Overview: Parametric Modeling
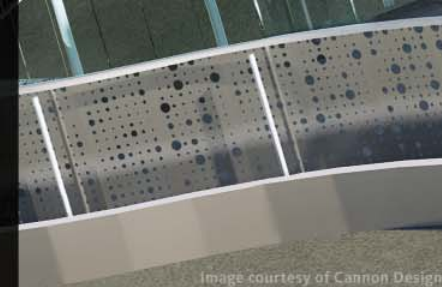
In this lesson, you learn the basic principles of solid, parametric, and feature-based modeling for conceptual design. You learn the significance of each of these modeling processes and when they are appropriate to use for a particular design objective. You also learn how these processes provide for different levels of variability and relationships through custom parameterization, and how they enhance the control of geometry.

Objectives

After completing this lesson, you will be able to:

- Explain the principles of various modeling approaches, including solid modeling, parametric modeling, and feature-based modeling.

- Describe the strengths and potential attributes of each modeling approach for conceptual design modeling.

- Demonstrate the capabilities of various Autodesk applications with respect to each modeling approach.

The following Concept lessons refer to:

- Presentation: *2-1 Parametric Modeling.pptx*

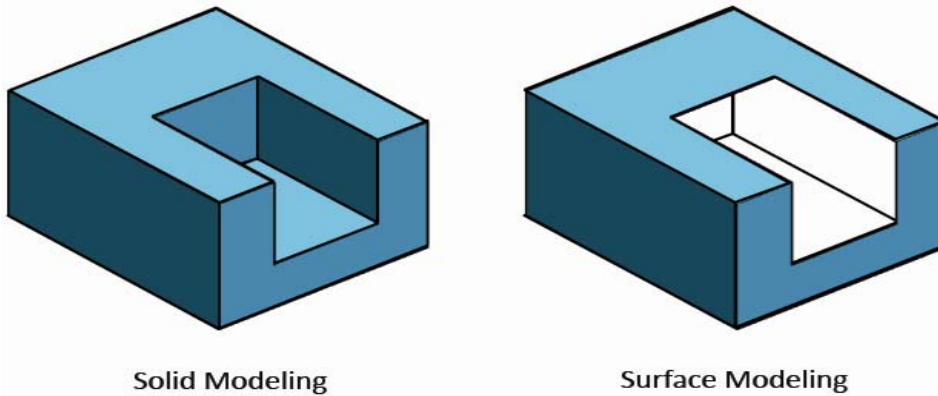Autodesk

Concepts

Solid Modeling

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® 2011 software and Autodesk® Revit® Architecture 2011 software providing native support for solid modeling. Models created by sewing surfaces in Autodesk® 3ds Max® 2011 software and Autodesk® Maya 2011 software can be exported as DWG files and converted to solids using AutoCAD 2011 software.
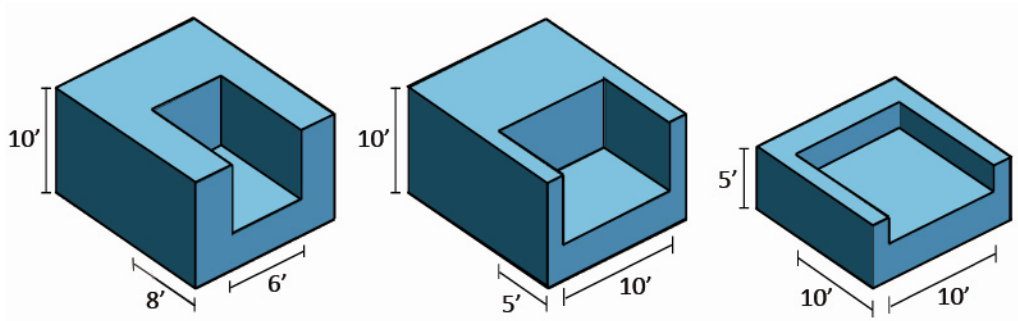
Parametric Modeling

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.
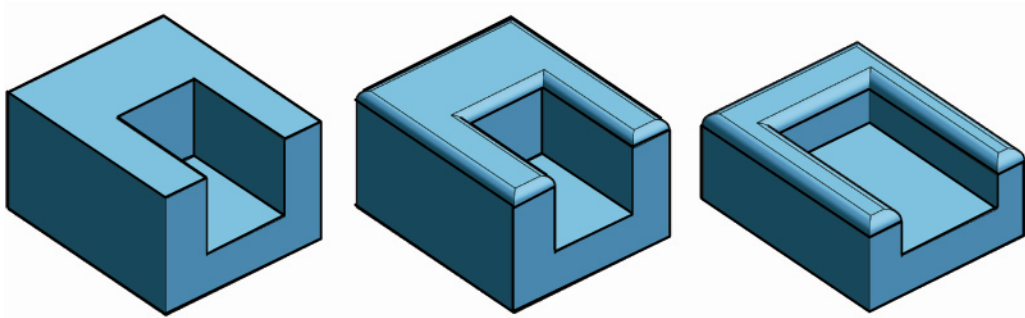
Feature-Based Modeling

Figure 3: Application of a fillet feature to geometry, a technique used with 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® Inventor® software, 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.

Assessment

Challenge Exercise

Instructors provide a challenge exercise for students based on this lesson.

Questions

1. What are the two types of solid modeling and how do they differ?

2. How are parameters used in conceptual design?

3. What are some potential advantages to using parametric modeling software packages?

4. How does feature-based modeling differ from parametric modeling?

5. What industries might find these design processes most beneficial?

Lesson Summary

This lesson focused on introducing various modeling processes that form the basis for parametric modeling within conceptual design. The underlying principles for each modeling approach were described, as well as their applicability for different design objectives. Autodesk provides a comprehensive collection of software platforms for the creation and manipulation of these parametric models during conceptual design, each offering a distinct set of features. You focus on how these concepts can be applied in Lesson 2-2.

Overview: Bridge Parametric Design

In this lesson, you 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.

Objectives

After completing this lesson, you will be able to:

- Explain object hierarchy.

- Create parameters.

- Explore iterations and geometric relationships.

- Develop a system of referential geometry.

Exercises

As you learned from the previous lessons, there are a variety of ways to construct geometric elements within CAD software platforms. The elements that you create, as well as the way you go about constructing them, are largely based upon the product that you anticipate concluding with. In Lesson 1-3, you explicitly modeled a waterfront tower. Explicit modeling, as discussed, is likened to a sketch model because the operations that are used to construct the form are generally less precise and premeditated. They are typically based on intuition, and while they may be deliberate, there is not a substantial amount of planning that goes into their development. Associative modeling, on the other hand, because of its dependency upon relationships, requires both foresight and planning through the entire modeling process to achieve a successful product. Because of this, you should envision what you would like to create, how you would like to construct it, and how it should ideally perform before substantial modeling begins, and you should revisit this approach throughout the modeling process. Of course, being aware of the best modeling strategy comes after plenty of experimentation through trial and error.

The following exercises are provided in a written overview and step-by-step videos in this lesson:

1. Creating a Solid Geometric Object from a Spline

2. Adding Parametric Variability to Geometry

3. Referencing Geometry

4. Instancing Parametric Modifications

Exercises 1–4 refer to:

- Presentation: *2-2 Bridge-Parametric Design.pptx*

- Video: *2-2 Bridge.mov*

- End File: *2-2 Bridge - End.max*

Exercise 1: Creating a Solid Geometric Object from a Spline

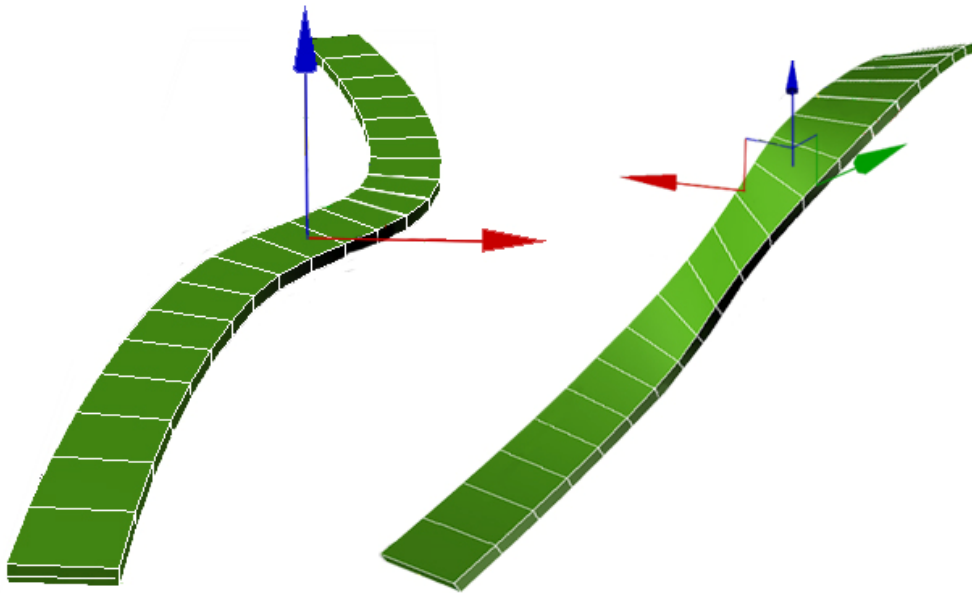In this exercise, you learn how to use a spline as a base reference to create solid geometry.

Figure 1: Process and generating an associatively linked solid geometry from a spline.

The model that you intend to 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, you first extrude it in the positive Z-direction. Following this, you select the surface and offset it, transforming it from a surface to a 3D solid. Because of history, any manipulations that you make to the base spline will affect your solid as well because the solid is associatively linked to the spline.

Exercise 2: Referencing Geometry

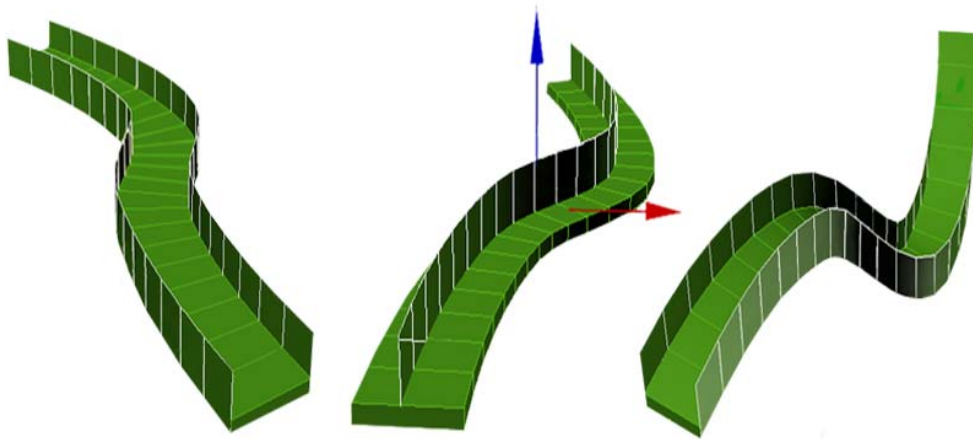In this exercise, you learn how to create geometry through the process of referencing.

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, you want to ensure that all geometric objects are based upon this spline. To insure this, you 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: Adding Parametric Variability to Geometry

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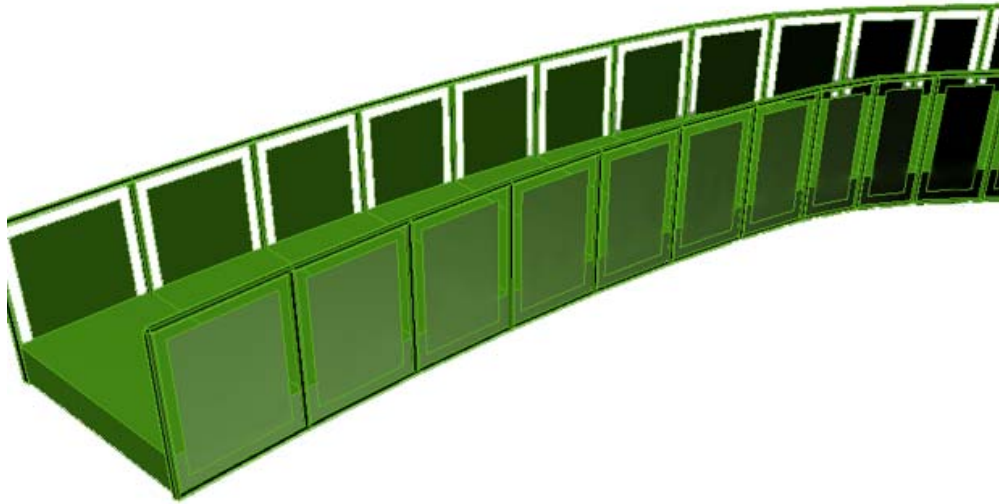

Figure 3: Using the same global operations, but with differing values, at a local scale to detail the bridge railings.

Once your 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 your geometry. You make additional elements using some of the tools from the previous exercise, but you modify the control parameters in order to satisfy different modeling requirements. For example, you created the base of the bridge by first extruding and then offsetting the original spline. To create the bridge railings, you 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.
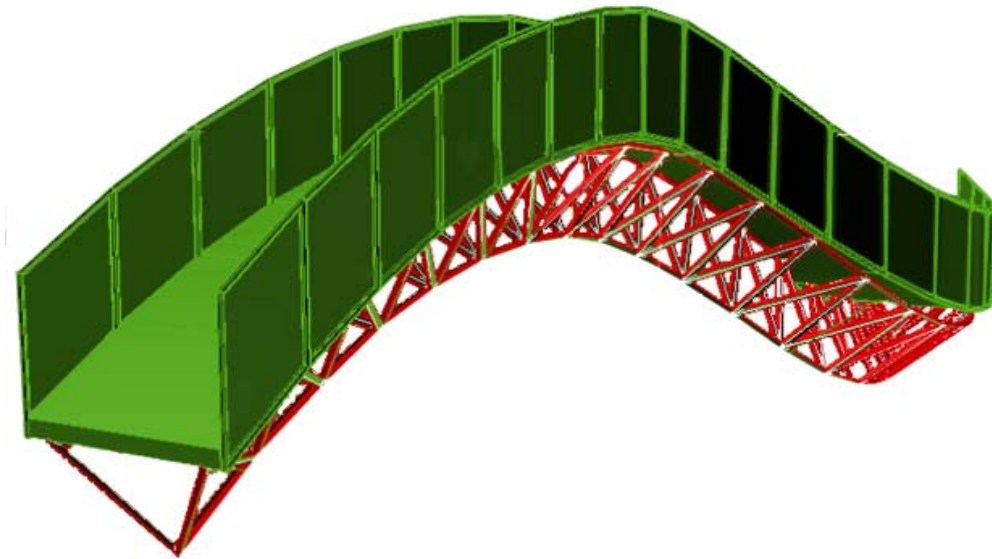

Figure 4: Instancing bridge parameters onto its truss so that both geometries create a complex associative system.

Creating an instance is yet another form of copying. In this exercise, you create instances of parameters that you have already applied to existing geometry, and you apply them to additional geometric elements. By generating instances of parameters already in use and applying them to new elements within the model, you 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, you have chosen to instance the parameters of the bridge and the railing, so that the movement of one affects the other in a consistent manner.

Assessment

Challenge Exercise

Instructors provide a challenge exercise for students based on this lesson.

Questions

1. How can you construct 3D, solid geometry from a spline?

2. What are examples of operations that can be used to introduce parametric variability?

3. What are the advantages of referencing a geometric element?

4. What are the characteristics of instanced parameters, and how do they affect your parametric model?

5. Explain the principles and importance of an associative system.

Lesson Summary

This lesson focused on the creation and development of design variation through user-specified parameters. The underlying principles for each operation were described, as well as their applicability toward different design situations and objectives. Autodesk provides a comprehensive collection of software platforms for the creation and manipulation of these parametric models during conceptual design, each offering a distinct set of features. You focus on how these concepts can be applied in a more complex system in Lesson 2-3.

Autodesk Conceptual Design Curriculum 2011
Student Workbook
Unit 2: Parametric Exploration
Lesson 3: Waterfront Tower Advanced Parametric Design

Image courtesy of Cannon Design

Overview: Waterfront Tower Advanced Parametric Design

In this lesson, you build upon the knowledge of parametric modeling by developing a complex associative design system in the form of a waterfront tower. The following exercises address a tertiary phase of the design process in which a developed layering of associations creates a robust and cohesive parametric system. This layering of associations allows for the iterative exploration of multiple design solutions that meet the design criteria. This iterative process is essential, especially within the field of architecture, because each project is effectively a one-off and exploring a wide variety of possible design options virtually increases the chance of arriving at a better solution once the project is realized.

Objectives

After completing this lesson, you will be able to:

- Generate custom parameters.

- Describe and create local and global parameters.

- Model with history.

- Produce controlled variations.

Autodesk

Exercises

The parametric tower will be located on the same site, within the same context as the explicit tower you constructed in Lesson 3. Because of this, the same programmatic, contextual, and environmental design requirements still apply. As you learned in that lesson, explicit modeling is an excellent technique for exploratory design. Now that you have explicitly modeled the aesthetic intent of the tower, it is time to begin exploring variations through a parametric process. This means that you reduce the amount of intuitive direct modeling and increase precision and parametric control. This allows for the production of variation within a limited design space, enabling the exploration and refinement of a concept to better address the design criteria.

The following exercises are provided in a written overview and step-by-step videos in this lesson:

1. Constructing an Associative Building Mass

2. Adding Parametric Control

3. Exploring Design Alternatives

Exercises 1–3 refer to:

- Presentation: *2-3 Waterfront Tower-Advanced Parametric Design.pptx*

- Video: *2-3 Parametric Mass.mov*

- Start File: *2-3 Parametric Mass -Start.rfa*

- Start File: *2-3 Parametric Mass Project - Start.max*

- End File: *2-3 Parametric Mass - End.max*

- End File: *2-3 Parametric Mass Project - End.max*

Exercise 1: Constructing an Associative Building Mass

In this exercise, you begin creating associations for the building mass for the parametric tower.
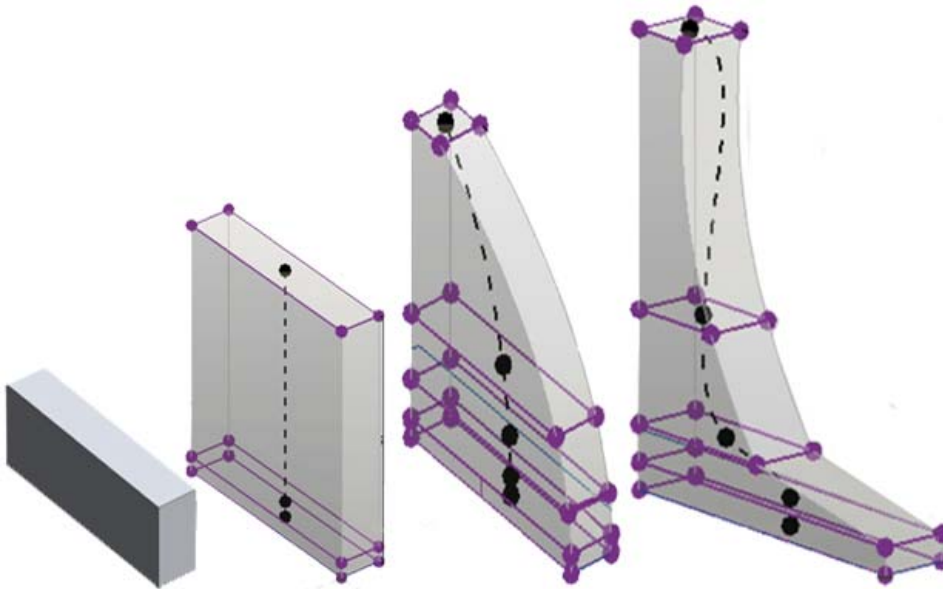

Figure 1: Process and development of the associative tower building mass.

To begin, much like Lesson 1-3, you use a profile to create the outline of the site and then extrude that profile to create the base of the building mass. To manipulate the mass extrusion, you can adjust the positioning of vertices, edges, or faces, as well as insert edges to add additional detail. Changes to the base profile will update the mass and affect all downstream modeling operations. You perform a series of explicit modeling operations to the mass in order to sketch out the overall form, and then begin to control variations of the mass by adding parameters. In this video, after generating a mass through extrusion, you insert additional edge detail to allow for sectional shifts, and then you manipulate the sub-object levels of the mass until it arrives at a stage with which you are satisfied. Once you are satisfied with the overall sketch of the mass, you can begin to explore variations using user-specified numeric constraints in the next exercise.

Exercise 2: Adding Parametric Control

In this exercise, you add dimensional parameters to your design in order to precisely control manipulations using numeric values.
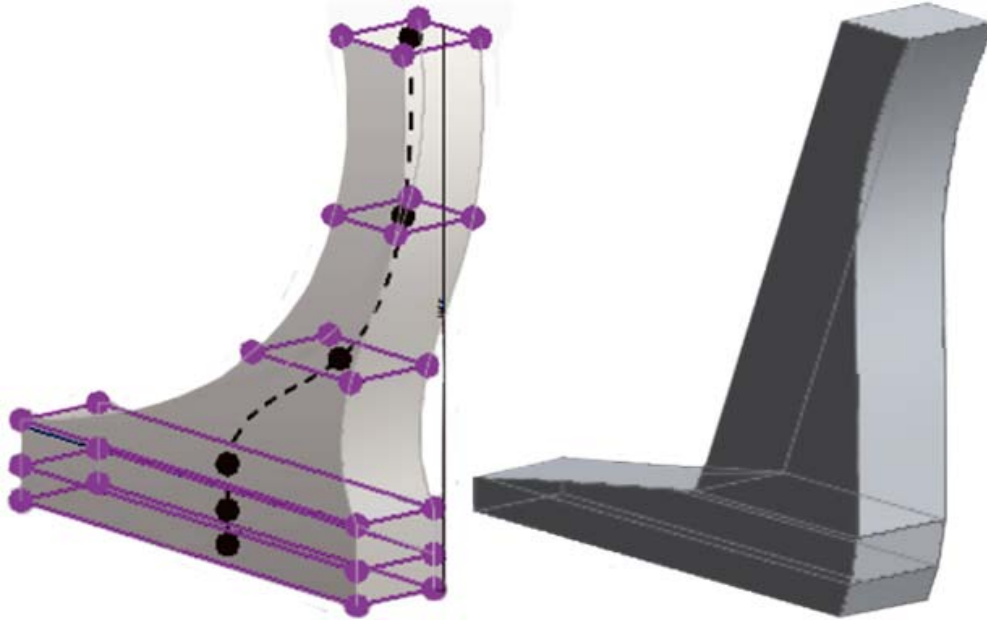

Figure 2: Implementing dimensional parameters for the building mass assists in controlling its overall form.

The transformations that you made to the building mass up until this stage were through processes of direct manipulation. In order to explore variation more precisely, you now begin adding dimensional parameters, enabling increased degrees of control through numeric input. With the introduction of these dimensional parameters, the model can be modified using both numerical and graphical means. The first dimensional parameter that you apply to the building mass is a height constraint, which you use to control the overall height of the mass. Once this constraint has been applied and changed, you will see the building mass update, affecting the initial form. From here, you can implement additional dimensional parameters as you find necessary to control the mass. In addition to the height parameter, you add a width constraint, as well as a constraint to control the proportion of the sectional profile. To ensure that the parameters are referentially linked and working together to create an associative system, you defined the parametric formula of the width and sectional constraints using proportions based on the building's height. Rather than using a single numeric value, you use existing parameters and mathematical operations to create relationships between different elements. Defining parameters in this way ensures associativity between all parameters that describe the building mass and can assist in arriving at a more cohesive final product.

Exercise 3: Exploring Design Alternatives

In this exercise, you manipulate the dimensional parameters to generate multiple design options.
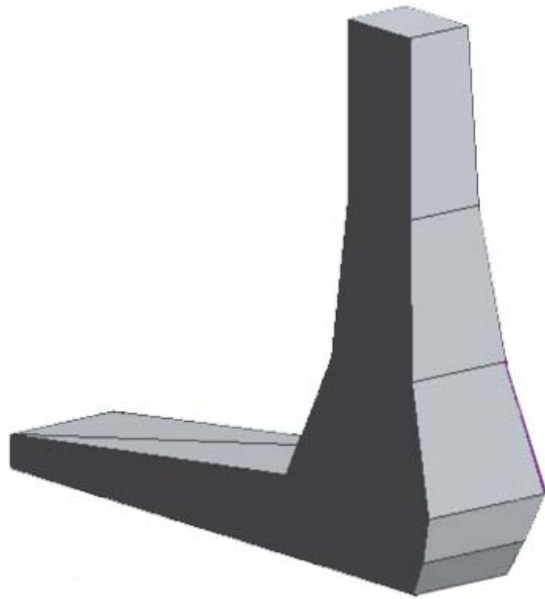

Figure 3: Manipulation of the dimensional parameters allows for quick visualization of multiple design iterations.

Using the initial parametric mass as an underlay, additional design options can be readily explored. For the purpose of producing iterations, a series of profiles can be created using associative snapping, which constrains profiles to the base mass. In addition, massing options can then be created using these profiles. These options can be modified by changing the dimensional parameters controlling the initial building mass with these updates automatically reflected in all massing options based on this initial mass.

Assessment

Challenge Exercise

Instructors provide a challenge exercise for students based on this lesson.

Questions

1. What is an associative building mass?

2. How are numerical parameters added to a building mass?

3. Why might numerical parametric control of a building mass be useful?

Lesson Summary

These exercises are intended to guide the student in creating a simple associative building mass, and then assigning numerical parameters to those dimensions. The parameters are then used to flex the model through a range of possible design options. Autodesk provides a number of tools that can accomplish this task; the videos for this section make use of Autodesk® Revit® software's parametric functionality.

Overview

An alternative method for creating parametrically controlled geometry is explored in this chapter. Previous methods involved a hierarchical object and an associative building mass; the technique presently discussed allows a shape to be constructed from a set of guide curves and a profile that connects them. Modifying any of the controlling guide curves will cause the model to be updated live. To accomplish this task using Autodesk® Revit® 2011 software, we use a new feature called an adaptive component, which allows the profile to adapt itself to a changing context (in this case, the hosting guide curves).

Objectives

After completing this lesson, you will be able to:

- Create a mass that is parametrically controlled by a set of underlying guide curves

- Employ adaptive components within a conceptual mass

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Exercises

The mass in this lesson is not constrained to any particular site. Instead, we will create a set of guide curves that will control its outer edges. An adaptive component will be created as a profile, which can then be swept along the guide curves to create a solid. Once created, the mass can be easily flexed by modifying the original guide curves.

The following exercises are provided in a written overview and step-by-step videos in this lesson:

1. Constructing an Adaptive Component Building Mass

2. Component Hosting

3. Exploring Design Alternatives

Exercises 1–3 refer to:

- Presentation: *2-4 Adaptive Components.pptx*

- Video: *2-4 Adaptive Components Mass.mov*

- Model: *2-4 Adaptive Mass Component – End.rfa*

- Model: *2-4 Adaptive Mass Family- End.rfa*

Exercise 1: Constructing an Adaptive Component Building Mass

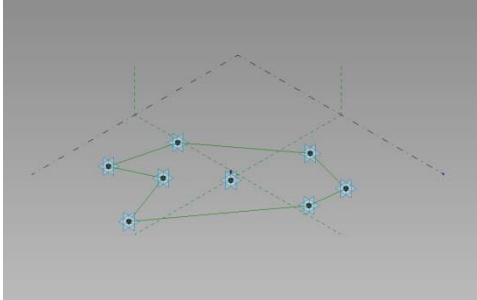In this exercise, you create a custom adaptive component to use as a mass profile

Figure 1: Adaptive shape handle points form a flexible framework for line geometry.

Adaptive components in Revit are intended primarily to be used in curtain panels—they allow components to adjust more flexibly to their context. In this case, however, we will be using adaptive components in a Conceptual Mass family, where we will be employing their unique ability to stay in plane while being hosted by other geometric elements.

The profile is an adaptive component, and is created by placing a number of points on the work plane. These points must be made "adaptive." The center point is a "placement point," which will be the point of instantiation, as well as the reference plane to which the other points will be constrained. The remaining points are "shape handle points," which can float freely while remaining on the plane of the placement point. The shape handle points are then connected by lines.

The profile component is now complete, and the family can be loaded into a Conceptual Mass family.

Exercise 2: Component Hosting

In this exercise, you host several instances of the adaptive component on reference geometry and use them to create a mass.
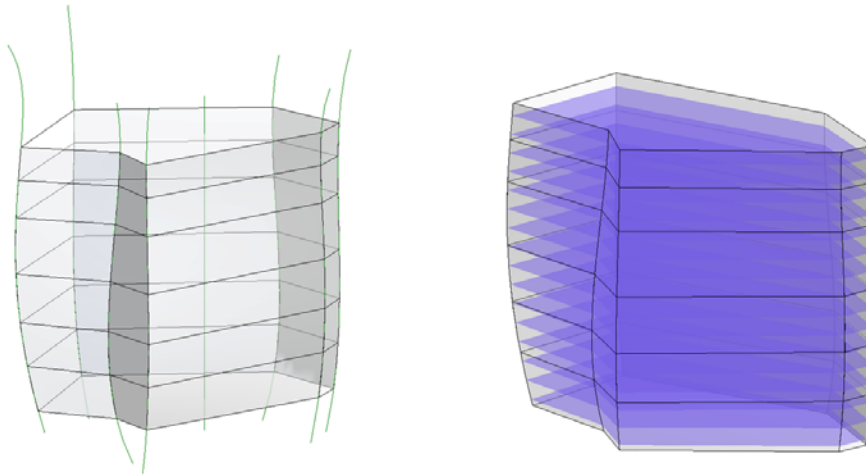

Figure 2: The adaptive component is hosted on guide curves and used to create a solid mass.

In our Conceptual Mass family, we have created a set of guide curves that bend in section. They will form the framework for our conceptual mass, which is essentially a swept solid (with the advantage of being fully parametric).

The shape handle points are then hosted to the guide curves. Once in place, the profile can be quickly copied to produce a series of profiles, which can then be swept to form a solid mass. The mass family provides functionality that can be useful when evaluating the design, including the addition of floors and panels.

Exercise 3: Exploring Design Alternatives

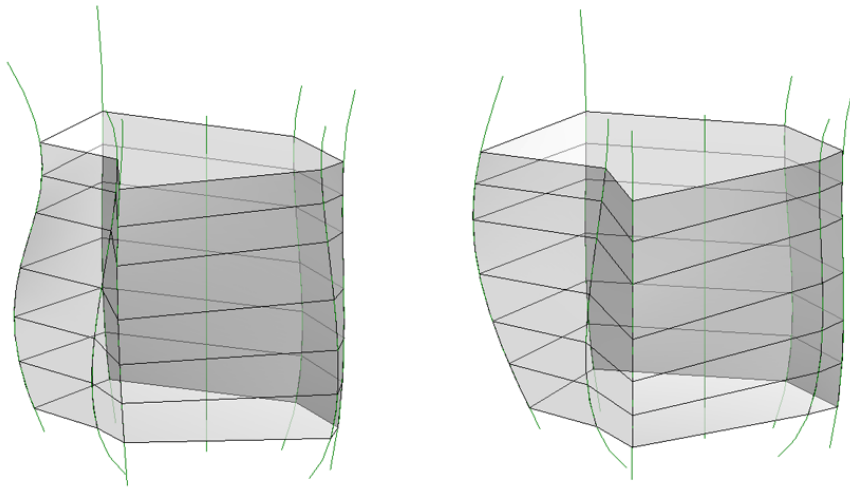In this exercise, you manipulate your reference geometry to flex your adaptive mass.

Figure 3: Because the geometry is parametric, it updates automatically.

From here, it is easy to compare the advantages and disadvantages of each approach and evaluate all options against the design criteria. A floor mass schedule can be used to quickly determine the floor area determined by each geometric solution, and panelization options for each alternative can be explored using Revit software's built-in tools.

We could, if desired, add further parametric control to the model by adding numerical dimensions to the guide curves. They could then be related to various environmental factors, including the constraints of the site, the solar insolation, the costs of materials, and so on.

This is an example of how parametric modeling enables quick, iterative design exploration. While in earlier lessons you modified and refined the mass through explicit operations, you now use dimensional parameters to precisely control and assess these modifications against the design criteria.

Assessment

Challenge Exercise

Instructors provide a challenge exercise for students based on this lesson.

Questions

1. What aspects of the geometry might be suitable for more parametric control?

2. Why might a designer want this type of control over a model?

Lesson Summary

This lesson focused on a particular technique for creating a parametrically controlled solid mass using Revit 2011 software's newly added Adaptive Component functionality. The steps for reproducing the example were discussed, along with the advantages and challenges of this particular approach, as well as possible future extension of the example.

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