Session 2 - Part B

Revit Conceptual Massing in a REAL Project

Kelly Cone, The Beck Group

Class Description

The massing editor can be an invaluable tool for managing change all the way through CDs. In the class we'll dive into a 700,000+sq.ft. project in South Korea where the massing editor was used extensively. From early studies to manage the limitation on above grade floor area ratios to updating the building's skin less than three weeks from issuing 100% DD documents, we'll show you how careful planning and creative family building can keep your project on schedule despite having to generate hundreds of schemes and make last minute design changes.

About the Speaker:

Kelly Cone is the Innovations Director at the Beck Group, an integrated Development, Architecture, Construction, and Technology company headquartered in Dallas, TX. Since receiving his Master's degree in Architecture from the University of Texas, Kelly has been focusing on the implementation of BIM across integrated disciplines. This covers a wide range of software including Autodesk® Revit®, Navisworks®, Innovaya®, Synchro®, and DProfiler®—our own in-house macroBIM application. The implementation process includes the creation of customized design-build-oriented content and the alignment of costing and scheduling assemblies to that content. Kelly plays an integral role in representing Beck's BIM capabilities, attending and speaking at numerous conferences and teaching classes about BIM. He is also heavily involved in the BIM community at large participating in the AUGI revit forums, his collaborative blog Revit Futures Council, and through our own site BIMexperts which he co-founded.
Presentation Background

This class is based on the work done for a project in Seoul, South Korea. It has been presented at AU, several RUG meetings, and most recently showed up in Mastering Revit Architecture 2012. This handout is an excerpt from that book, namely Chapter 21. We will cover the same process in the class, though we will pay more attention to things not covered directly in this handout since, well, you have this handout. I highly encourage you to pick up a copy of MARA2012. Aside from the general training the book provides, this year has several chapters in addition to #21 that address the use of Revit on live projects. That kind of learning experience is invaluable to anyone learning or using Revit on a daily basis...

Key Learning Objectives

- Learn techniques for making complex building forms parametric.
- Describe how to use mass and mass floor schedules to study building areas in advance, and how the conceptual energy analysis tools in Revit work with masses.
- Understand how the conceptual massing editor relates to building elements and define the workflow required to maintain mass to element relationships through the DD and CD phases.
“James, Phil, and Eddy are the best teachers you could ask for.”
From the Foreword by Anthony Hauck, Revit Product Line Manager
Part VI: Construction and Beyond

In the previous chapters, we focused on the architect’s role in design and construction using Revit. As the uses of Revit continue to expand beyond documentation, we wanted to touch on several other uses of the tool beyond the traditional scope of the designer. In the following chapters, we are going to discuss several uses of Revit and how it can be used to augment design and documentation after construction documents are complete.

For this part of the book, we worked with leading industry experts in these individual fields. Thanks to all the contributors for their excellent looks into BIM.

- Chapter 21: Making Projects Parametric  
  With Kelly Cone, Beck Architecture
- Chapter 22: Revit in Construction  
  With Laura Handler, Tocci Building Corp.; and Josh Lowe and Mike Whaley, Findorff & Son Inc.
- Chapter 23: Revit in the Classroom  
  With Swee Bing Teoh and Choy Ling Chan, Singapore Polytechnic
- Chapter 24: Virtualization  
  With Peter Streibig, Bohlin Cywinski Jackson
- Chapter 25: Getting Acquainted with the Revit API  
  With Don Rudder, HOK
- Chapter 26: Revit for Film and Stage  
  With Bryan Suton, Camel Design
This chapter covers using massing and family techniques learned earlier in this book to extend the use of parameters into your projects and leverage those parameters for some different types of analysis. Using massing like this requires an upfront investment in the massing model but pays large dividends downstream in design and documentation.

This chapter will focus on concepts to make a fully parametric mass using the form editor and how to use that for analysis and change management.

In this chapter, you’ll learn to:

- Use generic model outline families
- Understand advanced conceptual massing
- Find additional resources

Figure 21.1 should give you an idea of where we’re headed in this chapter. Massing isn’t just a tool for designers in the schematic phases of a project. Using massing in this manner can allow you to save tens or even hundreds of person-hours on your project from schematic design (SD) all the way through construction documents (CD).

**FIGURE 21.1**
Finished model based on massing
We’ll be using this example project throughout this chapter to show how massing can make a Revit project parametric. This is by no means a simple project, so some terminology is employed to help make sense of the parameters in the families. Figure 21.2 should help explain what some of the abbreviations and terms refer to. If you get lost at any point, just turn back and take a look. And with that, let’s get started!

**Figure 21.2**
Example project terminology

**NOTE** The intersection between Major and Minor reference planes defines the origin of the mass and the origin of most of the model line families. It is the center of the ellipse shapes; any dimensions “to ellipse” are to this origin. The ellipsoid is a distended ellipse, where one side has a larger minor axis than the other side. Major, minor, and add axes are what we refer to in the family.

**Generic Model Outline Families**
Complex building forms frequently require different individual forms joined to or cut from one another to create the final building shape. Just as in any other family, the more complex it gets, the more difficult it is to properly constrain. Each form element requires its own set of constraints and parameters and sometimes requires additional constraints on the original form element to keep it stationary when the second element is flexed. Multiply this by 10 form elements, and you can imagine how difficult it could be to keep control of the family.

Fortunately, there are alternatives to this highly complex environment. Nesting families into other families simplifies what would otherwise be a difficult family to make. Almost every piece of content has at least one nested family in it. In the massing editor, you can nest any category of
family into the host massing family. For our examples, we’ll be using the Generic Model template to create the basic outlines of our forms.

The “outline” part is important. If you aren’t used to the massing editor, you need to understand that all the shapes it can make are based on combinations of 2D outlines. So, in trying to create a nested family to simplify the form, you are really attempting to create the outlines of the extrusion, loft, revolve, or whichever primitive you are trying to get.

Now we’ll get started with the footprint of our building. This is a complex form with quite a bit of math to make it work.

Building Footprint

In this tutorial we’ll focus on defining a fully parametric building footprint that can be used to generate a complex mass form. For your project, you can start by creating a new family from the Generic Model template in your library. You can choose a nonhosted or a face-hosted family template. Do not choose a template for hosting on a system family since there won’t be one to host it on in the mass family.

For this example there is a start file with a majority of the legwork for things you’ve already learned done for you. There are also videos for each step on the book’s web page, www.sybex.com/go/masteringrevit2012.

1. To begin, open 01 Footprint Template.rfa. You’ll see this family already has all the parameters and formulas you’ll need to finish (Figure 21.3).

![Figure 21.3](image)

**Footprint template**

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width Edge</td>
<td>1568.00</td>
</tr>
<tr>
<td>Height Edge</td>
<td>1776.00</td>
</tr>
<tr>
<td>Top Face Radius</td>
<td>111.00</td>
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<tr>
<td>Bottom Face Radius</td>
<td>111.00</td>
</tr>
<tr>
<td>Height Edge Radius</td>
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<tr>
<td>Top Face Radius</td>
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<td>Height Edge Radius</td>
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<tr>
<td>Height Edge Radius</td>
<td>111.00</td>
</tr>
</tbody>
</table>

2. To establish the overall constraints, the first step is to bring in a background. Load File Footprint Outline.rfa into a blank project and place it on the workplane Level 1. This is an outline of the building footprint you will be creating a parametric version of. You need to set up three overall constraints to get started. Draw three reference planes and then dimension these back to the center reference planes, defining the origin as shown in Figure 21.4. Then, assign the parameters shown in the figure to those dimension strings. Your family should look like the figure when you finish.
3. We’ll continue on the south tower side of the building by constraining the main arc of the front façade. To do this, we need to set up constraints for the front façade and the center of the arc. First, draw a reference plane along the front (plan north) of the building and dimension it back to the origin plane. Then, draw two reference planes crossing each other down and to the right of the origin. Dimension each of these back to the origin as well. Then, assign the same parameters seen in the finished image, Figure 21.5.

4. Moving on to the core side of the South Tower, we have a fillet arc on the corner of the building. To constrain it, draw two reference planes for the center of the circle and dimension them to the side and back reference plane. You can assign them both to the ST Core Side Fillet Radius parameter.

5. Now, we’ll place the first lines. The lines will all be model lines, and for simplicity’s sake we’ll just use the default subcategory for these. You can either pick lines for the two sides
and the arc or just draw them. Once they are placed, select the arc; in the Properties palette check the Show Center option. Doing so gives you a crosshair for the center of the arc that you can constrain. Now align and lock the two sides to the reference planes they are on top of, and align and lock the center of the circle to the two reference planes for the center. Last, place a radial dimension on the arc, and assign it to the same parameter as the reference planes. Once you're done, go ahead and flex the parameter to make sure you have the first three lines constrained (Figure 21.6).

6. This step is your first encounter with some difficult math. You need another fillet arc, but this time it is between a line and an arc. Because you might have to change the radius of both the main arc and the fillet, you need some formulas to make sure the fillet arc remains tangent to the arc.

To constrain an arc, you must constrain its radius and its center point. The radius is one of our parameters, but the center point is difficult to define in this condition. You need to know two things to do this. First, you can find the center point of any fillet arc by offsetting the two things you're trying to fillet together by the same dimension as the radius of the fillet arc. You also need to constrain where the main arc ends and the fillet begins. For this you can rely on the fact that for a line to be tangent, it must be perpendicular to the radius at that point on a circle. What this means to you is that the centers of the fillet arc, the main arc, and the offset arc you're using to find the fillet arc center have to lie on one line. The angle of this line will change as the main arc and the fillet arc radii change. See Figure 21.7 for how this works out in our case.
7. Since the radius of both the main arc and the fillet are parameters and can change, you need a formula to calculate the center point as the parameters change. You can use some basic trigonometry to do this. If you treat the offset line of the side of the building as one leg of a right triangle and the line perpendicular to it back to the center of the main arc as the second leg, the hypotenuse is the angled line through the center of the center points. With a right triangle, you can use SOH CAH TOA to find the angle.

**THE SOH CAH TOA MNEMONIC**

The SOH CAH TOA mnemonic is a helpful way to remember the ways to solve a triangle for the missing sides or angles.

- **SOH**  \( \text{Sine} = \frac{\text{Opposite}}{\text{Hypotenuse}} \)
- **CAH**  \( \text{Cosine} = \frac{\text{Adjacent}}{\text{Hypotenuse}} \)
- **TOA**  \( \text{Tangent} = \frac{\text{Opposite}}{\text{Adjacent}} \)

The mnemonic is Some Old Horses Chew Apples Happily Throughout Old Age.

The hypotenuse is always going to be the radius of the main arc minus the radius of the fillet arc. The adjacent side is always going to be the difference between the distance to the south edge and the sum of the offset from the center of the circle and the origin and the radius of the fillet arc. You can see all the formulas in the family types.
Of course, you still have to draw it. Start by drawing a reference line from the center of the main arc up through the intersection of the offset lines. Lock and align the start point to both reference planes at the center of the main arc. Then, dimension it to the horizontal reference plane at the center of the main arc with an angular dimension, and label it per the image. Next, draw the main arc, check Show Center Point, and constrain the center to the reference planes. Dimension the radius and label it. Draw a vertical line at the origin, constrain it to the origin plane, and trim the left side of the arc to it. Then, drag the right side of the arc until it snaps to the reference line. Then, align and lock the endpoint of the arc to the reference line. This gets your main arc drawn.

8. Now, to draw the fillet you need to change the workplane. Since the center of the arc moves with the reference line, pick the reference line as the workplane. Next, draw the fillet arc with the center on the reference line, and align the center point to the reference line. Then, dimension from the start point of the reference line to the center of the fillet arc and label it. Dimension the radius of the fillet arc and label it, and drag the left side of the fillet arc to the reference line and lock and align it. It should now meet up with the main arc. You’ll need to draw one more reference plane to define where the other side of the fillet arc stops. Draw a reference plane parallel but below the plane defining the front edge of the façade, and dimension and label it as well. Then, you can drag the fillet arc end to the plane and align and lock it. Last, align and lock the south side line to the reference plane, and you’re halfway done (Figure 21.8).

9. As always, flex the family between steps, at the end of steps, and any other time you feel like it to make sure you’re getting everything constrained correctly. It is a lot easier to troubleshoot when you’ve only made one or two changes since it last worked than it is if you wait until you think you’re done.
We’ll continue with the north tower main arc constraints. These are set up similarly to the south tower constraints, just with different values; so follow those steps on the north side and label accordingly. It should look like Figure 21.9 when you’re done (south tower constraints are hidden for clarity).

**Figure 21.9**
North main arc constraints

The north side is much more complicated than the south. The side is at an angle and is curved to boot. So, you’re going to construct this with reference lines first and place model lines later using the Pick Lines tool. This is important because you’ll need to use the “reference line as a work plane” trick a lot to make this side work.

1. Create two reference planes with the same label; draw a reference line arc this time, center mark visible; and constrain the center to the intersection of the planes you constrained. Dimension the radius and give it the same label. The right end of the arc can be dragged over and then aligned and locked to the vertical reference line. Now, create an angular dimension from that vertical reference plane to the endpoint of the arc and label it as shown in Figure 21.10.

2. Now you’re going to get work plane crazy. Go to a 3D view and pick a new workplane. Pick the end reference plane of the reference line arc you just finished constraining. Draw a reference line on it that is perpendicular to the arc at the endpoint but parallel with the level in the project. This line will now move with the end of the arc as you flex it. Go back to the plan view and pick this new reference line as your workplane. Draw yet another reference line, starting at the end of the arc and running tangent to it a little ways out. Place an angular dimension between it and the perpendicular reference line and lock it at 90 degrees. Dimension from that perpendicular reference line to the end of the tangent reference line, and label it as well. Flex it by changing the North Tower Side Angle parameter and the North Tower Core Side Fillet Radius. It should all look like Figure 21.10.
3. To get the front side fillet and main arc fully drawn, you’re going to use the same trick that you used on the south tower. Unfortunately, you’ve complicated things by making the north tower side an angle that is changeable. So, although the same concept applies, you now have to create much longer formulas to take that changing angle into account. Figure 21.11 shows how you’re doing this conceptually, but we won’t go through all the math steps this time. The formulas are in the family. Also, because of the way the math was done, the front side and core side fillet radii have to be equal on the north tower. You can make the math work with individual controls like the south tower, but the formulas get even more complicated.
4. To draw this out, we’ll go through the same steps as on the south tower. First, set your workplane back to the reference level. Draw a reference line from the center of the main arc to about where the center of the fillet arc will be, and align and lock the start point of the reference line to the reference planes defining the center of the main arc. Use an angular dimension to the vertical center plane of the main arc this time, and label it per the image. Next, using model lines, draw the main arc and constrain it to the center reference planes for the main arc, and dimension and label the radius. Draw a horizontal line on the horizontal origin reference plane, and align and lock it to the plane. Then, trim the line to the vertical line on the right, and to the main arc on the left. Drag the left side of the arc to the reference line, and align and lock it to the reference line.

5. For the fillet arc, you need to define the work plane as the reference line you just constrained the main arc’s left end to. Then, using the Reference Line tool (not the Model Line tool), draw the fillet arc with the center on the reference line and align and lock the center to the reference line. Dimension from the start point of the radius reference line to the center point of the fillet arc reference line and label it. Then, dimension the radius of the fillet arc and label it. Finally, drag the right end of the fillet arc to the reference line to align and lock it, and then make an angular dimension from the radius reference line to the endpoint of the fillet arc reference line and label it as well. Again, flex this to make sure it all works (Figure 21.12).

6. The next step is to make the north side of the building a curve, not a straight line. Now, this seems complicated, but it is much easier than what you’ve already done. You decided that the center of the side arc would be along the reference plane you used to define the center of the core side fillet angle. In order for the side arc to also be tangent to the front side fillet arc, you can use chord theory to determine the angle of the arc. The straight line of the north side reference line is actually a chord in a circle. From that, you can draw a line perpendicular to the chord at the center of the chord, and that line will be a radius of the circle. The angle between that and horizontal is then half the chord angle, which is your arc angle. Also, since the half chord line just described makes a right triangle, you can likewise calculate the radius of the arc required to be tangent to both fillet arcs. Figure 21.13 graphically explains this in more detail.

7. To draw the north building constraints, you’ll need to add a few more things. First, change your work plane back to the reference level. Then, add a reference plane a ways to the right of the fillet arcs. Dimension from the north edge reference plane to this new reference plane and label it. Then, draw a reference line from the intersection of the new reference plane and the horizontal reference plane defining the core side fillet center out through the center of the front side fillet center. Align and lock the start point to the reference planes, and then label an angular dimension between the horizontal reference plane for the core side fillet center and the reference line.

8. Now, you just have three more model lines to draw, and you’ll be done. Your work plane should still be the reference level. Create a model line by picking the core side fillet reference line arc. Lock it to the reference line arc, and then drag the north end back to the horizontal reference plane. Align and lock the end of the model line arc to the reference plane. Switch the work plane to the reference line you just drew for the side arc. Then, draw the side arc or pick it from the model line family you placed in the first step. Align and lock its center point to the reference planes defining its center, and then drag the endpoints of the arc to the reference line on the top and to the reference plane on the bottom.
Align and lock them. Switch work planes to the reference line from the center of the main arc. Draw the front fillet by again picking the reference line arc and locking the model line to it. Then, drag the ends to the correct reference lines on either end and align and lock it to those reference lines (Figure 21.14).

The finished product should look something like Figure 21.15.

**Figure 21.12**  
North front side fillet constraints

**Figure 21.13**  
North side angle constraints diagram
**Figure 21.14**
North side angle constraints

**Figure 21.15**
Finished product
Once everything is constrained, you should flex the parameters any way you can think of. There are some things the family can’t do, as you’ll find out. Limitations crop up due to the geometry having to intersect and some of the math shortcuts made to simplify the formulas. But, for our purposes we were able to flex this family as far as the site and program constraints would allow. So, the family serves its purpose well.

Now that seems like a lot of work for a bunch of lines, doesn’t it? The footprint example is the most complicated model line family for the project. It took about 12 hours and a lot of trial and error to get it right the first time through. Most of the rest were one hour or less endeavors. The model line families took about three days of work. The advantage of all this is that the mass itself was extremely fast to construct. All of the model line families needed for this mass are on the book’s companion webpage, you can skip to the next section and start making a mass.

**Advanced Conceptual Massing**

Making a parametric mass requires some planning. Part of it involves working on the nested families, part of it consists of planning the parameters you’ll use, but the most important part is understanding how that mass will be used in the project.

If the mass is going to be used to create mass floors or you want it to compute floor area and building volume in mass schedules, Revit requires that the massing be solid and not contain surfaces.

This mass is also intended to be used to define curtain systems. So, you need the mass to have enough detail to differentiate the surfaces you want those systems applied to. If you are intending on having two different systems on the same face of the building, it is best to create a division in the form somehow so that you can just apply the system to the face without a lot of editing.

There are also some requirements for energy modeling and solar radiation studies mainly involving the complexity of the shapes you are creating, since these then get faceted for analysis purposes. If you exceed the limitation on the number of faces, some analyses won’t complete.

Some of the steps that follow may at first seem unnecessary for making the form, but these reasons are why they are being done. So, with that in mind, you can start making your mass.

**Parametric Building Massing**

By the end of this tutorial, you’ll have a working mass family that is highly parametric and can be used for a variety of analyses.

If you’ve done the legwork we have done with this example, the mass happens fast. Since all your constraints and formulas are in the nested line families, you just have to define the three constraints that locate the nested family’s origin relative to the mass family’s origin. Then, you connect the dots by linking the parameters in the nested families to parameters in the host family where needed to get the control you want. Then, create some forms and voids and you’re done. Let’s get started!

As with the previous example, the parameters and formulas you need are in the starting family already, as are some constraints to the levels in the mass family. That way, you can focus on
placing the line families and creating the forms from them. Also, don’t forget to flex the family frequently as you go through the steps.

You’ll start by placing the footprint model lines. Since you have these as nested families, you don’t have to worry about anything more than constraining the origins properly. For the footprint model lines, you want to constrain the origins in the family to the origin in the mass. In the 3D view, set the work plane to Level 1 and place the footprint model lines on Level 1. Align and lock the center of the footprint to the center reference planes in the mass. Then you just need to map the parameters from the nested family to the parameters with the same name in the host family. Map every parameter you can find a match for. If you have any questions, open
the completed version from book’s web page. There are several files for this section available in the Parametric Building Mass folder included in the chapter download.

1. To create the form, you generally can just select the generic model family and click Create Form. The massing editor has a tough time with this particular model line family, so you’ll need to Tab-select to each line in the nested family and click Create Form after you have them all selected. Once the form is created, align and lock the top of the form to the T.O. South Tower level. It should look like Figure 21.16 when you’re done.

2. Place the Ellipse Void model lines similarly. Select Level 1 and place it in the middle, and align and lock it to the center of the mass family. Pay attention to make sure the add axis in the ellipse family is facing the front of the footprint, not the back. The add axis is the larger dimension, and if it isn’t clear, you can increase the size in the instance properties to make it obvious. Once you have it placed, place a second one on the T.O. South Tower level as well, and align and lock it to the center reference planes too. Once you have it placed, map the lower ellipse parameters to the Ellipse Plaza Axes parameters in the host, and map the upper ellipse to the Top Ellipse Axes parameters.

3. To create this form, select the bottom family, and then the top family, and choose Create Void. This creates the central void in the mass; it should automatically cut from the footprint mass, as shown in Figure 21.17.
4. Next, you need to cut out the form to make the skybridge. For the bridge elements, you’ll change the work plane to the front/back reference plane. Place the Center Void Model Lines family on the reference plane twice, once with the arc opening up and once with it opening down. Once you have it placed, you can map the parameters of both instances as follows:

- Tangent Arc 1 and 2 parameters map to the Bridge Cut Fillet Arc Radius.
- Angle 1 maps to Bridge Cut ST Angle, and Angle 2 maps to Bridge Cut NT Angle.
- Main Arc Angle 1 maps to Bridge Cut ST Main Arc Angle.
- Main Arc Angle 2 maps to Bridge Cut NT Main Arc Angle.
- On the top instance, map the Outline Height to T.O. South Tower, and on the bottom instance map it to T.O. Arch above Plaza Level.

Depending on how you place the parameters, you may need to switch side 1 of the nested family to map to the north tower instead of the south tower, and vice versa. The steeper angle should be on the north tower.

To constrain the elements, align and lock both instances to the center left/right reference plane. The bottom instance can have the bottom edge locked and aligned to level 1. The top is more complicated. You want the glass roof on the bridge to be adjustable up or down from level 5. You can use a trick to get this to work. The T.O. Bridge Glass Offset From Level 5 parameter accepts positive or negative values. To make the constraints
work, create two reference planes, one above and one below level 5. Constrain the bottom edge of the arc in the nested family to the lower reference plane using Align and Lock. Then, dimension from level 5 to the reference plane above it and label it T.O. Bridge Glass Positive Offset. Next, dimension from the reference plane above level 5 to the reference plane below level 5 and then label it T.O. Bridge Glass Negative Offset. You’ll see the conditional formulas in the families that make this work behind the scenes.

Once it is placed and constrained, select one instance and create the void. You want these voids to start in the middle and punch through the back of the mass only. We were able to leave the positive offset set to 0 and mapped the negative offset of the void to the back wall from the ellipse center parameter. Do the same thing with the other instance, and you should end up with Figure 21.18.

Figure 21.18
Bridge cutout model lines

5. To trim the top of the mass, place the top void model lines on the front/back reference plane. Constrain the left/right in the middle just like with the bridge cutout family. For the vertical alignment, there is a reference plane in the nested family that is below any of the model lines; this should be aligned with level 1.

6. Map the parameters; this family is all type parameters in case you were looking for them in the Properties palette and didn’t see them. The ST Top of Main Arc parameter should map to the T.O. South Tower parameter in the host; NT Top of Main Arc maps to T.O. North Tower. The rest map to identical parameters in the host family (Figure 21.19).
7. The last change to the form comes from two revolves, one cut from each tower. For these, you need to add a reference plane on each side in a plan view and place them a bit in front of the building (plan north). Once they are placed, dimension them back to the center front/back reference plane and label them as shown below in Figure 21.20.

8. Next, go to a 3D view and select the reference plane in front of the south tower as your work plane. Draw a reference line vertically near the south edge of the building form. Dimension from the center left/right reference plane to the reference line and label it according to the image shown below in Figure 21.20. Then, place the Orb Void Model Lines: South Tower on this same reference plane. To set left/right alignment, align and lock it to the reference line. To set up/down alignment, align and lock it to the level called South Tower Orb. Map the major and minor axes parameters to the ST Orb Major and Minor Axes parameters.

9. For the north tower, change the work plane to the reference plane in front of it. Draw a reference line horizontally this time, and align and lock it to the level called North Tower Orb. Then, place the Orb Void Model Lines: North Tower type. Align and lock it vertically to the reference line. Dimension from the center left/right reference plane to the center of the family, and label that dimension per Figure 21.20. Then, map the type parameters for the north tower orb just as you did for the south tower.

To create a revolve, you can either Tab-select and pick the profile first and the axis in the family second, or you can use the reference line as the axis of revolution. Once you have the families, create voids from both line families individually. You should end up with Figure 21.20.
10. The last thing you need to do is prepare for the analysis steps. For a variety of reasons you want to be able to split this mass in half in the project.

The simplest way to do that is to create voids that can be controlled with yes/no parameters. Start by drawing two small boxes on the B1 Level out of reference lines, one under each tower. Select each box and create a void form for each. Once you do, label the positive offset for the one under the south tower as **ST Void Height** and label the void under the north tower as **NT Void Height**. Next, align and lock the two reference lines toward the middle to the center left/right reference plane. Last, dimension the remaining three reference lines for each void back to the center reference planes and label them as shown in Figure 21.21. If you go to Family Types, you can toggle the check boxes for each tower individually and see the result. You can leave them both on, both off, or see just one at a time.

As with any family, you want to flex the parameters to whatever extremes you think you’ll want to try. That way, you can test for limitations and make sure you didn’t miss a constraint somewhere along the way. Once you’ve got a good feel for what this mass family can do, you’re ready to move on to analysis (Figure 21.21).

This mass will give you everything you need to run the analyses you want to try. More importantly, changing the mass to attempt different iterations takes only seconds. You can even use formulas so you can try hundreds of iterations instead of just a few in the same amount of time.
Performing building performance analysis in early design is one of the best reasons to use massing in Revit. The earlier you can get feedback about your building, the easier it is to make inexpensive changes that have a major impact on the building’s performance. The tools available to you in Revit are not designed to provide highly accurate results; however, accuracy isn’t necessary during schematic design. What you’re looking for is the change you can achieve between iterations and for the best-performing iteration relative to your other designs.

For our energy analysis, we’ll rely on Vasari, since it bundles both the solar radiation tool and the energy analysis tools in one package. Also, we’ll place the mass only once, and leave both the north tower and south tower checked. That way, we have continuous surfaces for the analysis to run on.

**Solar Radiation**  As you saw in earlier chapters, you can use the solar radiation tools with massing elements to quickly determine building form and shading strategies. The advantage a mass like this offers over a typical mass is iteration. Figure 21.22 shows an example of the overall solar exposure on the building. Since the site was so constrained, we had no ability to rotate or change the massing relative to the sun. However, we were able to use this analysis to help determine where we needed to have solar shading on the exterior of the skin. The analysis also helped inform the use of triple glazing on the elliptical glazing panels to reduce heat loss. Last, since much of the sun hitting the ellipse is coming from the sides, we used vertical shading fins to help shade the ellipse on the north tower, which does get a significant amount of solar exposure.

![The resulting mass form](image)
Green Building Studio Similarly, you can analyze masses for whole building performance. This approach is particularly useful for looking at building orientation—which wasn’t an option on our constrained site—but as you can see in Figure 21.23, building orientation can have a significant impact on building performance.

Figure 21.22 Solar radiation

Figure 21.23 Building energy analysis
Mass and Mass Floor Schedules for Area Analysis

Another great thing about masses is that you can inform them which levels they intersect in order to place floor area faces. These floor areas can then be scheduled in a mass schedule that will tell you the total floor area in each mass, as well as a mass floor schedule that will tell you level by level how much area is in each mass. If you’re working on a project with area restrictions like this one, this feature can be a lifesaver.

On this project, we started with a floor area ratio (FAR) of 400, which was reduced to 375 after a few months in negotiations with the municipality. Then, the site area was reduced for public right-of-way, further reducing the area above grade we were allowed on this site. The owner wanted to max out the FAR and we were asked to remain under 100 square meters below the FAR. On a roughly 70,000 square meter project, that goal is tough to accomplish. In order to solve this problem, we used the following techniques:

**Mass Schedules**  Once you have a solid mass, telling it what levels it should intersect with is simple. In the project environment, select the mass and then open the Properties palette. Click the Edit button next to Mass Floors to access a list of every level in the project. Once selected, Revit will dynamically fill out the Gross Floor Area (GFA) parameter for the mass. If you change a parameter, that parameter is automatically updated in the schedule. If you make 20 copies of the mass and change a few parameters in each, they all report their individual gross floor areas. On a rectangular building, you could probably do calculate the GFA in your head, but on a complex building form with sloping and curved surfaces, calculating the areas this way much quicker and more exact. It is also a far better way to modify your building area to hit target floor areas in the design. (Figure 21.24).

![Figure 21.24](image.png)

Mass iterations and schedule
Mass Floor Schedules  Sometimes it is beneficial to see floor by floor what the differences are in an area. Fortunately, you can also create a mass floor schedule, as shown in Figure 21.25.

**Figure 21.25**

Mass floor schedule

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<tr>
<th>Comments</th>
<th>Level</th>
<th>Floor Area</th>
</tr>
</thead>
<tbody>
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<td>Level 1</td>
<td>2794 sq ft</td>
</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 2</td>
<td>2792 sq ft</td>
</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 3</td>
<td>2566 sq ft</td>
</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 4</td>
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</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 5</td>
<td>2794 sq ft</td>
</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 6</td>
<td>1766 sq ft</td>
</tr>
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<td>1.5 Scale Factor</td>
<td>Level 7</td>
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</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 8</td>
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</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 9</td>
<td>1690 sq ft</td>
</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 10</td>
<td>1006 sq ft</td>
</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 11</td>
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</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 12</td>
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</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 13</td>
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</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 14</td>
<td>852 sq ft</td>
</tr>
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<td>1.5 Scale Factor</td>
<td>Level 15</td>
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</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 16</td>
<td>9110 sq ft</td>
</tr>
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<td>Level 17</td>
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<tr>
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<td>Level 18</td>
<td>2792 sq ft</td>
</tr>
<tr>
<td>1.5 Scale Factor</td>
<td>Level 19</td>
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</tr>
<tr>
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<td>Level 20</td>
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</tr>
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</tr>
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<td>Level 22</td>
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</tr>
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</table>

**Curtain Systems on Mass Faces**

The real reason designers play with masses is curtain systems. The relationship between masses and curtain systems (or walls, or roofs, or floors) is quite simple. Where the face of the mass is, the curtain system is. Where the face of the mass isn’t, the curtain system isn’t. You pick the face, make the system, and there you have it! It’s that simple! Now, let’s step through an example of how this is accomplished.
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Creating Curtain Systems by Face Selection. We learned several limitations of curtain systems on this project that affected how we managed the faces of our mass. To save you the rework time, the limitations we found are listed here:

**Grid Line Overlap**  One neat feature of curtain systems and curtain walls is that you can remove portions of the grid where you don't want a mullion or a split in the panel. The bad news is that this is a cosmetic change. We had two towers (as shown in Figure 21.26), and the entire west wall (both towers) was originally one curtain system. Since the levels had different floor-to-floor heights in each tower, we had cases where the grid from one side was less than the mullion thickness of the grid from the other side. In such cases, bad things happened. So, in this project, we eventually split the west wall in half.

**Solids Overlapping on Curves**  We had an addition late in the game when our machine-roomless elevators switched to regular ones. All of a sudden we had to add a penthouse to the form, and the mass didn't have that level of adjustment. We created an additional form and joined it to the existing mass. On flat faces everything went as planned, but on the curved face we ended up with two distinct faces (and curtain systems as a result), with the split where the old and new face met. This issue appears to be fixed in the current version, but be wary of joining coplanar curved surfaces, because you might not get the result you want.
Pimp your system. The great part about curtain systems is all the bling you can add to a project in a relatively short amount of time. Getting to a finished product is fast. Here are some simple and quick steps that will help you add some showy features to the model:

Intermediate Grids Most real-life curtain systems aren’t perfectly repeating in both directions. Fortunately, you can place curtain grids wherever you want them. Select the Curtain Grid tool and go click happy. You might not want a mullion on every line so that some panels can span over a grid. To achieve that, select a grid and click the Add/Remove Sections tool in the ribbon; then click on a section to remove (or add back) a section of the grid line.

Mullion Profiles Once your grid is set up to your satisfaction, it is time to create your profiles. Profiles can be as parametric or as dumb as you want—the only advantage to making them parametric is you have the ability to change the parameters in the project. Incorporate shading fins, fancy cap details, and anything else you like into the profile, and then just pick Mullions and switch them. Don’t forget that you can right-click during selection and select all the Mullions along a grid line much easier than using the drag selection.

Custom Panels If you really want to pimp your system, custom panels are the way to go. Have an insulated spandrel panel behind the glazing to create a shadow-box effect? There’s a custom panel for that. How about an interior pane of glass to raise the STC rating of the curtain wall? There’s a custom panel for that too. There are two drawbacks to these panels, however. The first is that they cannot be placed on anything but a rectangular panel. So, all those panels with angled edges and curved tops in this project won’t accept a custom panel. System panels only, please. The second drawback is that on curved
(in plan) curtain systems, custom panels will come in with their origin reversed. Inside is out; outside is in. So, if you have straight and curved curtain systems you will have to make duplicate custom panels, one mirrored for use in the curved systems.

Solar Shading  As mentioned earlier, you can include shading fins in mullion profiles to your heart’s content. But what if you have a separate sunshading device with hundreds of fins around the whole building? Well, that sounds like a curtain system with empty panels and angled mullion profiles to us. The system in Figure 21.27 is made entirely with mullions at seven different angles.

**Figure 21.27**  Sunscreen design detail
Learn to manage change effectively. We all know real projects change—a lot. So, how does this system manage change? That’s what Update To Face is for, right? Well, if you make a change that causes the face to be deleted in the mass, any association in the project to that face is gone. When that happens, you’ll notice the Update To Face button becomes unavailable. If you reassign the system to a new face, you’re just deleting the curtain system you had and making a new one with the type settings of that curtain system type (Figure 21.28). All that customization you just did? Gone.

In our project, each façade had at least four or five hours of work devoted to adding that customization. So, any time you have to start over, change can be your worst nightmare. We had no less than 34 major changes to the building envelope (including design changes, changes to the site boundaries, changes to the maximum building height, changes to the maximum floor area ratio on the site, and more changes to the site). That’s a lot of time to lose.

Now you know why it is so important to make a fully parametric mass that doesn’t require reconstruction at the mass family level to adjust to changes. We weren’t perfect; three of those changes required rebuilding the mass due to things we didn’t anticipate (like making a side that was previously straight into a curve). But every other change was as simple as clicking Update To Face and fixing a few stray panels and mullions where the change occurred (Figure 21.29).
Chapter 21
Making Projects Parametric

Occupancy, Egress, and Plumbing Calculations

Another analysis you can do in a project involves running a set of occupancy schedules based on the mass floors or floor slabs, or using rooms or areas placed in the model that are defined by the walls tied to the mass. In this example we used rooms, but the concepts are applicable to any schedule. This approach allowed us to quickly assess egress requirements or plumbing fixture counts, and roughly size vertical transportation elements in various building arrangements.

Let’s look at how you can create the types of calculations within Revit.

Key Schedules

The code changes, but not on a per-project basis. So, anything you can encode into a key schedule can save your users time and lessen the likelihood of errors. Key schedules are based on direct input from IBC 2006. The point of key schedules is to give your users the ability to pick an item from a prepopulated drop-down and have it fill out a number of relevant fields. These analysis types include:

Occupancy  Occupancy rules for IBC 2006. Some things are hard to encode into a Revit schedule, but do your best (Figure 21.30).
Exiting  Exiting requirements per IBC 2006, as shown in Figure 21.31.

Plumbing  Plumbing fixture requirements per IBC 2006, as shown in Figure 21.32.
Occupancy Schedule  The occupancy schedule lets you select the key values, run the calculations, and then update the shared parameter that shows up in room tags. Unfortunately, you cannot create formulas to control shared parameters in projects, which is why massing is the only way to create parametric relationships between project elements. You have a calculated value and a shared parameter for occupancy, and you can use conditional formatting to make sure that when the two parameters don’t match, it stands out like a sore thumb. The formula (see Figure 21.33) to calculate the value from the key schedule information is as follows:

\[
\text{IF}(\text{Area Per Occupant} = 0 \text{ SF}, \text{Seating Occupancy}, (\text{Area} / \text{Area Per Occupant}) + 0.49)
\]

Exiting Requirements  The information here is identical to the occupancy schedule but is limited to the exiting-related information. You’d place a schedule like the one in Figure 21.34 on a sheet devoted to exiting requirements.

The two formulas in the calculated values that make this schedule work are as follows:

Stair Exiting Width

\[
\text{if}(\text{Sprinklered}, \text{Calculated Occupancy} \times \text{Stair Exit Width Per Occupant Sprinklered}, \text{Calculated Occupancy} \times \text{Stair Exit Width Per Occupant Unsprinklered})
\]
Horizontal Exiting Width

\[ \text{IF(Sprinklered, Calculated Occupancy} \times \text{Horizontal Exit Width Per Occupant Sprinklered, Calculated Occupancy} \times \text{Horizontal Exit Width Per Occupant Unsprinklered)} \]

**Figure 21.34**
Exiting schedule

**Figure 21.35**
Plumbing schedule

**Plumbing Calculations**  The plumbing schedule in Figure 21.35 contains the same information as the occupancy schedule but once again is limited to just the plumbing fixture requirements.
Some of the formulas for this calculation are more complicated because they have to include additional statements to cover what happens when your occupancy exceeds the first requirement for fixtures and the rest of the occupants are covered by the less stringent second requirement.

**Male Water Closets**

\[
\text{IF}(\text{Male Water Closet Requirement} \geq 0, (\text{if}(\text{Water Closet 1st Requirement Limit} > 0, \\
\text{IF}((\text{Calculated Occupancy} \times 0.5) > \text{Water Closet 1st Requirement Limit}, ((\text{Calculated Occupancy} \times 0.5 - \text{Water Closet 1st Requirement Limit}) / \text{Male Water Closet Requirement} 2) \\
+ (\text{Water Closet 1st Requirement Limit} / \text{Male Water Closet Requirement} 1)), \\
(\text{Calculated Occupancy} \times 0.5) / \text{Male Water Closet Requirement} 1)), \\
(\text{Calculated Occupancy} \times 0.5) / \text{Male Water Closet Requirement} 1), \\
\text{Calculated Occupancy} \times 1)
\]

Fortunately, the Lavatories and Drinking Fountains don’t have the second requirement, so they’re relatively simple.

**Female Lavatories**

\[
\text{if}(\text{Female Lavatory Requirement} > 0, (\text{Calculated Occupancy} \times 0.5) \\
/ \text{Female Lavatory Requirement}, \text{Calculated Occupancy} \times 1)
\]

**Drinking Fountains**

\[
\text{if}(\text{Drinking Fountain Requirement} > 0, \text{Calculated Occupancy} \\
/ \text{Drinking Fountain Requirement}, 0)
\]

Be aware that there is a risk involved when using room schedules for code calculations. Technically many of these requirements are based on the entire floor area or even building use as a whole. We’ve found that using a room-by-room requirement usually inflates the occupancy loads (or other values) over the code requirements so be sure to check your numbers against the total area information in the schedules. Ideally, we’d use a calculated value working off the sums of the room areas, but that isn’t something Revit currently allows.

**Documentation**

With complex geometries, construction documentation of building elements in Revit can sometimes be difficult. For our project, the slanted elliptical curtain wall was particularly challenging. Since Revit cuts the floors at a height above the level but we want our dimensions for a sloped façade to be right where the slope is at the floor line, we thought we were going to have to either make some complicated plan regions or draft in lines to dimension to. Both of those solutions are bad ones, with a lot of extra work anytime the building changed. Here are some other suggestions for documenting complex building forms using Revit.

**Generic Model Line Families, Part 2**  To help manage change in building form, and get dimensions for the mullions, we started making a spreadsheet that would calculate the lengths automatically and any elevation.

However, we realized this approach could be another good use for those Generic Model line families we had constructed to control the mass (Figure 21.36). The line families work just as well in the project to give us something intelligent and parametric to dimension to, and save us time on changes. In Figure 21.36, the blue lines are the same Generic Model line family used in the mass to define the ellipse, with one little change: It uses the formulas from
Microsoft Excel to calculate its exact size at any elevation in the project. The following is for the major axis:

$$\text{IF(Use Elevation for Axis Size, (Base Major Axis + Elevation above Plaza}$$

$$\times ((\text{Top Major Axis - Base Major Axis) / Top Ellipse Elevation)}), \text{Manual Major Axis})$$

**Figure 21.36**

Ellipse dimensioning

---

**Is It Really Flat?** We also ran into a challenge proving that the panels in the sloped elliptical curtain wall were flat. First we used dimensioned 3D views to document the individual panels in the system, as shown in Figure 21.37.

**Figure 21.37**

Panel dimensioning
The second was a trick Zach Kron and Robert Manna demonstrated at Autodesk University 2010. An adaptive component can be applied to a divided surface and displays a color if something is planar or is warped. This approach is a great way to leverage families in Revit for constructability analysis. Figure 21.38 shows a series of shapes with variations in ellipse and circular forms. Any panel that is dark blue is perfectly flat. Red is beyond the maximum deflection criteria. The other colors are in between, with cyan meaning slightly warped, green in the middle range of allowable deflection, and yellow at the extreme end of allowable deflection. You can also see our mass in the background, with all blue panels verifying that it too is made with flat panels. This way of analyzing geometry and illustrating it graphically is a fantastic communication tool for working with owners and contractors.

**Figure 21.38**
Adaptive planar component

---

**Finding Additional Resources**

As you can see, complex families like this require a lot of formulas to properly constrain. Revit’s help documentation is quite good at explaining the specific syntax to use in the formula fields, but it doesn’t help you with finding the right formula for the geometry you’re wanting to control. Here are some tips and websites to turn to for help with formulas:

**Excel**  Not surprisingly, Excel has the formula game down pat. If your formula in Revit has a lot of parentheses or commas and you are getting errors that the end of the expression is “unexpected,” you probably misplaced a parenthesis or comma. Copy your formula into Excel and it will color-code your commas and parentheses so you can find where you’re off. Revit and Excel have similar formula syntax, so if the formula works in one, it will work in the other. Don’t have Excel? Many other spreadsheet applications have similar functionality.
If you're struggling with geometry, there is a wiki page ready to help you. Wikipedia’s math pages are very thorough and give you almost everything you need to calculate that versine of the chord in your circle. You can search for Circle, Triangle, Ellipse, or Schrodinger’s Cat online at Wikipedia.

MathWorld  Still not finding that last pesky little formula? MathWorld is another free site that provides cryptic definitions and formulas that might just make the difference between approximating a solution and making it work perfectly (mathworld.wolfram.com).

Wolfram Alpha  So, you found your formula but algebra isn’t your strong suit? Problem solved (pun intended). Wolfram Alpha is a sister site to MathWorld with one big difference: It solves equations for you. Type in the formula you found on Wikipedia, and tell Wolfram Alpha to solve for whatever variable you need. The site will do the computation, and even show you all the steps—just like your high school teacher always wanted. It also does lots of other neat tricks, and even has an app for your phone (www.wolframalpha.com).

The Bottom Line

Use generic model outline families.  Using massing families can be the basis for creating many conceptual shapes and forms. Understand how to create outline families using parameters.

Master It  Using at least five different parameters within a massing family, of which at least two are nested within others, create a model outline type that can be flexed between forms.

Understand advanced conceptual massing.  Once you understand the mechanics of creating parametric model outline families, the next step to utilizing them to generate complex geometric forms is to bring those families into a mass.

Master It  Bring the families created in this chapter into a massing family to leverage the applied parameters.

Find additional resources.  Learn where you can find additional resources and how best to use those resources to guide you further.

Master It  Using the websites listed in this chapter as a basis for understanding parameters, find other sites and links.