Animated Parametric Rapid Prototyping

Earl Mark
University of Virginia, School of Architecture, USA
http://faculty.virginia.edu/mark
ejmark@virginia.edu

Abstract. This paper reports on the use of animation to enhance the observable range of choices in parametric rapid prototyping. Animation extends parametric rapid prototyping in three ways. First, it is used to reveal dynamically a set of possible forms from which to pick out one that may best serve a particular design project. That is, by animating the parameters that drive the geometrical model, we can visualize the continuum of alternatives that lie between specific key-framed settings of an architectural form. Second, animation can be used to pre-visualize a series of geometrical constructions for transforming a relatively raw three-dimensional form into one that satisfies the demands of a completed architectural project. Third, animation can be used to pre-visualize transformations of a given structure based on parameters set to adapt to varied conditions. In each case study, physical models were assembled through CNC fabrication.

Keywords: animation; scripting; parametric; rapid prototyping; design studio.

Case Studies

Animation can be applied at several stages of pre-visualization in an iterative design process that begins with defining architectural forms setup with parametric control, moves on to fabrication, and then continues with studies of the physical objects. In one study, a range of alternatives is animated when the members of a tessellation structure are adjusted in response to the transformation of the underlying surface geometry so as to maximize sunlight penetration in the middle part of the day. In a separate example, animation is applied to pre-visualizing the progressive twisting of a structure as in the palm of a hand turning itself flush with the ground. Animation of these alternatives is undertaken before actual fabrication begins. Analogously, in photography, a common technique is to bracket a series of exposures for ensuring a wide enough set of samples of lighting levels for recording an image before the prints are developed. Similarly, the coupling of animation to fabrication allows for continuous variations to be recorded and permits the end user to view a more complete set of parameters depicted in a gradient of changing values from which to pick out the most promising ones. By contrast, without animation, the spectrum of choices is more isolated and the optimal settings may be overlooked. The case studies presented through this paper are based on two courses, a parametric rapid prototyping seminar and a design studio.
studio, taught by the author. The work in the seminar was also tied in two of the case studies to the studio of a colleague.

As reported in a previous paper, customized animation of the CNC tool paths for a milling machine served as a way to gain a better understanding of how to control the texture and graining of the resulting milled object. Animation can be adopted to pre-visualize and directly control the G and M codes guiding the tool paths (Mark 2002). In the present paper, animation is used in the studio and design seminar settings to more dynamically explore a range of possible forms, to explore how they are produced, and to show how any particular set of those forms may be flexibly re-arranged.

**Animating possible forms**

The first example shows how parametrically constructed animation provides for a kind of bracketing technique to arrive at a geometry for light emitting openings in a structure. Several factors are animated to arrive at an optimized form. The openings in the geometry are determined by their relative curvature on an undulating surface. The undulating surface is controlled through a polynomial equation that can be modified. The openings normal to the southern orientation of the sun are relatively open. The openings normal to the east and west of the sun are relatively closed. These settings change as the curvature of the underlying hyperbolic parabolic surface is modified. The student was given an introduction and example of the parametric description of a hyperbolic surface, and then wrote functions for parametrical control of the geometry and its cone like openings. She built into the logic of her program the conditions by which the openings were increased or closed. Her work process initiated with parametrically programmed geometry, animated a continuously varying set of alternatives, and proceeded with 3D printed models as a better way to grasp the form of her cell-like structure.

In the example of figure 3, the development of a tension membrane fabric structure was facilitated through a series of physical and computer animated models. Having abandoned a number of earlier schemes due to limited external surface movement, the student arrived at a structure that accommodated a greater range of configurations. It was designed to retract for storage. It was also designed to unfurl in stages to adjust to varying degrees of occupancy. Furthermore, it was designed to lower its profile during peak wind conditions. Thus, the movement of the structure had to accommodate varying parameters for storage, occupancy and wind. The student explored these alternatives through structuring the animation of her model, then 3D printing...
of alternative joints that allowed for interoperable movement, and then testing for fit with her design intentions.

In the next project depicted in figure 4, the student was interested in movement of armor on a forearm and wrist as it might be described in a parametrically animated structure. The development of an algorithm for describing the structure began with a scan of the student’s arm and wrist.

The scan was then studied by contouring its surface. The algorithm was written using bspline surfaces to rebuild the arm into a more normalized and parametrically variable structure, inspired by the techniques suggested in the morphological studies of D’Arcy Thompson. The resulting geometry was thus parametrically controlled, with greater movements at the wrist and less movement in the base of the forearm. In this way, the student arrived at a scheme in which degree of movement was progressive through the structure. The variations then led to twisted structures that met the ground similar to how a person might turn their wrist in order to position their hand on the ground when doing a push up.
Animating alternative CNC construction alternatives

Similar to the proceeding example, a student started with a static three-dimensional form from the surface of a kiwano fruit. The fruit’s surface geometry was captured with a five-axis table scanner. The resulting data cloud was sampled at varied resolutions and converted to a polygon mesh model. Thus these first steps established the raw data and basic geometrical form. The raw data was then used to create a parametrically generated surface, where variance in the degree of curvature between extreme values was animated. A color chart of the changing angle of geometry along the surface was also incorporated into the procedure so that the rate of curvature could be mapped as a three-dimensional color-coded terrain model.

The animated surface was visual inspected for changes in the degree of curvature. Incorporated into a relatively simple macro, scalar values for the surface were parameterized to create the animation of it between the extreme values. Animating the surface resulted in both an animated color chart diagram of curvature and also more directly a three-dimensional depiction of changes in surface curvature. The final surface was arrived at in part through the analytical advantage of the color chart, where a closer range or colors indicated that a “fair” surface of relatively more coherently changing curvature had been determined. A visual inspection of the dynamically changing three-dimensional model was in effect a secondary form of validation that a desirable “fair” surface geometry was achieved. The final surface was tested through 3D printing a few different alternatives and laser cutting a final version.

Within the next example of figure 9, a set of
louvers was animated. The movements of the louvers were determined by parametrical control in direct response to occupancy or movement. The objective in this example is to create a responsive wall system made from stretchable fabric that allows a person moving through an interior space to determine the angle of louver openings to afford a view and admit sunlight. When not following the person, the louvers would be relatively closed to provide shading.

The intention of a studio project depicted in figure 8 was to create an adaptive fabric structure that could follow the varied site conditions of a meandering pathway through an urban hydrology field. The geometry was also to transform according to a set of generative rules that permitted a structure to be constructed with a well-ordered modular set of reproducible elements. The student adapted rules of a golden triangle to her problem as well as a three-dimensional projection technique.

Through parametrical control, she realized an adaptations to the varied site constraints, letting the geometrical series adjust in size of radius and other dimensions to requirements of particular places along the pathway where the surrounding topography was deeper or turned more sharply. Her process was focused on geometry, and involved rapid prototyping of forms to reinforce her investigation into the fit to site considerations and coherence of her structure.

**Animating the transformations for a given construction**

The development of a tension membrane structure required an assembly from a set of collapsible ribs that rested on top of legs with joints to facilitate the structure’s movement (see figure 10). The
movement of the structure involved designing several alternatives set of legs that would respond to being dragged along the ground by rope or possibly propelled by a motor. The movements were controlled through rotational variables and reflected distinct strategies for different types of legs, each one realizing some advantages of economy of movement over the preceding prototype until a more functional design was realized. These studies required animation with parameters created to determine ranges of different leg movements on a rocky site. Additional parameters were used to control the collapse of the tension membrane fabric structure to a base platform that was supported by the legs.

Within the same studio project, another student was faced with developing a collapsible tension membrane structure at an island research site (see figure 10). The structure was to shrink within a 1/3rd of its overall volume during off-season use. The movement of the structure needed to be visualized to explore how the surface geometry, a tension membrane fabric, would respond to a retraction. The geometry was thus set in motion, moving from a simple cylinder to a parabolic of revolution. Parameters were varied to test for the degree of twisting, the degree to which the length of the original cylinder would collapse, and the sequencing of twisting that occurred from section to section along the cylinder’s longitudinal axis. The bottom set of frames in the figure below is taken from an animation of the
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Figure 11
Pre-visualization of collapsing cylindrical form, Bynum.

Figure 12
Frames from animation, physical 3d printed model and computer rendering, Keller.

study model. The top row of images depicts the final proposal.

In another case study, a structure that aligned itself to the direction of a water pathway was intended to provide series of plant draping structures in a linear sequence. Each instance of the structure had a variable number of branches. Parameters were used to determine a) the number of complete leaf-like structures along the total path, b) the number of “veins” (secondary structure) within a given leaf, and c) the growth of vegetation (tertiary structure) along a particular vein of a given leaf. Thus, this set
of modular structures was described according to geometrical progression not unlike a leaf or series of leaves along a branch and pulled along the current of a stream. The parametrical variables allowed for experimentation with the density and growth of the individual leaves. Animating the parameters allowed discovery of optimal settings for this particular site location in the studio project. Here the constructed sequence was similar to the natural phenomenon of under-water plants responding to the current in a small brook or stream. The direction of the leaf was intended to provide a hanging structure that would accommodate plant growth in the direction of water movement (see figure 12).

In these examples, a group of final year architectural design students were taught animation and parametrical programming techniques. Animation of the forms, CNC parameters and of the potential post-fabricated parts constitutes an expanded design search space. The study points to methods of further exploiting dynamic representations in design and fabrication where a matrix of alternatives needs to be examined for every stage in the design, fabrication and construction process. The projects focused on the use of a 3D printer, laser cutter, and, to a smaller degree, on a 3-axis computer controlled router and milling machines.

A number of the student projects required some direct assistance in scripting their examples by this instructor. A full set of tutorials in writing GC Scripts (see acknowledgements) was developed for the seminar and studio students. Extension of an architectural design studio into the world of scripting and animation seems to engage a generation of design students increasingly at ease with technology and willing to take on the rigors of directly controlling it. The methods move towards a potentially new normative model for design education. Students wrote graphical functions to incorporate procedurally based descriptions. They set out to establish a design space in which parametric variables were animated. Their approach depended upon seeing the result visually and also examining the prototypes physically.

Though it is possible to seek out design solutions based upon abstract measures of materials or their performance, it is more in the traditions of a design studio to work visually and tangibly with media. In the cases examined, animation allows a designer to reason visually with respect to the process of going from schematic geometrical forms to their pre-fabricated and fully assembled realization as architectural objects.

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**References**

