PARAMETRIC MODELLING OF ARCHITECTURAL SURFACES

GREG PITTS, SAMBIT DATTA
The School of Architecture and Building, Faculty of Science and Technology, Deakin University Australia.
grip@deakin.edu.au, sambit.datta@deakin.edu.au

Abstract. Parametric modelling is gaining in popularity as both a fabrication and design tool, but its application in the architectural design industry has not been widely explored. Parametric modelling has the ability to generate complex forms with intuitively reactive components, allowing designers to express and fabricate structures previously too laborious and geometrically complex to realise. This allows designers to address a project at both the macro and micro levels of resolution in the governing control surface and the individual repetitive component. This two level modelling control, of component and overall surface, can allow designers to explore new types of form generation subject to parametric constraints. Shading screens have been selected as the focus for this paper and are used as a medium to explore form generation within a given set of functional parameters. Screens can have many applications in a building but for the purpose of the following case studies, lighting quality and passive sun control are the main functional requirement. A set of screen components have been designed within certain shading parameters to create a generic component that can automatically adapt to any given climatic conditions. These will then be applied to surfaces of varying degrees of geometric complexity to be analysed in their ability to correctly tessellate and create a unified screening array true to the lighting requirements placed on the generic component.

Keywords. Parametric Modelling; Screening; Design; Fabrication.

1. INTRODUCTION

The aim of this paper is to explore the requirements of an individual component, known as a Representative Volumetric Element (RVE), and the ability to control
this within a larger governing surface form. Representative Volumetric Elements are a representation of the smallest repeatable element within a given tessellated form (Bingham et al., 2007). One of the key differences between an RVE and a standard CAD component is the ability of an RVE to have an awareness of its place within a larger pattern as well as adhering to any set parameters and governing surface geometry. This is an important factor in the creation of both an intelligent RVE and a cohesive and tessellated product that fits within all the required fabrication requirements. These requirements encompass function, material and structural needs that can all be expressed as parameters within a modelling environment. To successfully create any parametrically driven model, a clear understanding of the end product is required. The ability to tessellate effectively with the entire array is one crucial element in an RVE’s modelling, but consideration into the final product’s material strength, manufacturing accuracy and required aesthetic or functional needs are all equally important. If these are determined before modelling begins the process of trial and error can be cut down significantly (Eastman, 2004).

To achieve these goals, a wall component has been selected as a subject to express part of a design through strict functional requirements. These include the passive control of lighting quality and direct heat gain from the sun as well as material, structural and fabrication requirements. This, when modelled as a single component, can then be applied within a governing surface geometry to form a tessellated and cohesive structural solution, (refer Figure 1). From this information generated by the model, the pieces can be easily fabricated using Computer Numerically Controlled (CNC) machines from the geometric data provided.

Figure 1. Example of a Louver Component and Application in an Array.
2. Parametric Modelling

The first computer aided design (CAD) tools, introduced in the 1970s, were primarily a replacement for the drawing board. Based on a drafting paradigm, they improved productivity and accuracy of drawing creation. They do not support exploration of design alternatives, variations and changes. Parametric modelling is based on a simple idea, attributed to Geisberg: linking dimensions and variables (parameters) to geometry in such a way that when the parameter values change, the geometry updates accordingly. With this innovation, many design concepts could be explored and changes could be made remarkably quickly compared with the redrawing required by traditional CAD. One key difference between parametric modelling and other CAD tools is the way geometry is modelled. Parametric modelling software solid primitives called features consisting of common engineering shapes such as holes, slots, bosses, fillets, chamfers, protrusions, shells, etc. These features know how to behave relative to each other and are defined by a set of parameters. Rather than drawing the geometry line by line and arc by arc, the designer specifies constraints and relationships between features. The geometry results from these specifications. This means that designers can change and modify the relationships and the geometry will adapt to stay in sync. This kind of modelling streamlines design exploration by making it practical for designers to create many more design variations at a higher level of integrity and precision. A key concept in such systems is associativity, where changes can ripple through from components geometry through the design and all related representations.

The parametric program Generative Components (GC) has been used for the following trials of RVE application within a governing surface geometry. The scripting basis for this program gives it a very wide scope in its modelling application. This is both an advantage and a disadvantage for the following test. The wide scope does not restrict the program unnecessarily within a given field but at the same time was not designed for a specific discipline so experimentation with the interface and capabilities is necessary. Unlike traditional CAD software, GC operates on a hierarchy of events demonstrated in the form of a symbolic tree.

As the name suggests, GC has the ability to create components and apply them to a surface as an array, (refer Figure 2).

Figure 2 demonstrates a construction plane which defines a component, comprising of three rings, and the application of the component to a control surface. This component, or Representative Volumetric Element (RVE), would apply equally to each facet across the surface. The construction plane is a parametric definition for the RVE. This means that when built, it has no fixed dimension values and will orientate and deform to fit within the correlating
facet on the control surface. Because of the components inherent relationship to the construction plane, all the component parts will also orientate and deform along with the construction plane.

The advantage to this process is that complex tessellated arrays can be automatically created from an RVE and a larger governing surface body, eliminating the need to define and orientate each part of an array individually.

3. Component Control

The definition and control of the component geometry is integral to creating correct tessellation in the final array. As previously mentioned, Generative Components has the ability to calculate a components deformation when applied to a controlling surface. This means that to successfully control the performance of a component it has to be built within controlling surface planes that will correlate to the planes in the final application.

Figure 2 demonstrates the application of a single construction plane to a surface. When dealing with more complex 3D components, however, a more accurate method of control is required. The biggest issue with only using a single control plane is that it can only control an RVE in 2 dimensions. To counter this, a third dimension has to be added before the RVE is modelled. As can be seen in figure-below-, by using two offset control surfaces, the entire RVE is always encompassed within a defining cube. As long as the component is not built outside the bounds of the surfaces, the RVE will automatically deform relative to the positions of the eight corner points. The addition of
another input surface also requires a second correlating control surface in order to apply the RVE, (refer Figure 3).

This ensures that as long as the control surfaces have a correctly defined grid with the same division of facets, the RVE will tessellate correctly as an array.

4. Part Composition

The aim of the component was to create a cohesive unit that could be fabricated very simply from the geometric information generated by the parametric model while still adhering to its functional parameters.

To accomplish this, a stackable tessellating unit was designed as a frame to house the required parts to achieve lighting control. The component comprised of external louvers for correct lighting control, a centre planar sheet for weather proofing and an internal screening component to be used for both lighting filtration and aesthetic purposes, (refer Figure 4).
The louvers are the main parametrically variable element of the component. Their aim is to control the sunlight to maximise interior light admission while eliminating direct heat gain from the sun to interior spaces. These would be cast as one piece within the frame based on the optimum positioning determined by the parametric inputs. This requirement is achieved through the use of the solstice angle of the sun at its highest point during the day. As a model to completely eliminate direct heat gain throughout the day, this is not completely efficient. A fixed louver can never be optimal for the range of daily sun angles, but using the fore mentioned solstice angle model as a determining value will eliminate the harshest range of daily and yearly sunlight. To achieve 100% efficiency, a mechanically reactive system would need to be implemented.

The centre plane’s main functional requirement is weather proofing, but as a design element could be varied in its level of transparency to emit more or less light into certain sections of the interior spaces. This parameter has not been included in this model but could be decided during fabrication to achieve different lighting effects. As an automated model, the variation in material transparency could be responsive to design elements such as views into and out of the building or amount or quality of light received. This could be achieved through a proximity alga rhythm to determine the transparency and resulting material requirements for all components.

The internal screens are based on a tessellating pattern design and have been broken down into the smallest possible repeating geometry to be cast as a tiled component. From an aesthetic point of view, these screens could take on any form and may even be a further variable within the model. The only restrictions placed on this part of the component are that it has to fit within the framework and has to work as part of the larger cohesive interior surface. Once again, as an automated model the screen may be adapted to work on a similar alga rhythm to the centre planar element or even work in conjunction to achieve desired views or lighting qualities.

5. Programming Method

Within the requirements of the component a lot of elements were left unknown. These were addressed through the use of graph variables. A graph variable is a type of parameter that is manually controlled within a pre programmed range of values. This differs from other parameters used which will automatically find a single fixed value depending on the given scenario. One example of the use of graph variables is the input of the sun’s solstice angle for a given area. When applied to a specified control surface, the component will automatically fit itself within the determining parameters. This results in most elements only
having a single possible geometric solution for that scenario. The sun angle, however, depends on the geographic location of the structure and therefore requires the input of information that is not directly gained from the control surface or any physical element within the model. This is where a graph variable is used to give the louvers a range to exist within, e.g. - 25 to 80 (Figures representing degrees of altitude angle) Therefore, once the specific design information is known, it can be manually transferred into the generic component as a fixed value (i.e. - 51 degrees for Melbourne), allowing the louvers to automatically orientate themselves to the optimum position for the given climatic data. (Figure 5)

There are three main graph variables used within this components setup:

- \( y^0 \) - solstice angle
- \( y^1 \) - louver angle
- \( h^2 \) - louver thickness

Of these three, the solstice angle is the determining variable that the other two adhere to regardless of their own changes. As can be seen in figure 5 this
is achieved through the use of a hidden framework within the model that controls the entire array as a hierarchy of events. Generative Components has no facility to apply a world orientated angle input so the formwork has to be set up with this in mind. The entire array is controlled from a centre point with an attached coordinate system. The result of this setup is a localised orientation where the coordinate system can order the model elements relative to its individual application rather than having a blanket control for the entire array. Therefore, individual components can behave differently from their neighbours to form a more cohesive and successful array.

From this basis a combination of fixed and variable lines were used in conjunction with the following equation to form the defining framework for the array.

\[ h^0 = \tan(y^0) \times X^0 \]  

In this formula \( X^0 \) is a fixed value while \( h^0 \) is variable depending on the solstice angle value. Despite being a fixed unit, in this circumstance \( X^0 \) is stated as such because it is an arbitrary unit value.

The current models framing size is based on the use of aerated concrete for its fabrication. Due to this, an automated parameter is used to calculate the frames thickness based on the governing surface geometry while adhering to the required thickness for concrete fabrication. This parameter can easily be replaced with a graph variable to manually input the optimum requirements for a range of materials. This type of control would allow engineers or fabricators to immediately have input into the modelling process, to ensure structural integrity, while analysing the resulting impact on the component form.

\[ \text{Figure 6. (left) Completed Array. (right) Exploded view of the Individual Elements} \]
7. Conclusion

The use of scripting to drive the parametric model provided many benefits. The visual, environmental, material and transparency requirements of the façade could be simultaneously addressed within a single model giving a somewhat non-deterministic form within strictly deterministic parameters. This is one of the main design strengths of parametric scripting. Rather than conceiving a design and then having it changed and compromised by each construction requirement, the model is used as an immediate, variable visualisation and design tool. The synthesis of competing requirements arising from the tests could then be optimised within the variable range of the parameters to encompass aesthetic decisions as well as fabrication and construction requirements. By this method each decision and requirement can have immediate impact analysis on the design at both the individual component and the greater building assembly level.

The application of parametric modelling to architectural design allows designers to address the design exploration at both the macro and micro levels of resolution. The key aims of the paper are to explore the range of design allowable within fixed functional parameters and the effect this will have on building design and fabrication.

To facilitate this, an individual component, known as a Representative Volumetric Element (RVE), is used to demonstrate the ability to control repeating geometry within larger governing surface forms. In addition to the modelling process, a case study in sun shading, lighting quality and passive sun control has been incorporated to form a generic component. These components have been designed to adapt to any given climatic conditions through automated geometric variation. The RVE are then applied to surfaces of varying degrees of geometric complexity, as a medium to explore form generation within a given set of functional parameters.

The results of this case study have opened up new directions of research in the design and engineering of building surfaces. For example, the next stage of work will explore the mechanics of movement associated with variable solar conditions and orientation constraints. Another avenue of research with potential is the development of dynamic facades that respond to changing light and shading requirements based on electro-mechanical control of movement and orientation.
References


