Parametric Modeling of Vaults for Notre Dame in Revit
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Learning Objectives
- Learn how to use reference points
- Learn how to use adaptive points
- Learn how to create reference lines from hosted points
- Learn how to create surfaces from reference lines

Description
In this class, you'll create an adaptive parametric Revit family that represents one of the types of crossed vaults used in the ground-floor ceiling of the Notre-Dame cathedral in Paris, France. This class is a result of Alfredo Medina’s collaboration in Andrew Milburn’s initiative about creating a Revit model of Notre-Dame, a work motivated by the love of using Revit software as a "BIM pencil" (Mr. Milburn’s words) to study historical buildings. Mr. Milburn started the model in April 2019, soon after the fire. Using BIM 360 Design software and a BIM 360 Document Management hub, several enthusiasts from different continents have collaborated in this project. One of the tasks that Alfredo Medina volunteered to do is the group of vaults in semicircular array at the end of the nave. This class is a step-by-step, hands-on lab to show you how to make one of these types of vaults and insert it multiple times in different orientations in the layout of ceiling vaults.

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Alfredo Medina is a very experienced and knowledgeable BIM / Revit professional with a background on architecture, high skills in training, troubleshooting, technical support, parametric modeling, extraction of quantities, definition of standards and best practices, clash detection, and coordination of large BIM projects. Alfredo has several years of experience and a reputation as an expert due to his participation in forums and international conferences.
Lab Assistants

The attendees and I will have the honor to have as lab assistants these friends and Revit experts: Andrew Milburn, Paul Aubin, Rina Sahay and Philip Chan.

Andrew Milburn -
Architect

Paul Aubin -
Author/Consultant
Paul F. Aubin Consulting Services, Inc

RINA SAHAY -
Architectural Technician III
Paradigm Design

Philip Chan
BIM manager
Associate at The Beck Group

NOTE: I wanted to have Philip in the team, but the organizers say that I can have three lab assistants, only. He will be there anyway and will help you if necessary. Thank you all, my friends.
Mentions

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Chapter 1: Readings
(as published in Linkedin)

Part 1: Studying Parts and Proportions of a 4-part Vault

This image below is a reflected ceiling plan of the Notre-Dame de Paris cathedral at ground level. Notice that it contains grid lines and dimensions. Even though this drawing is not fully accurate, it is a good reference for this handout; it is useful for identifying types of vaults and their location in the cathedral.

Highlighted above, between grid lines 7 & 8, and F & G, is an example of the first type of vault that we are going to study. This one is the simplest of all types. This one is known as a "4-part vault", and it is commonly known as "crossed vault", or "groin vault". To start getting familiar with these terms, see the following image and learn the names of some parts of a vault:
A = Arch (a bearing arch between two supports, on the edges of the vault). Also known as "double" arch, probably because it is most of the time next to the arch of the adjacent vault.

- S = Support (either a column or a bearing wall).
- r = ridge (the top edge of a vault, surface, part).

R = Rib (a bearing arch between two supports (usually semicircular) crossing the vault diagonally, forming an "x" in the reflected ceiling plan).

P = "part", commonly known as a vault between two arches. (The term "vault" can be used for a part or for the whole).

Geometric Proportions of a 4-part Vault

According to our illustrations above, our sample 4-part vault is approximately 18 feet x 18 feet (5.48 m. x 5.48 m.). However, to study the geometric proportions, we will use a "prototype" that is a 1 x 1 square (either 1 foot or 1 meter).

In Revit, to study these proportions, we can work in 2D first, using a generic model family and some geometry. In the plan view of a generic model family, I create reference planes separated by 1 unit (1 meter, in my example), and then I draw some reference lines to define the location in plan view of edges and diagonals (arches and ribs) as shown in this illustration, where I have also identified all the corners and the center point with letters A, B, C, D, and E, and the center points of ridges with letters F, G, H, and I.

To find the apex or total height of the vault, in the plan view, in 2D, I create a semicircle with center in point e, going from point A to point C.
Notice that the radius of that semicircle is 0.7071, for a vault that is 1 x 1 square. For any vault of this type, square or rectangular, that distance is half of the hypotenuse of the triangle A D C. This distance, if we were to draw the semicircle following the diagonal in the same way, but in the vertical plane, will mark the highest point of the crossed vault, or apex. The following illustration shows the semicircles intersecting at an elevation of 0.7071, for an imaginary vault of 1 x 1 in plan.

In the construction of the actual vaults, these semicircular arches are the ribs, the first elements that need to be built.

Now, let's go back to our 2D study, the plan view, and let's find the geometry of the arches. There are several methods. Here I am following one method that Eugène Viollet Le-Duc describes in his dictionary of French Architecture as a method that became popular around the 13th century, because it was practical and easy. This was, most likely, the method that the builders of Notre Dame used to find the dimensions of a vault based on the available space between supports.

From the plan view, draw an auxiliary arc with center in point A, and with length equal to segment A-E, going to line A-B, and mark that intersection (point 2). Do the same from the
opposite side, drawing an arc with center in point B, with length equal to segment B-E, going to line A-B, and mark that intersection (point 1) as shown in this image:

Now, use point 1 as the center of an arc that goes from point B towards the left, and use point 2 as the center of an arc that goes from point A towards the right. The intersection of these two arcs form the geometry of a pointed Gothic arc, one of several kinds. In our sample, this arc is the geometry of the "double" arch that goes on the edges of the crossed vault.

The proportions of this arc, for a vault of 1 x 1 square, are these:
Now, let's go back to a 3D view, and, following the same system, let's draw these arcs on all four edges, now that we know their proportions:

Now we need to draw the ridges. In the actual built vaults, the ridge is just the line of intersection between two sides of a vault (part) that is supported between two arches. At the intersection, the masons interlock blocks (in the same way as courses of bricks are interlocked). In Revit, we will see the ridges as hard lines, if we intersect solids and voids in generic families, or if use reference lines to create surfaces in adaptive families.

Notice, in the previous image, the difference between the height of the ribs 0.707, and the height of the pointed arches 0.676. The difference is 0.031.

Going back to the plan view of our generic family, just for understanding the geometry of the ridges, we can draw in 2D an arc that goes from point I to point G with a sagitta of 0.031, and another arc from point H to point F with the same sagitta (distance from the center of the arc to the center of its base).
If we pass this to the 3D view, we need to draw arcs in between the top of the pointed arcs, like this:

The elevations should look like this:
These descriptive geometry exercises, and these numbers that we have found, such as 0.707, 0.676, 0.031, for heights, and 0.293, 0.414, 0.293 for drawing the pointed arcs, will be useful to drive the geometry of vaults of this type for any size. This is a simple way to find parametric relationships.

This geometry is still very simplified, because it does not take into consideration some things, such as the thickness of ribs and arches, the vaults (surfaces) between ribs and arches, and the space they need to have on top of the capitals. Notice that ribs and arches start at points A, B, C, and D. In reality, there needs to be an offset around those points to accommodate the thickness of multiple arches coming to the same point.

Even though this exercise simplifies the geometry, it provides an understanding of the proportions, a first look at the relationships that we need to see before moving forward, in the same way as the builders at that time drew some triangles and arcs on the ground to figure out things with geometry, before building.
Part 2: Making Room for Arches and Ribs on Capitals

In Part 1 of this handout, we learned to identify the main parts of a vault, and we created a wire-frame model of a 4-part vault that is 1 x 1 units in plan, to study its geometry and proportions. In this Part 2 we are going to enhance that model by introducing the space that is necessary at the supports, to accommodate the base of multiple arches starting at the same point.

Our wire-frame prototype looks like this, so far:

![Wire-frame model of a 4-part vault](image)

But actual stone arches cannot start at a point as these arcs do at points A, B, C, D. Each arch has some thickness and a specific place on top of the capital.

In the wire-frame model above, there are 3 arcs starting at each corner. One diagonal (which will be a rib) and 2 pointed arcs (which will be 2 arches), like this:

![Diagram of 3 arcs starting at each corner](image)
Now what happens if we put another vault next to this one? Now there are 2 supports with 5 arcs, while the others have 3.

And what happens if there are 4 vaults together, like this? Now there some supports that have 3 arcs, some that have 5, and one at the center that has 8. That is the maximum number of arches and ribs starting from a support in Notre Dame. In plan, it looks like this:
And in 3D it looks like this, below. Around the support at the center, I have drawn blue arrows to represent the ribs (diagonals) and red arrows to represent the arches that start at that support.

And if you were inside the Notre Dame cathedral, if you looked up to the capital of one of those columns, like the one marked with a number 8 above, this is what you would see: 4 ribs and 4 "double" arches starting at the same capital.
Therefore, we need to modify our initial ideal prototype model, including either a regular octagon or a circle at each support, making the arcs and diagonals start from the vertices of the octagon or from the intersections of the circle with the diagonals and edges. The size of the circle or octagon could be driven by a parameter, to adjust it according to the size of the capital. The apex point (height of ribs) and the height of the arches need to be calculated again. But we already know the proportions and how to draw it. Like this:

![Diagram](image1)

In 3D view, our wire-frame model now looks like this:

![Diagram](image2)
And now the elevations look like this:

![Elevation Diagram]

And the group of four vaults, in plan view, looks like this:

![Plan Diagram]
In the 3d view, now we see that all ribs and arches have some space in between to coexist on top of a capital.

Because this, below, is more or less what happens when you have multiple stone arches starting from the same capital. (Illustration by Viollet Le-Duc, from his Dictionary of French Architecture).
Part 3:

- Methods for Modeling Vaults
- Modeling Surfaces of Vaults

In Part 2 of this handout we separated all the arcs around the supports, by placing a circle at each corner and making the arcs begin at the intersection of circles with diagonals and edges. In this Part 3 we will discuss whether we should use a generic or an adaptive template to complete the vault.

So far, we have this, a wire frame model of the basic geometry:

![Wire frame model of the basic geometry](image)

But this is just a wire frame. The question is, which kind of family template should we use to complete the vault? Generic or adaptive? Let's compare the two methods first. Then I will propose a third method.

**Method 1: Generic family with Solids and Voids**

In the generic templates, we have these tools to create forms: Extrusion, Blend, Revolve, Swept, and Swept Blend, as solid or as voids.
To create a cross-vault with these tools it is necessary to use voids. The approach in this template is simply "solid minus void". One way to do it is this: create a cross by intersecting two solid extrusions of a closed shape that represents an arc with thickness (marked as "S" below), and then create another cross, by intersecting two void extrusions of a closed shape that is a pointed arc with a line at the base, almost like a triangle (marked as "V" below); then the voids will subtract their volume from the solids. The result would be like this:

The result shown above is a crossed vault; however, not the type of vault that is used in Notre Dame. These are the differences:

a) Notice that the ridges in this result are horizontal; in Notre Dame, ridges are curved.

b) Notice that the diagonals (ribs) in this result are the intersection of the two extrusions, and since extrusions follow a straight direction, all these ridges are flat and meet at the center at the same height. In Notre Dame the diagonals (ribs) are semicircles, which creates an apex point at the intersection, higher than the top of the arcs.

c) Notice that in this result, ribs, arches, and apex are different than in Notre Dame; therefore, the surfaces in between, the vaults, are different, too.

**Advantages of Method 1:**

a) It gives the idea.
b) It is quick and easy (if you are doing just one square crossed vault).

Disadvantages:

a) The geometry is not correct!
b) This family will not adapt to irregular layout plans, at least not without great efforts (or more voids? which makes things worse). How would you adapt this to different radii, different heights, trapezoids, triangular plans, special conditions? The more these vaults deviate from the typical 4-part square type, the more incapable this generic method becomes.
c) Voids slow down the performance of Revit models. 1 solid and 1 void = 2 elements to compute.
d) Adding voids means adding more reference planes and more parameters, if you need to keep the result parametric.

Method 2: Adaptive Family Based on Reference Points

In the Adaptive templates, we have these other tools to create forms:

The most important tool of this template is marked with a red arrow: the reference point. The presence of this tool allows us to think of any form as the result of this sequence: points -> lines -> surfaces -> volume.

Therefore, the first task is to locate all the points. First, points "on the ground". These points will host other points that are projected upwards. Then, if the points of the ground move, the points "on the air" will move along. And, since points drive lines, and lines drive surfaces, the whole vault will be adaptable to irregularities in plan, heights, widths, etc.
Below is an example of a vault created with Method 2:

In the illustration above, notice the points "on the ground" and the points "on the air". For every point on the air there is a point on the ground that is its host.

**Advantages of Method 2:**

a) It creates the correct geometry.

b) It can produce shapes that are difficult or not possible with the generic template, such as: conoids, hyperbolic paraboloids, ruled surfaces, double curvature.

c) The same vault family can be used for rectangular or trapezoids plans, and parts of this family could be used for triangular plans.

c) Heights and widths of arcs can be adjusted easily by parameters.

**Disadvantages:**

a) The thickness of the vault will be done with individual elements in the project because each face needs to be materialized as roof by face or wall by face.

b) It can be difficult and time consuming to find the location of all points with precision.
Method 3: Adaptive Families with Adaptive Points and Nested Families

This method appeared as a response to the disadvantage "b" of Method 2, above. The idea is to "pre-build" the ribs and arcs in other families, instead of having to find points for all the geometry as in Method 2. Therefore, if you need a diagonal rib between two points, you load a family that takes care of that. You need a pointed arc between two points? Then you load a family that does just that. This image below shows the 3 families that create the wire frame:

Then, in the vault family, you insert these components, and eliminate that time-consuming part that was a disadvantage in Method 2.

The process would be like this:

In an adaptive family, we made a square of four reference points. Optionally these points can be converted into adaptive points. Then we connect these four points with reference lines:

Then we load a family that we have done with the adaptive family. This family is a semi-circle as a model line between two points. The semi-circle is made with 2 arcs (to allow for selection of left or right side). The two points are adaptive, so that we can create the diagonal by simply clicking on two points, as shown below.
Actually, we click a little bit away from those points, to allow some space for arches to coexist on top of capitals (As explained in Part 2 of this handout). Notice the enlarged view of point D in this illustration, and notice the diagonal starting away from point D.
Then we insert a second family, which is a pointed arc, as a model line, from two points, and with this family we create the four-pointed arcs around the square, clicking on two points. After inserting the pointed arc families, the result would be like this:

Now at the callout around point D, notice that we see one diagonal and two pointed arcs:

Then we insert a third family to create an intermediate "broken arc", which is necessary to create the correct surfaces and curves. This family creates a pointed arc by clicking on 3 points. In plan view, this broken arc looks like a triangle. The projection of the 3 points A, q, D, creates
the broken arc that is highlighted below. In this image all the four broken arcs have been created).

Now we have the 3 arcs that we need to create a surface correctly. Using the Tab and Ctrl keys of the keyboard we select one half of each of these 3 arc families together, and then do Create Form > Surface. The result would be like this:
Then, we repeat the process to create the other surfaces. The instances of the nested families are set to be not visible. The result would be like this:

Advantages of Method 3:

a) It creates the correct geometry.
b) It uses nested families, with the geometry and proportions already figured out, therefore the process of making the surfaces goes much faster than Method 2.
c) It is still adaptable to variations in layout, heights and widths

Disadvantages:

a) Probably only the same mentioned before, that the thickness of the vault will be done with individual elements in the project because each face needs to be materialized as roof by face or wall by face.
Part 4:
- Adding Parameters
- Placing Vaults on Columns
- Modeling Ribs

At the end of Part 3 of this handout, our 1 x 1 prototype of a 4-part vault looked like this:

In this Part 4, it's time to make the vault grow because we need to model ribs and arches with their actual size. If we inserted the vault now into a project, and put a person next to it, this is what we would see. Not very impressive yet.

There are different ways to control the size of the vault (or any family in the adaptive template)
Method 1: Reference Planes, Dimensions and Parameters

In plan view, align and lock reference points to reference planes, in both directions x and y. Create dimensions to control the distance between reference planes, and convert dimensions into parameters for Width and Depth. The heights are already controlled by the nested families that we created before.

Method 2: Hosted Reference Points with Offsets

This has to be planned from the beginning. After creating reference point A, host a point B on a vertical plane of point A (the plane that is aligned with line A-D); then associate the Offset parameter of point B to a parameter for Depth. Then host a point D on a vertical plane of point A (the plane that is aligned to line A-B); then associate the Offset parameter of point D to a parameter for Width. Then host a point C on a vertical plane of point D (the plane that is aligned to line A-D); then associate the Offset parameter of point D to a parameter for Depth. This method does not use dimensions nor reference planes, only points.

Method 3: Shape Handle Points

Select reference points A, B, C, D, and change their "Point" property to "Shape Handle Point (Adaptive)."

If you use this method, the vault will be inserted in the project at the same size it was modeled in the family, and if you need to change its size you need to move all four points to the desired dimension.

Method 4: Adaptive Points
Select reference points A, B, C, D, and change their "Point" property to "Placement Point (Adaptive)".

If you use this method, the vault will be created only after you finish clicking points A, B, C, D, in the proper sequence, in a project or in another family. It's like executing a program by steps, 1, 2, 3, 4, done.

Which method should we use?

Method 1 is the same method we use in generic families. It is simple and practical for adaptive families that are simple, co-planar, like the host family of this square vault. For more complex families, I prefer Method 2. Method 3 is user friendly in the project, but it might be slow. Method 4 is necessary only if you need to adapt a family to multiple shapes and varying conditions, such as the vaults at the semicircular array in Notre Dame. You should choose the method that works better in each case. If you use Method 4 for a family that could be done easily with Method 1, probably you will end up complicating things.

To control the width and depth of the vault, I am going to use Method 1. The heights are already controlled by the nested families using Method 4, based on the distance between two points. Therefore, to control width and depth, I do this:
Now, in the project, our vault has its actual width, depth, and height, and we start getting a sense of its scale. Assuming that the vault is still on the floor, not on columns yet, it would be like this:

But only when we add the vertical dimension, that impressive vertical dimension of Gothic cathedrals, putting the vault on top of columns, 6.8 meters tall (approx. 22’ 4’’), the same vault creates now a totally different effect.

If that module of a vault on top of four columns is repeated over and over, we start feeling that effect of grandiosity. Look at the size of our man now in relation to the space created by just repeating columns and vaults:
Now that we have the actual size of the vault, let's model the ribs. That is what the builders had to build first, the ribs. Well, after the wooden scaffolding for the ribs was ready.

What was the profile of stones used for the ribs? According to some illustrations in Viollet Le-Duc's dictionary of French Architecture, the profile is something like this, below (the purple area represents the stone blocks of the vault in section).

What are the dimensions of the profile? I don't know exactly. Using Leica's panoramic images and measuring tools, when I measured that profile, I always obtain something similar to one foot wide, give or take. You can try this by yourself, here:

https://notredame.truview-cloud.com/scan/99c5a977-eb9e-4c39-afc5-3e21dd74fa4d
Therefore, I am going to assume that the profile is one foot wide, like this:

Other illustrations in Viollet Le-Duc's dictionary suggest that the profile has a central deeper section; something like this:
When I say "profile", speaking of a profile to be used in an adaptive family, I am referring to a generic model family, work-plane based, not always vertical, that contains a flat closed shape made with model lines.

To use my profile, I load the profile family into the vault family, then use reference > point, click on "Draw on face" (1), then put the point on the diagonal of the semicircular arc, then use the Set tool (2) and select a plane of that point as the current work plane (the plane that is perpendicular to the semicircular arc), and then place the profile family on that point, using the Tab key until the profile is oriented properly (highlighted below). Then select the profile family and set its Visible property to be off.
Then, select both the diagonal and the profile, and do Create Form. Now you should have one rib. Repeat the process for the other diagonal. Now you should have two ribs, like this:

If we turn on the surfaces and load the family again into a sample project, now we see the ribs, as shown below. And we realize that the top of the capitals needs to be bigger, to accommodate these ribs and the upcoming arches. The diameter at the top of the capital is now approx. 90 centimeters in diameter (some 3’), which is more or less what the Leica’s panoramic images show. (These columns are just place holders and will be replaced later).
Part 5:

- Modeling Arches
- Placing Vaults on All Columns

At the end of Part 4 of this handout, we had already put vaults on columns, at their full size, and modeled the diagonal (ribs) of the vaults, like this:

In this Part 5 of the handout, we are going to model the arches that go on the four sides of the vault. These arches can have different profiles. Let's say "A", "B", and "C". If an arch is in between two vaults of the same kind, it uses a profile "A"; if the arch is exposed as a "facade" of the arcade, it uses a profile "B"; if the arch is adjacent to a space that has a vault of a different height (as in the chapels), the arch uses a profile "C".

In this image from Leica's True View Cloud, I have marked these three types of profiles. You can explore this by yourself at:

https://notredame.truview-cloud.com/scan/99c5a977-eb9e-4c39-afc5-3e21dd74fa4d
Note: I think that the profile of the arch adjacent to the chapels ("C") is different than the profile that faces the nave ("B"). But for this exercise, to simplify things, we are going to use profile "B" for the arches marked as "C" in these images.

In our reflected ceiling plan, I have marked in red the arches that use profile "A"; in blue those that use profile "B", and in green those that use profile "C".
Profile "A"

In this illustration, taken from Viollet Le-Duc's dictionary, he talks about the geometry of the stones used for the arches, not for Notre Dame in particular, but in general. Highlighted in yellow, is a section of a stone for an arch that goes in between two vaults, which is what we need for profile "A".

It is basically an enlarged version of the profile of the ribs, but instead of being 1 foot wide (approx. 300 mm), this profile is approx. 500 mm wide (approx. 1'-8"), based on Leica's panoramic images and measurement tools. Therefore, I have scaled the profile of the rib, and saved as my profile "A", like this:
We load this profile "A" family into the vault family. Then we place a reference point, using "draw on face", on one of the arcs. Then we use the Set tool to set one of the work planes of a reference point as the current work plane, the plane that is perpendicular to the arc on the left or the arc on the right side of the vault, like this (profiles highlighted in yellow).

Then we select one arc and one profile and do Create Form. Then we do the same on the opposite side. The result would be like this:
Even though the profiles are different depending on the position of the arch in the project, we could use the same profile "A" in all the arches to begin with, and then use an instance Family Type parameter to change the profile family as per the location of each arch. Therefore, let's put the same profile "A" in the other two arcs, front and back, like this:

Then, let's select profile families and arcs, and then do Create form, as explained above. The result would be like this:
If we turn on the surfaces, the vault family would look like this, below. I turned preview visibility on, to check that the profiles families are not going to be seen in the project.

Meanwhile, in the project, I have copied my group of columns and vaults to create the two isles, north and south, and part of the great nave in between, like this:
If we load now our vault to the project, without having changed all the profiles of the arches yet (all arches are using profile “A” so far), it would look like this:
But remember that the arches that face the nave need to have a different profile. Maybe for structural reasons because those arches not only carry their share of the vault but also their share of the weight of the walls and other elements that enclose the nave. According to Viollet Le-Duc's illustrations, that profile "B" is something like this (highlighted in yellow, below).

It's like an enlarged profile "A" (but with a width of 600 mm instead of 500), plus one additional stone below, to increase the depth of the arc. Something like this:
It's literally two stones, one on top of the other. However, for our vault family, we need to simplify the profile, erasing that line in between the two stones, to make one single closed shape, as if the two stones were merged into one, like this:

Then we load this family into the vault family. But we don't have to place it on any arc. Loading it is enough. Then, in the vault family, we select one of the instances of profile "A" (the one that corresponds to the "front" of the view cube), and create a new parameter, such as "Profile for Arch-Front", like this:
Then we select another instance of profile "A" on the right side, and create "Profile for Arch-Right" parameter, and so on, until we have something like this:

Now in the project, we can select a vault, and specify which profile, A or B is each arch going to use, depending on its position. Remember, all the arches facing the nave use profile B. In that case, in the project, we select each vault, and make sure that the arch facing the nave uses "profile-stone-arch-B" for one of its parameters. The words "front, back, left, right" don't need to match the orientation of the vault. It would be good, but that does not matter.

Once you assign profile B to all the arches facing the nave, you would have something like this, below. In this cutaway view, notice the profile B creating the arches that face the nave, and the profile A that creates the arches in between vaults. Also, notice that the capital of the columns facing the nave need to be different than the capitals of the columns in between arches. That is a different topic that we will address later.
This is enough for Part 5 of this handout. In Part 6 we will add thickness and material to the surface of the vaults. So far, we have this, below. All arches on the exposed side of the vault are using profile "B".
Part 6:

- Adding Material and Thickness to Surface
- Placing Vaults on First and Second Floor

At the end of Part 5 of this handout, we had already modeled the arches that go on the four sides of the vaults, using at least 2 types of profiles, and our model was at this point:

In this part 6, we are going to model the thickness of the vaults and do more progress on the modeling of other vaults of the same type in the cathedral.

Modeling the thickness of the vault is easy. In the project, we use Roof by Face, like this: from a 3d view, use Massing and Site > Roof by Face. Then create a roof type that is 4" thick. We will apply a material later. On the ribbon, "Select Multiple" is selected by default. Then, click on the eight surfaces, like this:
Notice that in the properties, we are using "Faces at Top of the Roof". This is why we left a gap of 4" between the top of the profile families and the path of the arches. That gap is going to be infilled now by the roof. After selecting the last surface, we click on Create Roof, and this is the result:
Now we should create a material for the roof type. There are different ways to do that. One way is to use a model pattern that represents blocks of stone. We can use a reduced version of the "Block 8 x 16" pattern that comes with Revit. I don't know exactly what the size of the stone blocks was, but after seeing some illustrations in Viollet Le-Duc's dictionary, I can tell that the block pattern conveys the idea in a good way, like this:

Another way to create the material is using an image file. Anyway, let's leave it like this and let's go to Viollet Le-Duc's dictionary for a moment and read about how the masons put the block stones in between the arches.

This illustration below, number 57 from chapter 4 of the dictionary, shows how the first courses of a vault were built. That part was relatively easy to do. It's like building a wall with bricks, slightly sloped in the vertical plane, following the curve of the arches and using the arches as support.
However, the inclination of this wall and the distance from point A to point B shown above increases at every course. After this height, the masons needed something to keep the curve consistent, and to get temporary support. That something was this clever device shown below.

Two pieces of wood of the same shape, interlocked and secured with two wedges. This served as a template to maintain the curvature of the vault between points A and B, and as temporary support. To adjust this device to different widths, the wedges were removed, the wood pieces were moved to the desired distance from A to B, and then the wedges were put again. Illustration number 59 below shows the device in section view. I have indicated it as "d" in both images, section and 3d view. Also, I have marked the approximate location of these devices in all the vaults.
In regard to the direction of courses of stone blocks, there were different ways to do it. In Notre Dame, the direction of the blocks is perpendicular to the pointed arches. In other cathedrals and other types of vaults the direction is sometimes diagonal, similar to the result I got in Revit after applying a material with a model surface pattern to the roof by face. We can see the difference comparing a picture from Leica's panoramic images against a view of our Revit model.
Now that we have resolved the roof of one vault, we can reuse it as many times as needed in the cathedral. I have extended my model and I have created a basic mass of the cathedral and placed this vault in all the places where it goes, first and second floor:

For practical reasons, I am over simplifying the cathedral because the topic of the class is the typical vault, so I have copied my group of columns and vaults to the second floor and I have added a floor. Now that the vaults have thickness, a partial section would look like this, without the mass of the cathedral:
(For the exercise files of the class, I will have a better version of the columns. For this handout, I have been using just a generic architectural column family).

Now let's go to a transparent front view, with the mass of the cathedral. Look at the size of the man in the main nave.

And now let's go to a 3d view of the mass, showing all the vaults of the same type:
Well, I think this would be enough for a 90-minute hands-on lab at Autodesk University. Thank you very much for your interest in the class and for reading this handout in Linkedin. Believe it or not, this 4-part vault is the easiest of all the types of vaults in Notre Dame. I have learned a lot making this, and I hope that you have learned, too, and that you feel inspired to learn some more.
Chapter 2: Step by Step Instructions

Workflow and Legend of Colors
# 4-part Stone Vault

## Working on:

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Step</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start a new Revit family with the template for the vault</td>
<td>1. <strong>New &gt; Family &gt;</strong> (from the Templates folder, select this)</td>
<td><img src="https://example.com/image1.png" alt="Image 1" /></td>
</tr>
<tr>
<td>To create reference points locked to the length parameters, that will be hosts for the circles that will host divided paths.</td>
<td>2. From the reference level plan view, do: Reference &gt; point &gt; (create 5 points, as shown on the result, put a point at each of the four corners of the vault and one on the center) &gt; Click on Modify to finish.</td>
<td><img src="https://example.com/image2.png" alt="Image 2" /></td>
</tr>
<tr>
<td>To save this as the vault family</td>
<td>3. <strong>File &gt; Save</strong> (in &quot;My Families&quot; folder, save as “4-part Square Vault”). &gt; Save</td>
<td><img src="https://example.com/image3.png" alt="Image 3" /></td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Reference &gt; Circle (Draw on Face or on Work plane) &gt; Radius: 1 &gt; click on all 5 points to create a circle hosted on each point.</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>For each circle at the four corners, do this: select the circle &gt; convert the temporary dimension into permanent.</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Select all four radial dimensions, and convert them into parameter “R1”</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>To set a radius for the base of arches on top of capitals.</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Select all four circles at the corners at once. &gt; Divide path &gt; from the Properties window set the number of nodes to 8.</td>
<td></td>
</tr>
</tbody>
</table>

To create reference circles which will be divided, to create nodes that will be used as start and endpoint of arches.

To control the radius of the reference circles to control the space of arches on top of capitals.

To set a radius for the base of arches on top of capitals.

To create start and endpoints for all arches.
To create start and end points for the Middle arcs (Arc 2).

9. Using Visibility Graphics (VG) turn OFF the Dimensions category. For each of the circles at the corners, do this: draw a reference line (Draw on Face, 3d Snapping, Chain activated) with three clicks as shown on the result, on the quadrant of the circle that is inside the square vault. Then select all four chains of lines > Divide path > set the number of divisions to 5.

To create a circle that, once divided, can mark the endpoint of the Middle arcs (Arc 2).

10. Using Visibility Graphics (VG) turn ON the Dimensions category Select the circle at the center of the vault. Select the temporary radial dimensions and convert it into parameter “R2”.

To find a point that is at half of the distance of the side of the vault.*

*For RECTANGULAR VAULTS, USE AN ELLIPSE.

11. Select that same central circle > Divide Path > Set the number of nodes to 4. Save.

If you got lost, close this family and open “4-part-Square Vault up to Step 11.rfa” from the “Catch Up Families folder”.

---

*For RECTANGULAR VAULTS, USE AN ELLIPSE.
<table>
<thead>
<tr>
<th>Purpose</th>
<th>Steps</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start a new Revit family with the template for Arc 1-Semicircle</td>
<td>12. New &gt; Family &gt; (from the Templates folder, select this). ![Template for Arc-1-Semicircle.rft](Template for Arc-1-Semicircle.rft)</td>
<td><img src="Result" alt="Result" /></td>
</tr>
<tr>
<td>To create reference points that will be converted to adaptive points later.</td>
<td>13. From the reference level (plan) view, do this: Reference point (draw on face or on work plane)&gt; (create 2 points as shown; put a point at each intersection of the reference planes. Click on Modify to finish.</td>
<td><img src="Result" alt="Result" /></td>
</tr>
<tr>
<td>Purpose: eliminate references that might cause errors when creating dimensions.</td>
<td>14. Erase all three reference planes.</td>
<td><img src="Result" alt="Result" /></td>
</tr>
<tr>
<td>To create a line where to host a point that is at the midway of the distance between the two adaptive points.</td>
<td>15. From the reference level (plan) view, do this: Reference line &gt; (activate “3d Snapping”) &gt; (create a line from one point to the other as shown. Click on Modify to finish.</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>To convert the two reference points into adaptive, so that we can click two points in the vault family to generate this arc.</td>
<td>16. Select the two points &gt; Click on “Make Adaptive”.</td>
<td></td>
</tr>
<tr>
<td>To create a dimension to be converted into a reporting parameter</td>
<td>17. Create &gt; Aligned dimensions (from adaptive point 1 to adaptive point 2), place dimension, Modify or Escape to finish.</td>
<td></td>
</tr>
<tr>
<td>To create a reporting parameter to be used in a formula, to calculate the radius of the arc.</td>
<td>18. Select the dimension &gt; From the “Label” drop down menu, select parameter “D”(report).</td>
<td></td>
</tr>
<tr>
<td><strong>To have a point that is at the middle of distance “D”, to be used as the center of the semi-circle.</strong></td>
<td><strong>19. Reference &gt; point (Draw on Face) &gt; put a point on the midpoint of the reference line.</strong></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>To set a work plane for the model line arc.</strong></td>
<td><strong>20. From the Front View, use Set &gt; from the dialog box select “pick a plane” &gt; use the Tab key to find the work plane of the point that is perpendicular to the view. If necessary, Tab, Tab, then click to finish.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>To draw a model line arc (only half of the semicircle).</strong></td>
<td><strong>21. Model &gt; Arc (center-ends-Arc), first point at the middle point, second click on adaptive point 2, third point to complete a 90-degree arc. Click on Modify.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>To control the radius of the model arc by parameter.</strong></td>
<td><strong>22. Select the model arc. Click on the symbol below the radial dimension to make this dimension permanent. Then select the new dimension and from the “Label” drop down menu, select parameter “R”.</strong></td>
<td></td>
</tr>
<tr>
<td>Step</td>
<td>Instruction</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>23.</td>
<td>Select the model line arc &gt; click on the temporary angular dimension; click on the dimension symbol to make this dimension permanent. Click on the angular dimension again. Find the pad lock icon and lock that 90-degree angle.</td>
<td></td>
</tr>
<tr>
<td>24.</td>
<td>Repeat steps 21 to create the other half of the semicircle, connecting to the first half.</td>
<td></td>
</tr>
<tr>
<td>25.</td>
<td>Go to the 3d view. Select one of the adaptive points and move it to the left or to the right. The two arcs should stay attached to the points, creating a semicircle.</td>
<td></td>
</tr>
<tr>
<td>26.</td>
<td>If the result was successful, do this: Load into Project and Close. Save family? Yes &gt; Save in “My Families” as “Arc-1-Semicircle”</td>
<td></td>
</tr>
</tbody>
</table>

Family “Arc-1-Semicircle” loaded into family “4-part-Square Vault”.

If you got lost, close this family and open “Arc-1-Semicircle.rfa” from the “Catch Up Families folder and load into the vault family.”
<table>
<thead>
<tr>
<th>Purpose</th>
<th>Step</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>To model arcs for the ribs of the vault.</td>
<td>27. From the plan view, (dimensions category OFF), Project Browser &gt; Families &gt; Generic Models &gt; Find “Arc-1-Semicircle” &gt; type &gt; right click &gt; Create Instance &gt; (draw on Face), click on one node from one corner, and click on a node on the opposite corner.</td>
<td>Result in plan view: <img src="image1.png" alt="Plan View Result" /></td>
</tr>
<tr>
<td></td>
<td><strong>Detail a)</strong></td>
<td><img src="image2.png" alt="Detail a" /></td>
</tr>
<tr>
<td></td>
<td><strong>Detail b)</strong></td>
<td><img src="image3.png" alt="Detail b" /></td>
</tr>
<tr>
<td></td>
<td><strong>Result in 3d view:</strong></td>
<td><img src="image4.png" alt="3D View Result" /></td>
</tr>
<tr>
<td>To verify that what we did is OK.</td>
<td>28. From Family Types, change the value of X to something else, and Apply. Do the ribs respond to the parameters? If yes, save. <strong>⇒⇒ If not, open Vault-Fast Forward to Step 28.</strong></td>
<td>Arcs for ribs created and responding to parameters.</td>
</tr>
</tbody>
</table>
### Working on: Arc-2-Pointed

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Step</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start a new Revit family with the template for Arc 1-Pointed</td>
<td>29. New &gt; Family &gt; (from the Templates folder, select this)</td>
<td>Result in plan view:</td>
</tr>
<tr>
<td>To convert the two reference points into adaptive, so that we can click two points in the vault family to generate this arc.</td>
<td>30. Select the two reference points &gt; Click on “Make Adaptive”.</td>
<td></td>
</tr>
<tr>
<td>To create a dimension to be converted into a reporting parameter</td>
<td>31. Create &gt; Aligned dimensions (from adaptive point 1 to adaptive point 2), place dimension, Modify or Escape to finish.</td>
<td></td>
</tr>
<tr>
<td>To create a reporting parameter to be used in a formula, to calculate the radius of the arc.</td>
<td>32. Select the dimension &gt; From the “Label” drop down menu, select parameter “D”</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>To have points that will be the center of the two arcs, the two halves of the pointed arch.</td>
<td>33. From the 3d view: Reference point (Draw on Face) &gt; put two points on the line, approximately as shown.</td>
<td></td>
</tr>
<tr>
<td>To use the same parameter “P” to control both points, we need to make one point measured from “End” and the other from “Beginning” of the line. Otherwise we would need two parameters.</td>
<td>34. Select one of the two points (the point on the right (from the default 3d view) and use its “Flip-measure from end” control.</td>
<td></td>
</tr>
<tr>
<td>To control the location of these two points by parameter.</td>
<td>35. Select both points &gt; set Measurement Type to be “Normalized Curve Parameter”, and then set the “Normalized Curve Parameter” value to parameter “P”.</td>
<td></td>
</tr>
</tbody>
</table>
To set a work plane to draw a model line arc.

36. From the Front View: Use Set > pick a plane > use the Tab key as necessary and click when you see the work plane perpendicular to the view, as shown.

To draw one half of the pointed arc.

37. Use Model line > Arc (start-ends-Arc),(visible), draw an arc like this: center: at one of the reference points, endpoint: on the farthest adaptive point, angle: 90 degrees.

To control the radius of this arc by parameter.

38. Click on the symbol under the temporary radial dimension to make that dimension permanent. Click on Modify, then select the new dimension and convert it into the “R” parameter.
<table>
<thead>
<tr>
<th>To draw the other half, and control the radius of both, by the same parameter.</th>
<th>39. Repeat the three previous steps to create the other half of the arc, until you have two arcs, as shown, with an angular dimension (unlocked) and their radius controlled by parameter “R”.</th>
</tr>
</thead>
<tbody>
<tr>
<td>To constrain the angle of the arcs.</td>
<td>40. Use the Trim by Corner tool to trim the two arcs. Then select each arc, make its angular dimension permanent, and then lock that dimension with the pad lock.</td>
</tr>
<tr>
<td>To verify that what we did is OK.</td>
<td>41. From the 3d view: move one of the adaptive points. The pointed arc should grow or shrink as you move the adaptive point.</td>
</tr>
<tr>
<td>To finish this family.</td>
<td>42. If the result was successful, do this: Load into Project and Close. Save family? Yes &gt; Save in “My Families” as “Arc-2-Pointed”</td>
</tr>
<tr>
<td></td>
<td>Family “Arc-2-Pointed” loaded into “4-part-Square-Vault”</td>
</tr>
</tbody>
</table>
If the result was unsuccessful, you may spend a couple of minutes trying to fix it.

If you can’t, open “Arc-2-Pointed” from the “Catch-up Families folder”, Load into Project > (load into your “4-part Square Vault” family, and continue.
<table>
<thead>
<tr>
<th>Purpose</th>
<th>Step</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>To model the first pointed arc on one of the sides of the vault (Front side).</td>
<td>43. From the plan view, Project Browser &gt; Families &gt; Generic Models &gt; Find “Arc-1-Semicircle” &gt; type &gt; right click &gt; Create Instance &gt; (draw on Face), click on one node from one corner, and click on a node on the opposite corner.</td>
<td>Result in plan view:</td>
</tr>
</tbody>
</table>

![Detail a)](image1)![Detail b)](image2) | Result in 3d view: |

![Detail a)](image3)![Detail b)](image4)
To model the rest of the pointed arcs (right, back, left).

44. Repeat the previous step 3 times, to create the pointed arcs on the other sides.

Result in plan view:

![Plan View Image]

Result in 3D view:

![3D View Image]

45. Flex the family. If it works, save.

➔➔ If not, open “Vault-Fast Forward to Step 45
### Purpose
To start a new family for the middle arc (Arc-2).

### Step
46. New > Family > (from the Templates folder, select this:

![Template for Arc-3-Middle.rft]

47. From the plan view, draw a dimension from adaptive point 1 to adaptive point 2, Modify, and then convert this dimension into parameter “D” (report).

![Dimension from adaptive point 1 to adaptive point 2]

48. From a 3d view, use Set and use the Tab key over adaptive point 1 until the work plane that is perpendicular to the reference line is selected. Then click.

![3D View with Tab key usage]
<table>
<thead>
<tr>
<th>To set a point that will be the center of the middle arc (Arc 3).</th>
<th>49. From the 3d view: Reference &gt; point (draw on Work plane) put a point on adaptive point 1. Modify.</th>
</tr>
</thead>
<tbody>
<tr>
<td>To control by parameter the point that will be the center of the middle arc (Arc 3).</td>
<td>50. Select the new reference point and set its offset property to parameter “R”.</td>
</tr>
</tbody>
</table>
| To create the model line arc. | 51. From the Front view: use Set > pick a plane, and set the perpendicular work plane of the new reference point as the current work plane.  
52. Model line > arc (start-ends-Arc), (draw on work plane), center on the new reference point; end on adaptive point 1, angle: until the angle matches the vertical reference plane of the end of the reference line at adaptive point 2. |
53. Select the model arc. Click on the angular dimension, make it permanent, and lock it.

54. From the 3d view, move adaptive point 2. The arc should grow or shrink.

55. If the result was successful, do this: Load into Project and Close. Save family? Yes > Save in “My Families” as “Arc-3-Middle”

Family “Arc-3-Middle” is loaded into the vault family.

If not open “Arc-3-Middle.rfa” from the Catch-Up folder and load into the vault family.
**4-part Stone Vault**

**Working on:**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Step</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>To create the first middle arc.</td>
<td>56. From the Project Browser, find the “Arc-3-Middle” family and create the first instance, on the front side, as shown.</td>
<td>Result in plan view:</td>
</tr>
</tbody>
</table>

**Detail a)**

![Detail a)](image1.png)

**Detail b)**

![Detail b)](image2.png)

Result in 3d view

![Result in 3d view](image3.png)
<table>
<thead>
<tr>
<th>Description</th>
<th>Instruction</th>
<th>Result in 2D</th>
<th>Result in 3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>To create the other 3 middle arcs</td>
<td>57. Repeating the previous step 3 times, complete the remaining middle arcs, as shown.</td>
<td><img src="image" alt="Plan View" /></td>
<td><img src="image" alt="3D View" /></td>
</tr>
<tr>
<td>To set a work plane on the model line that represents the rib.</td>
<td>58. From a 3d view: use Reference point (Draw on Face) and put a point on one of the ribs (Arc-1-Semicircle family). Then using Set, set the plane of that point that is perpendicular to the rib, as the current work plane.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To host a profile on a point that is hosted on a rib.</td>
<td>59. From the project browser, under Families &gt; Generic models, find this family and type: Right click &gt; Create instance &gt; On Work plane &gt; place it on the plane of the new point. Use the Tab key as necessary until the profile is oriented properly (flat part up). 60. Select the Profile and set its Visible property to Off. 61. Repeat the previous two steps for the other rib.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To create the ribs.</td>
<td>62. Select one model line from the Arc-1-Semicircle and one Profile-3-Stone-Arch-Rib family and do: Create Form. Repeat this to create the other rib.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To set a work plane on the model line that represents a pointed arc.</td>
<td>To set a work plane on the model line that represents a pointed arc. 63. From a 3d view: use Reference point (Draw on Face) and put a point on one of the pointed arcs (Arc-2-Pointed family). Then using Set, set the plane of that point that is perpendicular to the pointed arc, as the current work plane. Repeat this for the other three pointed arcs.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| To host a profile on a point that is hosted on a pointed arc. | To host a profile on a point that is hosted on a pointed arc. 64. From the project browser, under Families > Generic models, find this family and type:  
   ![Profile-1-Stone-Arch-A](image)  
   ![Profile-1-Stone-Arch-A](image)  
   Right click > Create instance > On Work plane > place it on the plane of the new point. Use the Tab key as necessary until the profile is oriented properly (flat part up).  
   65. Select the Profile and set its Visible property to Off.  
   66. Repeat the previous two steps for the other pointed arcs. |
| To control by a Family Type parameter the type of profile for the pointed arcs. When the pointed arc is facing the nave, it uses Profile B; otherwise it uses Profile A. | To control by a Family Type parameter the type of profile for the pointed arcs. When the pointed arc is facing the nave, it uses Profile B; otherwise it uses Profile A. 67. Select a profile for the pointed arch, and assign it to a label, selecting one of these Family Type parameters, corresponding to the position of each profile arch:  
   ![Profile-1-Stone-Arch-A](image)  
   ![Profile-1-Stone-Arch-A](image) |
<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>68.</td>
<td>From the 3d view, select one profile family and its corresponding model line, and do: Create Form. Repeat until completing all four pointed arches. Recommendation from Paul Aubin: close this family and open new family from template Fast Forward Vault to Step 73.</td>
</tr>
<tr>
<td>69.</td>
<td>Select each pointed arch and set its Visible property to the corresponding Yes/No parameter, selecting from this list (use the view cube as a reference). If you got lost, open “Vault-Fast-Forward to Step 69.rfa”</td>
</tr>
<tr>
<td>70.</td>
<td>Using the glasses icon, hide all arches and profiles.</td>
</tr>
<tr>
<td>71.</td>
<td>Using VG, hide reference planes, and dimensions.</td>
</tr>
</tbody>
</table>

(73) To avoid visual clutter in the family editor before creating the surfaces. (74) To avoid seeing the model lines in the project.
| To create the first surface for a vault. | 72. To create one surface, select 3 elements: (For first and third, you need to use the Tab key to find the: Line part of the family.  
2. Generic Models : Arc-3-Arc-Middle : Arc-3-Arc-Middle  
and then do Create Form. |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>To create all the surfaces.</td>
<td>73. Repeat the previous step as needed to complete all the vaults. There should be 8 in total. Save.</td>
</tr>
<tr>
<td>To reveal all hidden elements</td>
<td>74. Use the Glasses icon, reset visibility.</td>
</tr>
<tr>
<td>To have a project where to load this family.</td>
<td>75. Open &gt; Project &gt; from the “Sample Project” folder, open “Notre Dame Mass with Vaults.rvt”. Project opened.</td>
</tr>
</tbody>
</table>
To finish | 76. From the Vault family, if the result was successful, do this: Load into Project and Close. Save family? Yes, and load into the sample project. | Vault family loaded into sample project.

| ➤➤ If you got lost, open “Vault-Fast-Forward to Step 76.rfa” from the “Catch up Families”, Load into Project > (load into “Notre Dame Mass with Vaults.rvt”). |
## Purpose

To place the first vault in the project.

### Step

77. From the Ceiling Level 1 view, do:
- Architecture > Component > Place component, on Work plane. From the Placement Plane drop down menu, select “Top of Capitals First Floor” reference plane. Place a first vault close to intersection of grids D and 6. Align vault to grid lines. Turn off some arches to avoid repetitions, leaving on only Back and Right side (facing the nave). Change the profile of the Back side (facing the nave) to be “profile B”.

78. Repeat the vault as needed, on the first floor. If time permits, insert vaults on the second floor ceiling plan, on the “Top of Capitals Second Floor” reference plane.

### Result

Result in 3D view:

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## Purpose

To repeat the vault as needed.

### Step

79. If time permits, open the vault family, and assign a material type parameter to the arches and vaults: “Material for Stone”. Then, in the project, select one of the vaults > Edit type > Modify the material parameter. Search for “Stone” and choose “Stone Block” or “21_Stone”.

80. If time permits, add a roof by face to at least one of the vaults. See pages 45 to 47 for more information on this.

### Result

Result in 3D view:
If you made it up to this point, you’re awesome! Give yourself an applause! 😊

Thank you for attending this class!

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