be systematic, the objective of using algorithmic modeling as a design tool is not to turn the designer into a computer programmer, but to teach the grammar of a casual programmer, so that one might create ideas of architecture based upon ideas achieved through the script. (Çolakoglu and Yazar 2007)

Pre-processing

Videos on algorithmic modeling are by their nature rather procedural, obviously geared toward addressing a specific formal problem (some of the best are at digitaltoolbox.info). This tends to lead young designers to believe that algorithmic modeling is the start and end of the design. However, this could not be further from the truth. There is pre-processing required, along with post-processing. Given the nature of algorithmic modeling, it is important to fully understand the nature of the geometric and associative qualities of the program. This process becomes most fluid through executing a series of drawings. This time honored, conceptual phase has not changed and allows for a more effective use of time and energy when paired with algorithmic modeling. In essence, this becomes the "storyboard" (Figure 1) for the various compositional elements of the model. With this simple drawing, one can evaluate what methods should be used to create the proper script. This is a critical step. Just as designers should never enter the computer before having a clear basis for a building's design, the storyboard becomes the procedural logic upon which to base the script (scripts are a computer language from which algorithmic modeling is based. I teach and use Grasshopper, a visual scripting program plugged into Rhino). This logic helps designers to first visualize the procedure with the hand and eye so that they do not waste time scripting unusable outcomes, allowing the script to be only the armature of the idea, not the idea itself.

An example of the storyboard is shown in the first cell of Figure 1, which describes the profile for the major structural element used in the subsequent cells. The next cell identifies the given number and space between structural elements; each of these can become an adjustable parameter. The rest of the cells give further permutations which can be explored, making the design more complex, yet perhaps more responsive to its programmatic or contextual needs. Storyboarding is designed to be rather simple in its logical outlay. After designing and teaching algorithmic modeling over the last year, I have discovered that simpler is better. This allows the designer to flourish instead of the algorithm assuming the task of designer.

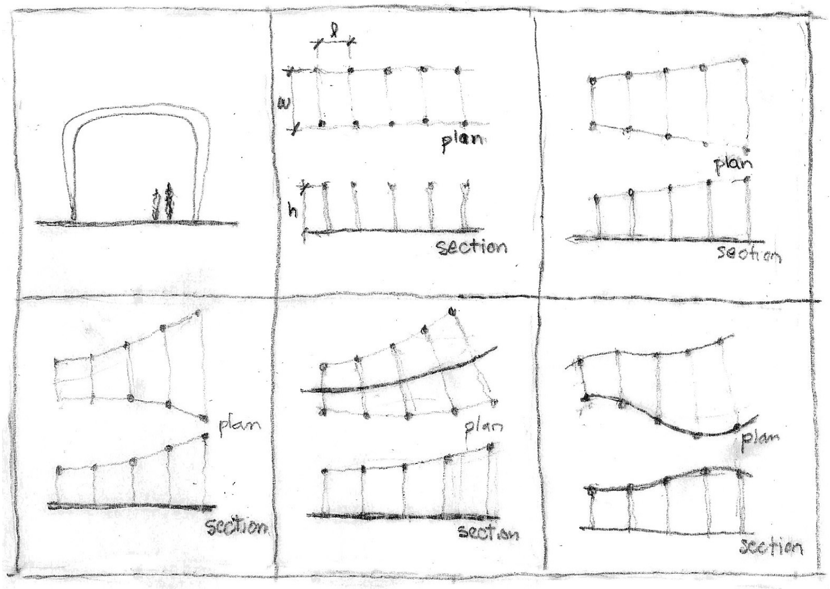


Fig. 1. An example of storyboarding; possible plan and section permutations to script and explore.

Algorithmic modeling

Once these series of formal relationships are established, the algorithmic modeling can begin in earnest. Consider the second cell of Figure 1. This is a structural grid at its most simple where w (width of structural span), h (height of structural system) and d (space between bays) have a constant relationship. This establishes proper relationships for each parameter and allows for their modification as new information is gained or further formal design rules are created. This first construct thus becomes the foundation upon which other layers of complexity are built. In this case, the next cell shows a desire for the plan and section of the structure to expand linearly in height ($h_n = 1.2 \times h_{n-1}$) and width ($w_n = 1.2 \times w_{n-1}$). This type of transformation is quite simple and easily achievable using a series component for the number of bays and scale factors from the established algorithm. Even given a more complex geometric construct, it is best to distill the transformation into its most basic parts and then build the complexity into the script, rather than starting with all complexities. As each step is established, further complexities can be added. When new to algorithmic modeling, this slow build will allow for immediate success, which will then lead to further opportunities as knowledge of algorithmic modeling is internalized.

Next, one can consider a more complex structural relationship by simply changing the algorithmic relationship from linear to exponential ($h_n = h^2_{n-1} - 2n + 10$) ($w_n = w^2_{n-1} - 2n + 10$), thus providing a parabolic relationship with the structural grid. This framework could then be further customized to add another source geometry, a curved spine that the structure follows, as shown in cell five. As is the case in the Marine Research Centre, the last case study, the final cell establishes a series of source geometry curves, which allow for a more sculpted appearance to the outcome in both plan and section. This framework becomes the hybrid between an algorithmic transformation, which cells two through five follow, and a parametric construct with source geometry interacting to create the basic skeletal form in frame six.

Once the major concept is clear, it is then helpful to consider the task at hand as the series of geometric translations it is. In this case, the structural grid was the point of departure. This is one of the most exciting qualities of the algorithmic modeling tool; it needs a framework to create the form. In architecture, the organizing scaffolding of design is consistently, the structure. Those who teach will understand that students have a tendency to think form first and structure hopefully second, but in the worst-case scenarios, it is dealt with last. Within the following case studies, one will see how this framework of structure is an essential consideration.

Case Study 1 : Dripple
Iterative Formal Constructs

This project asked students, in the first two weeks of studio, to transform their rather banal studio space by using simple materials and technologies on hand, with algorithmic modeling software, which I would introduce. This type of fast-track, design-build project creates an immediate relationship between design process and built form. With algorithmic modeling as the backbone for the project's formal quality, as well as its construction technique, the students could discover another methodology for design concept to actualization.

The design process was compressed. Each of the sixteen students presented their concept for the studio and then those concepts were quickly grouped into similar ideas and elaborated upon the same day. A constant conversation occurred through this process. Along with overall design objectives, we asked the questions, what materials will be needed, how will it be fabricated, and at what cost? This process produced a concept of an overhead cloud hovering above the studio. This cloud would be formed by a focal point, which would ripple away from the location of the studio's site model, located directly below (seen in Figure 2). The design chosen would achieve the form through sectioning thick cardboard, as seen in the image.

To fabricate the cloud, we used the school's laser cutters. The main problem with this concept, which we encountered during fabrication, was the tool itself, a laser cutter with an 18-inch x 32-inch bed.

The class recognized that the waffle sectioning system was a rather overdone fabrication technique and they desired to push the esthetic qualities of the design. Once again, the students divided into groups to further develop the fabrication and formal qualities of the design, given the conceptual rippled form. The various iterations of fabrication techniques, produced by the class, became a fantastic way to inform them of the myriad of alternatives available to achieve one form. The rippled form was adjusted, but remained relatively intact from the original concept. However, with different materials, ranging from cardstock to cardboard, chipboard, sheet metal and various patterns of construction, the students saw that the form could take on vastly different atmospheric and formal qualities. With each of the variations, the algorithmic scripts were created to render concepts and to estimate potential material and cost needs. The final design concept for fabrication revealed a unique technique of a cellular construction type.

This achievement of a 16-foot x 35-foot structure was not without its trials. Some of the cells, as they traveled further from the focal point, were so large that they needed up to three parts to make their whole, given the limitations of our laser cutter's 18-inch by 32-inch bed. Through the week of construction, the students had to coordinate the fabrication of over 800 parts. The students found that modular construction was the best method for installation. On the ground, they created an eight-foot section and then lifted it into place. This not only made the install more fluid but also allowed for multiple teams to work simultaneously. The final outcome (Figure 2) shows the students' cellular, rippled form that they affectionately named Dripple.

Case Study 2: SpiderLace
Establishing Form and Fabrication

This project created an installation based on ideas of lace. This was the first project I conceived with algorithmic modeling and thus many lessons were learned. The algorithmic modeling was not geared to simulate the physical structure of lace, but to come to an ideal of open and closed patterns that would imbue a sense of lace, and when light penetrated through the object, reflect a lace-like quality. While lace was the impetus, the pattern was driven by the natural system of spider web patterning for structure and overall formal effect, thus creating what became titled SpiderLace.

In constructing spider webs, the spider first creates anchor points at the periphery to provide the major points of tension. Once at least three points are stabilized, the spider works from inside out to create other spokes from the center. Once the spokes allow for the spider to span between each, the spider will work from outside in, creating concentric rings getting more dense in construction as the center is reached. This pattern results in a beautiful tensile structure and, as in lace, has a clear ordering system. However, it is organically constructed based on its context, the spider's body, and its function as a hunting device. This pattern is a voronoi pattern (a pattern found in nature which follows a natural ordering system of cellular construction, e.g. dragonfly wings, giraffe skins, cracks in dry soils). This type of ordering was an important element in SpiderLace's development.

The overall form would be created as a serpentine form to allow for a

Fig. 2. The final results of the Dripple hangs within the space transforming the banal studio into a truly creative environment where light plays through the form creating ambient light

freestanding, structurally stable element. This serpentine form became the pattern's context, from which the tension and foci pattern of the voronoi would be dispersed. The voronoi pattern utilized focal points, which were coordinated so that each adjacent panel would have connective tissue to the whole. These foci were then used to create a randomly ordered scattering of points from which a voronoi pattern was developed. These foci were thought of as individual spider webs strung together to create a field of organic tension. These ordering principles were part of a design rule set, generated by and placed within the algorithmic model, so that voronoi patterns could be analyzed quickly.

Beyond the pattern, there were other design goals adding their own complexity. To consider lace within the built environment, I felt it was necessary to give the individual a more one-to-one relationship to the piece, effectively immersing the individual into the qualities of light, color, reflection and shadow of the piece. Its scale became one of a 30-foot long by over-six-foot high sculpture. This scale not only fills an individual's field of vision but also immerses their periphery within the play of light and shadow.

Given the project's scale and formal qualities, specific measures of context also drove many design decisions. The first and foremost complexity was that it would be assembled here in the States for testing and then flat-packed to Australia to be on exhibit at the Powerhouse Museum in Sydney. This, along with the size of available fabrication tools and materials, made a panelized system the ideal scenario for conceptualizing the ideal and actual artifact. The second complexity was to develop a script that would essentially create the part files for fabrication by CNC devices, as seen in Figure 3. This would allow for precision and the mass customizing of the form and its structure. The final complication was in the actual fabrication. A handcrafted die-cutting tool had to be fabricated to turn a local CNC router into a large-flatbed die-cutting device. Heavy card stock, 0.05 inches thick, provided a lightweight material with which to work.

To allow for the correct patterning of both the panels and the whole, a script was written to create a randomly warped grid of points for each panel. Although this pattern worked well, generating a tension within each panel (also making SpiderLace a finalist in the competition), this system was scrapped because it became impossible to create connective points between adjacent panels. With a small team of students helping with the prototyping of SpiderLace and final full-scale product fabrication, we decided to go with a complete overall pattern that would be dissected into the various panels after the pattern was created. This provided for a cohesive whole. Once this pattern was established, another analysis of each panel had to be performed to

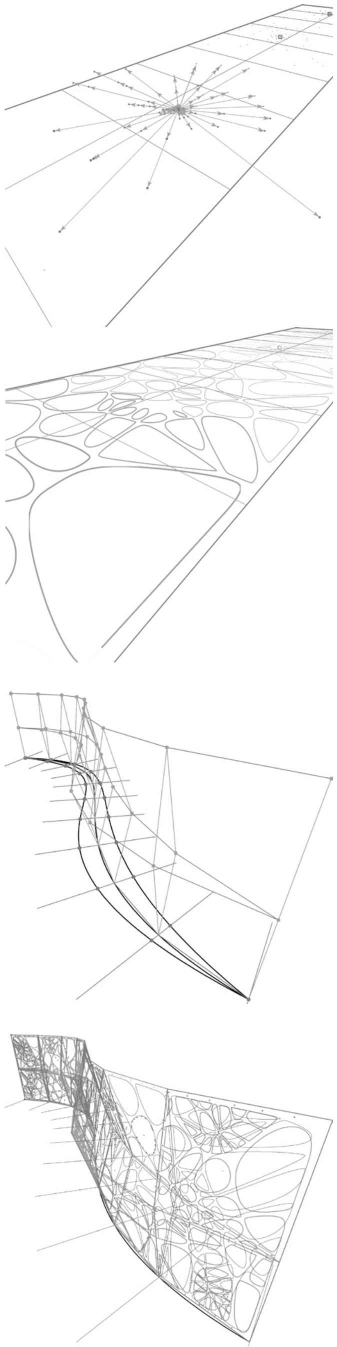


Fig. 3.

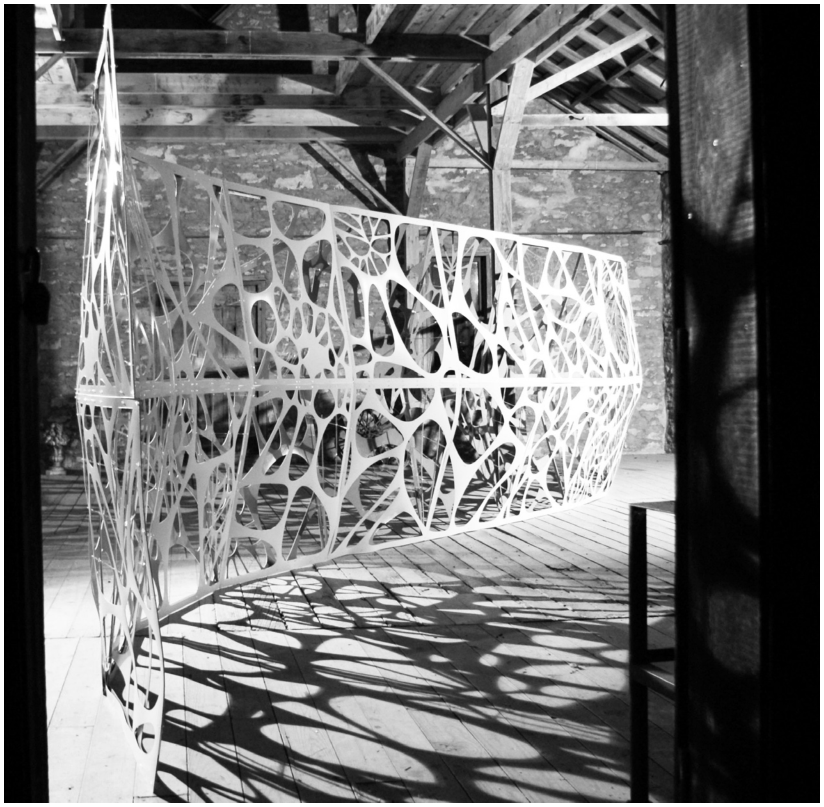
make sure its individual patterning was dense enough to be structurally stable. As the structure had two sides, the patterning of each was superimposed to analyze whether the open and closed patterns were complementary to one another.

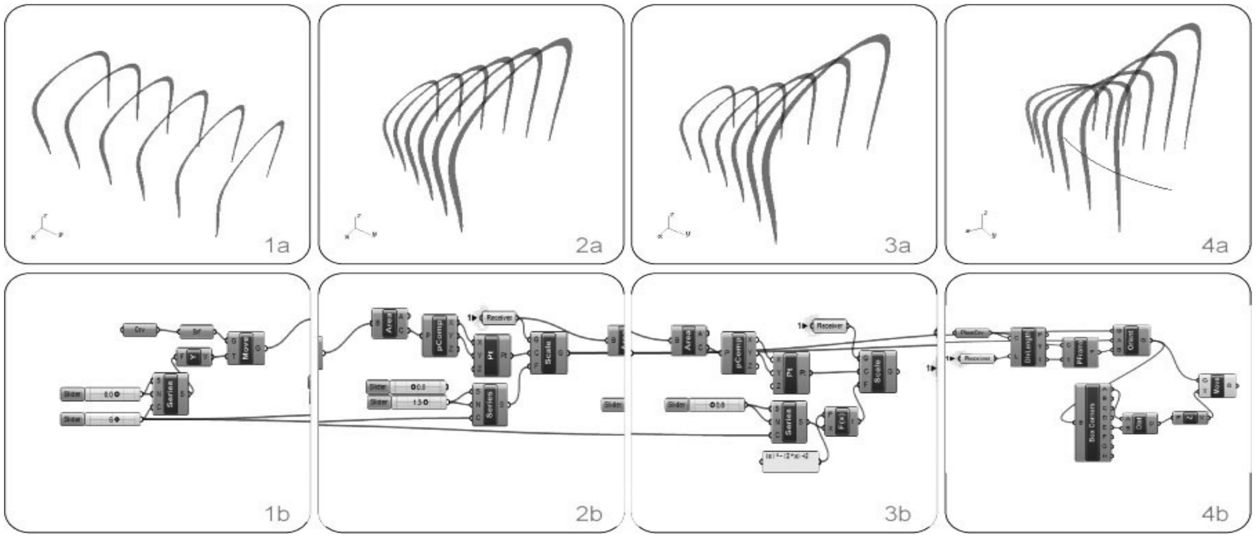
Further studies of the heavy cardstock material being used for the panels were analyzed to establish a set of performance-based parameters, which would allow for the structural integrity of each panel. This type of numerical sophistication gave complete control over a large field of variables. It is this type of overarching governance, over the entire formal and performative qualities of a design, which allows algorithmic modeling to augment the design process. One can run through an entire series of iterations quickly and make strategic design decisions both aesthetically and performatively in short order. One morning, the six of us working on the project sat down together with the patterns of both sides superimposed, projected on the wall of my office, comparing over thirty iterations in an hour. Using paper as the primary, experimental material had its own issues, specifically in its structural integrity. Paper can be a rigid material, but requires folding or curving to hold up when spanning a 36-inch by 36-inch panel.

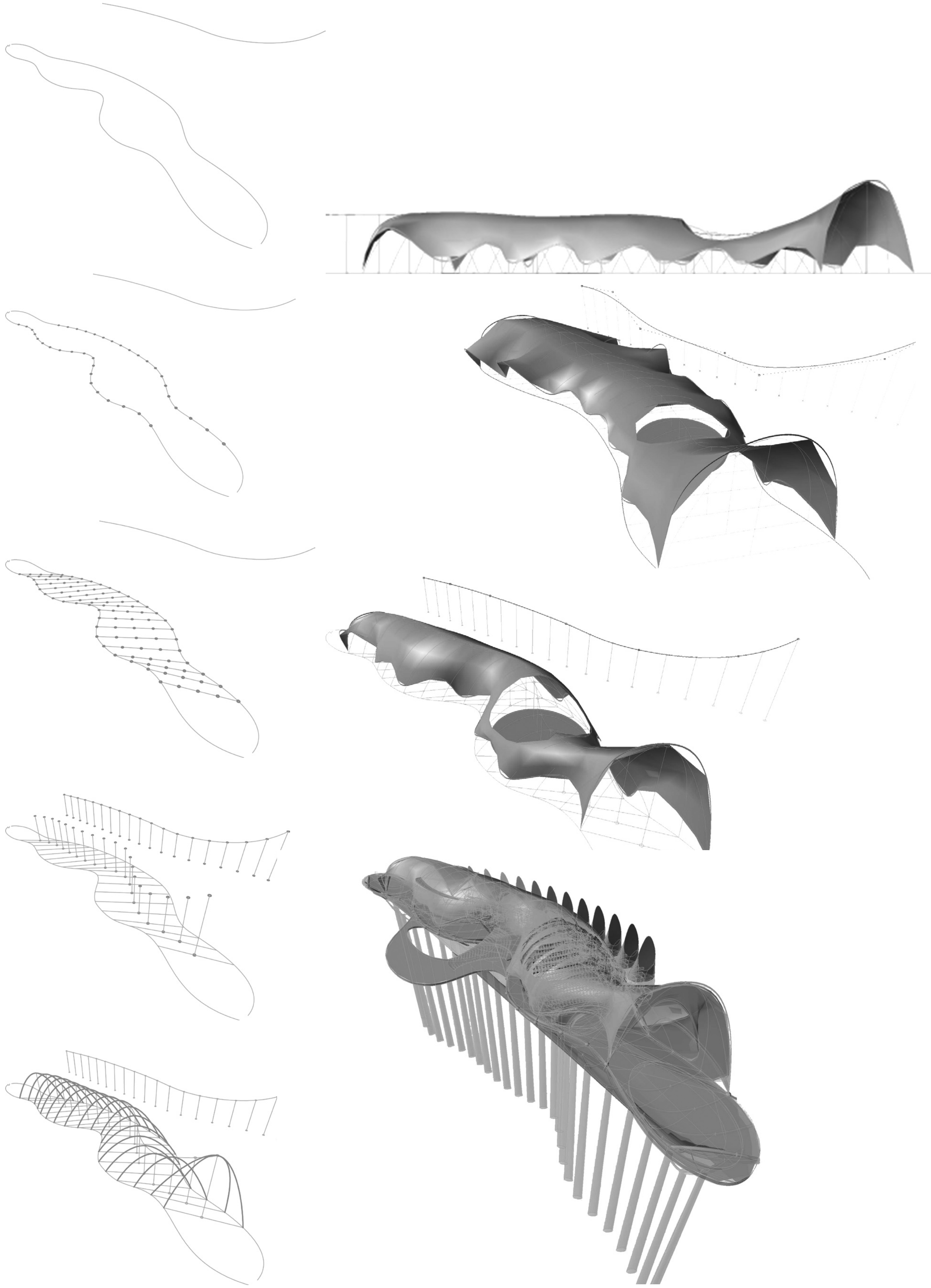
To resolve the structural issues of attaching the panels, a network of acrylic struts and fiberglass rods were used to attach each panel to one another. This produced a transparent layer of woven material seen directly below the cardstock panel. This interior pattern became literal webbing, making a cohesive, structural whole. This, along with the choice of coloring the interior of each panel blue on one side and yellow on the opposing side, made for a complex perception of light, color and form as one looks upon the interior and sees SpiderLace shift from a blue to yellow background of color.

Case Study 3: Marine Centre Parametric Modeling Buildings

The final case study, unlike the first two, does not consider the manufacturing of architecture, but gives an example of a complete workflow between data and geometrically driven algorithmic modeling from inception to conception. Although the outcome is formally driven, the design is still based on structural principles with spatial complexities. The workflow







shares how the potential of a design process might influence the process of architecture.

This project was a Marine Research Centre off the coast of Bali, Indonesia. Given the aquatic program and the tropical location, the formal geometries of the project required it to be fluid and open to the natural elements. Half of the program was to be underwater, so concepts of structure withstanding the forces of submersion were considered. As a marine research centre, the program was to house twelve scientists and staff for aquatic and tsunami research. The centre would be open to the public. Therefore, the program is split into public and private elements. The major spaces are an auditorium, research library, dining hall, laboratories and dwelling units for the scientists, aquatic garden, seawater pool and fresh water pool.

The concept of the building was for the overall form of the design to act as a literal and figurative shield to Bali. This created a base arc curve that would inform the basic organization of the program. This established itself in two curves on either side of a level floor plate. Much, as was discussed earlier where the structure was established as a subdivision of curves, occurs here, as well, where the two curves were subdivided into five-meter increments. These subdivisions were then further dissected into subsets, with every third bay used as the major structural bay. Each of these increments established parameters, which were adjusted from four to seven meters until the correct relationship was established. This base geometry was then supplemented with sectional source curves (also seen hovering above the two plan curves). This curve, along with a submerged curve (not shown) controlled the roof profile, as well as underwater form. These geometries were then subdivided and shifted to define the structural grid. This grid drove the major structure and other major elements of program that were also placed based upon this grid.

One of the other major, parametrically-driven elements of the design was the auditorium. This space is not only the major element that can be seen from shore in its gold gilding but also the major hinge point of circulation, bringing guests through an entry presentation at the beginning of a visit and then allowing them to exit on the stage level below to view the laboratories, as they work their way to the other major facilities. Using baseline parameters of floor levels of 0 and 4.5 meters, the form grew organically as the number of seats (200) and rake of seating were established. Each of these could be adjusted and the form would expand and contract, becoming more steep or shallow as the design evolved.

The end result of the parametrically-driven model was a design timeframe, which extended up to the moment of presentation. With the choice to render the presentation in watercolor, there was not much time spent rendering. The design phase worked seamlessly until brush hit canvas, and even then, some tweaking was involved.

Conclusion

Clearly, the power of algorithmic modeling augmenting architecture is staggering. It has the potential to influence and transform how we design and build architecture. It connects architects more closely to the fabrication process and it works at all scales. Whether designing screen partitions, atmospheric ceiling planes or entire research facilities, the logic and process of design is essentially the same. Geometric associations and given parametric logic proceeds to eventual output. Where this logic does not mandate good design, it augments the process of design.