Parametric Design Modeling with Autodesk® 3ds Max®


AV5711 This class will describe using Autodesk 3ds Max modeling tools to build iterative parametric design systems. In this class, we will cover Autodesk 3ds Max geometry types (Editable Mesh, Poly, Patch, and NURBS), combine modifiers to build complex systems, use wire parameters to quickly make geometric patterns, and provide an introduction to MAXScript. In this class, you will learn to reduce the amount of explicit modeling you do and instead build flexible design systems so you can focus more effort on design.

About the Speaker:

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David previously worked at SHoP Architects where he held the position of Director of Technology Research. His responsibilities included managing technology R&D initiatives and developing “direct to fabrication” initiatives with software manufacturers and fabricators through the use of BIM.

Since 2006, David has been an Adjunct Professor at Columbia University's Graduate School of Architecture, Planning, and Preservation where he teaches seminars and workshops focusing on the impact of technology on design processes. David received his Master of Architecture with honors from Columbia University where he was the recipient of the Lucille Smyser Lowenfish Memorial Prize and the Computer Aided Design Honor Award.

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This Class will cover the following topics

- Geometry Types
- Parametric Modeling
- Modeling Parametric Walkway
- Modeling Parametric Tower
Geometry Types

Concepts

Points

Figure 1: Point types in 3ds Max

Points are one of the most basic geometric elements and the foundation of most primitive geometric types. Points are represented by an ordered sequence of numbers (coordinates), conventionally represented as (x,y) for two-dimensional space and (x,y,z) for three-dimensional space. 3D modeling applications provide access to points in a variety of ways. In most explicit modeling applications, points are rarely defined directly; instead, they are defined implicitly by creating other geometric objects. Once created, however, these applications often provide access to points through sub-object selection or properties of the base object; for example, the Vertex sub-object selection in AutoCAD® 2012, Autodesk® 3ds Max® 2012, and Autodesk® Maya® 2009 software. Parametric modeling applications often use points more directly, giving users control over the way a point is defined and controlled, which is then used as the basis of other geometric operations; for example, the point object in the new Conceptual Mass environment of Autodesk® Revit® Architecture 2012. Point coordinates are a critical and frequently used geometric property for architectural design, as they often serve as the basis of information exchange between various modeling, analysis, and fabrication applications.
Curves

Curves are fundamental geometric elements for design and 3D modeling. Curves can be generalized mathematically as a continuous series of connected points. Therefore, straight lines, circles, helixes, and conic sections are all types of curves. Curves can be defined and represented mathematically in a variety of ways including parametrically, explicitly, and implicitly with various 3D modeling applications, giving users different access to these methods. Furthermore, curves have numerous properties that can be accessed and used by 3D modeling applications such as length, direction, area, tangency, curvature, radius, and points. In addition to the curve types mentioned above, most 3D modeling applications provide access to freeform curves such as Bezier, B-spline, and NURBS. Following the invention of these curve types in the 1950s, freeform curves can be controlled precisely using relatively few points that create a control polygon from which a curve is derived. NURBS (non-uniform rational B-spline) curves offer the additional shape parameter of weights, which enable users to modify the local influence of each control point on the shape of the curve. B-spline curves are a special case of NURBS curves in which all weights are equal. B-spline curves are composite Bezier curves that have the same tangent and same curvature at the connecting points. Autodesk Maya 2009 offers comprehensive creation and editing tools for NURBS curves, while AutoCAD 2012, 3ds Max 2012, and Revit Architecture 2012 all support NURBS, but offer fewer ways to create and manipulate them.
The ability to create and modify surfaces is a key feature of any 3D modeling application. Traditional surface classes such as extrusion, translational, rotational (surfaces of revolution), and ruled are created by smoothly sweeping a single profile curve on or around another curve. Cylinders, cones, spheres, tori, ellipsoids, paraboloids, hyperboloids, helicoids, and various other surfaces fall within these classes. These surfaces have numerous properties that simplify the process of rationalization into repeatable planar elements, so they are frequently used for architectural design. Yet, there are numerous shapes that cannot be created using these traditional surface classes, therefore it is necessary for 3D modeling applications to support freeform surfaces, most commonly in one (or more) of these three types: Bezier/B-spline/NURBS Surfaces, meshes, and subdivision surfaces.

Bezier, B-spline, and NURBS surfaces are based on the same mathematical principles as their curve counterparts, with a simplified control mesh made up of rows and columns of quadrilateral polygons from which a smooth surface is derived. Also, like curves, the main difference between B-spline and NURBS surfaces is the ability to modify the weight parameter of individual control points of a NURBS surface. NURBS have become the standard surface type within the product, aeronautical, and automotive industries where precise control over tangency, curvature, and surface continuity are a primary concern. But due to the costs associated with building these smoothly curved surfaces for large, one-off architectural projects, NURBS surfaces are rarely used directly in architecture. In most cases, these smooth surfaces are rationalized into panels or wireframe edges, with concerns of planarity and repetition often determining the approach to rationalization. This is where polygon meshes are useful.

Meshes are essentially ordered collections of points (vertices) that are connected by polygons (faces). These faces are typically triangles or quadrilaterals, but other polygons are possible. By varying the size, shape, and density of polygon faces, these meshes can be made to approximately represent the shape of a smooth surface. Mesh models must store the connectivity (mesh topology), which is the relationship between the vertices and faces, the
order of which determines the direction, or normal, of the face. All meshes made of triangles have planar faces, while the same is not true of quad-dominant meshes, although certain classes of quadrilateral meshes are planar and therefore lend themselves to architectural rationalization. Finally, and most importantly, meshes are used in virtually all aspects of computational geometry from visualization to analysis. Maintaining control over the mesh representation of complex geometry becomes extremely important when dealing with analysis applications that use meshes for finite-element (FEM), computational fluid dynamics (CFD), or thermodynamic calculations.

Despite the flexibility of both NURBS and mesh approaches to defining freeform surfaces, there remain certain shapes that are difficult to achieve with regular meshes or control polygons. This is where subdivision surfaces come in. Subdivision surfaces were initially created for use in 3D animated feature films. The process of creating a subdivision surface involves multiple levels of refinement of a coarse mesh, until the desired level of smoothness (which can achieve that of a B-spline surface) or face size (in architectural applications) has been reached. There are numerous subdivision algorithms available and 3D modeling applications often provide access to more than one. The three most common approaches are Doo-Sabin, Catmull-Clark, and Loop, which are all named after their inventors. Both Doo-Sabin and Catmull-Clark rely upon quad meshes, with Catmull-Clark producing smoother results that are further away from the initial control mesh. Loop subdivision utilizes and produces triangular meshes. Although subdivision surface modeling has made its way into architectural design via animation tools used by architects, their utility is limited due to the lack of control over the results of the smoothing algorithms. Therefore, geometry created through this process is often remodeled or converted into either NURBS or mesh surfaces for rationalization.

Revit Architecture 2012 provides tools to create and modify B-spline surfaces and supports NURBS surfaces created in other applications. Additionally, the new patterning tools give Revit users the ability to break smooth surfaces down into polygons. Maya 2009 is primarily a NURBS surface modeler, with some support for both mesh and subdivision surface modeling. AutoCAD 2012 is primarily mesh-based, with the new freeform modeling tools adding new subdivision surface creation and editing tools. 3ds Max 2012 is also primarily mesh-based, with the new Graphite Modeling tools building upon an already strong base of polygon mesh creation and manipulation tools. 3ds Max also supports subdivision surfaces, but has limited support for NURBS surfaces.
Parametric Modeling

Concepts

Solid Modeling

![Solid Modeling vs Surface Modeling](image)

**Figure 1:** Differentiation between solid modeling and surface modeling

Solid Modeling is a technique in computer-aided design (CAD) that allows for the representation of solid objects. Its primary uses are for fields such as architectural design, engineering analysis, computer graphics, animation, product visualization, and rapid prototyping, among other things. Originally, solid modeling software used one of two methods to define solid shapes, either constructive solid geometry (CSG) or boundary representation (B-REP). CSG uses solid primitives such as rectangular prisms, spheres, cylinders, and cones, and boolean operations such as unions, subtractions, and intersections to create a solid model. B-REP methods, on the other hand, begin with one or more wireframe profiles and generate a solid model through one of various processes such as extrusion, sweeping, revolving, or skinning. Additionally, solids can be constructed through a sewing operation, which is a process of combining surfaces that often have complex shapes. Because each of these solid modeling processes have their own advantages and limitations, it is often most beneficial to generate solid models using a combination of both CSG and B-REP techniques. Autodesk applications use a hybrid of these techniques with AutoCAD® 2012 and Autodesk® Revit® Architecture 2012 providing native support for solid modeling. Models created by sewing surfaces in Autodesk® 3ds Max® 2012 and Autodesk® Maya 2012 can be exported as DWG files and converted to solids using AutoCAD 2012.
Parametric Modeling

![Image: Precisely controlled modification of a parametric geometry]

**Figure 2: Precisely controlled modification of a parametric geometry**

A parameter, in its most general sense, defines a system and determines the limits and performance of the system. A feature of some CAD applications is the ability to construct a model parametrically. Within a parametric model, each entity such as a primitive solid, a line, or fillet operation possesses associated parameters. These parameters control the various geometric properties of the entity such as its length, width, height, radius, and so on. They also control the locations of these entities within the model and how entities relate to one another. For example, geometric entities can be located at the origin of a curve, the midpoint of a line, or the vertex of a face. Additionally, the parameters can be adjusted by the operator as necessary to create the desired geometry. This process is known as *parameterization* and is essentially the specification of a point, curve, or surface by means of one or more variables that take on values in a user-specified range. Parametric modeling is significant for conceptual design because it enables designs to be modified and controlled precisely, as long as these modifications are within the limits of the system. Revit Architecture provides a comprehensive set of parametric modeling tools, while both Maya and 3ds Max implement parametric behavior based on construction history. AutoCAD provides a new parametric drawing environment that allows for the creation of 2D geometric and dimensional constraints and relationships, in addition to dynamic blocks.
Feature-Based Modeling

In the late 1980s, software developers began implementing higher levels of abstraction to solid modeling construction techniques. These techniques became known as feature-based solid-modeling. A feature-based modeler is a CAD application that enables designers of various fields to define shapes using geometric features as opposed to CSG or B-REP techniques. A geometric feature is a higher-order CAD entity; for example, operations such as placing holes or filleting are treated as objects that can be updated, not one time operations. Additionally, parametric feature-based modeling packages use history to retain information about the building process of the model, as well as expressions to constrain associations among the geometric entities. This option and ability to regenerate the model's B-REP based upon changes, enables the user to make a modification at any state. Mechanical design applications, such as Autodesk\textsuperscript{\textregistered} Inventor\textsuperscript{\textregistered}, use feature-based modeling extensively. Autodesk 3ds Max provides geometric modifiers that can be layered or “stacked” on objects to achieve feature-based behavior. Although not supported directly, both Maya and Revit Architecture can achieve feature-based behavior by layering parametric and history-based modeling operations. Currently, AutoCAD does not provide support for feature-based modeling.
Modeling a Parametric Tower

Overview

In this lesson, we will explicitly model a geometrically complex tower. You will learn how to layer modeling operations and levels of detail in response to design criteria. The tower's form is constructed directly by manipulating the vertices, edges, and faces of the base geometry and enabling subdivision surfaces. You will also learn the techniques of extracting geometry from the tower to develop the building’s structure and skin.

Exercise 1: Context and Site Profile

It is important that the boundary of the site, as well as the footprint of the building, have contextual relevance. This site boundary was created by drawing a line segment and connecting its start point and endpoint, forming a closed spline. In order to maximize space for the allotment of program, we use the site boundary as the footprint of the building.
Exercise 2: Mass Extrusion

In this exercise, you will learn how to create a solid building mass from a closed spline through the process of extrusion.

Extruding a spline creates a closed element composed of polygons. When a polygon is extruded, it moves normal to the base profile while creating new polygons that form the sides of the extrusion, connecting the new object to the base profile. This is an easy way to transition from a two-dimensional drawing to a three-dimensional object and begins creating a form in a three-dimensional environment. Once a spline has been extruded in the Z-direction and a three-dimensional object has been created, in this case, a building mass, that object can be manipulated through various operations in the X, Y, and Z directions to create a unique geometric form. For the building mass, the site boundary was extruded to create a lower level of commercial space. To maintain street walls with the existing context, this lower level will be extruded to match the height of the surrounding buildings.
Exercise 3: Sub-Object Manipulation

In this exercise, you learn how to directly manipulate the geometry of a building mass using sub-objects.

![Figure 3: Process and development of manipulation to the building mass at the sub-object level.](image)

Once the solid building mass has been created, we can now select and directly manipulate its various sub-object attributes; that is, vertex, edge, border, or polygon. At the Vertex sub-object level, we can select single and/or multiple vertices and move them in space. Because vertices define the structure of other sub-objects, such as edges and polygons, any movement or editing of their positioning will affect the connected sub-objects as well. At the Edge sub-object level, you can select single and/or multiple edges and manipulate them through standard methods such as translate, rotate, and scale.

Because we are conceptually designing a form through geometric manipulation, and do not want to be inhibited by numeric precision, we will create the form of our tower through extruding polygons and moving vertices and edges until we arrive at an overall form that we are pleased with. Keeping in mind the positioning of the building, as well as its contextual location, we will extrude the polygon closest to the ocean and make that the basis of the waterfront tower, thereby maximizing ocean views as well as creating a back courtyard that integrates with the existing park and landscape.
Exercise 4: Implement Precision

In this exercise, you will learn how to implement methods of local precision using the Constraint and Snap features.

To further the development of our conceptual building design, and to enhance ease of use, implementing methods of local precision can be extremely beneficial. Two specific features that are very useful are the Constraint and Snap features. Standard snaps give you additional control in creating, translating, rotating, and scaling objects and sub-objects, and can be combined with free positioning, where constraints are used to specify limitations in the possible movements of those objects in space. The use of these precision features will enable you to achieve the exact form you desire with greater ease because of the additional control it provides.
Exercise 5: Information Extraction to Create Geometry

In this exercise, you learn how to extract two-dimensional information from your building mass.

Two-dimensional information extracted from a three-dimensional object can be used as a reference for further model development. To put this idea into action, section cuts can be generated from a three-dimensional model and arrayed in an equidistant fashion to create splines that will be used as the basis of three-dimensional floor slabs. Like the original building mass, the floor slabs are created by extruding the closed splines of the section cuts, transforming them from simple lines to a three-dimensional solid. This is a useful technique, particularly in respect to conceptual design within architecture, as it allows for a quick method for extracting planar information from a model, as well as the ability to apply a specific operation to more than one element at a time.
Exercise 6: Reuse Geometry

In this exercise, you learn how to isolate and edit specific geometry from your building mass.

Reusing geometry is an important skill in three-dimensional modeling because it enables us to isolate specific areas of our three-dimensional model and apply transformations on a local, as opposed to global, scale. In this case, we will be using this feature to isolate the sides of the tower that we will use to add structural and enclosure elements in later exercises. Based upon the tower's geographical location and orientation, as well as solar positioning, we have chosen to isolate both the south and east elevations to add structure and cladding. To isolate these faces from the rest of the mass, we need to select and then extract them. Once the faces have been extracted from the main building mass, they are ready to be modified using additional operations.
Exercise 7: Define Structure

In this exercise, you learn how to create building structure.

![Figure 7: Process and development of defining a structural pattern and converting it into solid geometry.](image)

There are a variety of ways to explicitly design and model structural elements. We will begin this process by creating a grid that can be used as a basis for designing the structure. For the tower, we will create a vertical structural system that is based off of a faceted, angular pattern. We will draw this pattern explicitly through the process of cutting faces, based on this underlying grid. In the previous exercise, we isolated the faces of the south and east elevations. We will use the pattern as a reference, cutting these faces with angular vertical elements that create a triangulated structural design. To then create panels out of these triangulated faces, we simply offset the faces to create a face and then extrude to give the structure thickness.
Exercise 8: Design an Enclosure

In this exercise, you learn how to create a pattern for a building's enclosure.

Figure 8: Detailing façade design at the local level and compiling all geometrical sets to form completed design.

Like the structural patterns, there are a variety of ways to design and model patterns for a building's skin. To maintain a consistent design methodology, we will again use the process of cutting geometry to create a faceted enclosure system. Unlike the large gestures of the structure, we can many smaller moves for the enclosure, as it requires a greater level of detail.

Once you have arrived at the level of detail that you deem appropriate, mirror the process that we used to define the structure to create this enclosure system. The faces simply need to be offset and extruded.

A further level of design detailing can be added at this stage by transforming this cladding from a mesh to a subdivision surface. This converts the original course faceting of the enclosure system into a smooth topology.
Bridge – Parametric Design

Overview

In this lesson, we will use parametric and associative modeling to create various configurations for the design of a bridge. The following exercises address a secondary phase of the design process where iterative variations on individual geometric concepts are needed. Custom parameters can be created, and used with associative history, for rapid regeneration of modeling procedures in order to refine ideas.

Exercise 1: Create a Solid Geometric Object from a Spline

In this exercise, you learn how to use a spline as a base reference to create solid geometry.

![Figure 1: Process and generating an associatively linked solid geometry from a spline](image)

The model that we will create in this lesson is a parametric bridge. The initial geometry is generated from a spline that you intuitively sketch. To create a surface from the spline, we first extrude it in the positive Z-direction. Following this, we will select the surface and offset it, transforming it from a surface to a three-dimensional solid. Because of history, any manipulations that we make to the base spline will affect our solid as well because the solid is associatively linked to the spline.
Exercise 2: Referencing Geometry

In this exercise, you learn how to create geometry through the process of referencing.

Figure 2: Creating additional associatively linked geometry from the base spline.

Creating a reference, based upon a selected piece of geometry, is a form of copying that maintains associativity to the original element. The first case in which referencing geometry becomes useful is in the construction of the bridge railings. Because the base spline is the foundation for the parametric bridge, we want to ensure that all geometric objects are based upon this spline. To insure this, we need to make references of the spline and then use those references to generate the additional objects. This will guarantee that all geometries possess the same basic attributes and are linked to form a referential system.
**Exercise 3: Add Parametric Variability to Geometry**

In this exercise, you learn how to introduce variability into your geometry through the process of applying and adjusting parameters.

![Bridge Railings](image)

*Figure 3: Using the same global operations, but with differing values, at a local scale to detail the bridge railings*

Once the base geometry is created, the modeling process becomes largely based upon the implementation of parametric variability and how those parameters can affect the form, detail, and positioning of the geometry. We will make additional elements using some of the tools from the previous exercise, but we will modify the control parameters in order to satisfy different modeling requirements. For example, we created the base of the bridge by first extruding and then offsetting the original spline. To create the bridge railings, we again extrude and offset the base spline, this time using smaller numerical values for the control parameters. The same operation is used, but the resultant geometry varies in both dimension and scale, based on the control parameters that correspond to different design criteria.
Exercise 4: Instancing Parametric Modifications

In this exercise, you learn how to copy geometric modifications through the process of *instancing* to create an associative parametric system.

Creating an instance is yet another form of copying. In this exercise, we create instances of parameters that we have already applied to existing geometry, and we apply them to additional geometric elements. By generating instances of parameters already in use and applying them to new elements within the model, we will parametrically link both sets of geometry to one another so that modifications to either one affect the other. This layering of parameters creates associations between disparate geometric elements and can be used to create complex systems relatively quickly. In this lesson, we have chosen to instance the parameters of the bridge and the railing, so that the movement of one affects the other in a